



Influence of Iron and Zinc Biofortification on Growth and Yield of Drilled Rice (*Oryza Sativa* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was conducted during *kharif* 2022 and 2023 to study the effect of iron and zinc biofortification on the growth and yield of drilled rice (*Oryza sativa* L.) at Krushi Vigyan Kendra, Navsari Agricultural University, Dediapada, Gujarat. The experiment was laid out in a randomized block design with ten treatments. Based on pooled analysis, almost all the growth attributes (periodical plant height, number of tillers plant⁻¹, leaf area, leaf area index and dry matter accumulation plant⁻¹), yield attributes (productive tillers m⁻², number of filled grains panicle⁻¹, panicle length, weight of panicle and 1000 grain weight), grain yield (3035 kg ha⁻¹) and straw yield (5336 kg ha⁻¹) were recorded significantly higher under treatment T₁₀ (soil ZnSO₄ + FeSO₄ each @ 25 kg ha⁻¹)

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and foliar ZnSO₄ + FeSO₄ each @ 0.5% at 30 & 60 DAS). Based on the results, it concluded that for achieving higher growth and yield in drilled rice, the crop should be fertilized with soil ZnSO₄ + FeSO₄ each @ 25 kg ha⁻¹ and foliar ZnSO₄ + FeSO₄ each @ 0.5% at 30 & 60 DAS along with RDF and soil ZnSO₄ + FeSO₄ each @ 25 kg ha⁻¹ along with RDF.

Keywords: Biofortification; iron; zinc; drilled rice; grain yield.

1. INTRODUCTION

Rice (*Oryza sativa* L.) is the world's staple cereal crop. It is a good source of calories for approximately 40 percent of the world's population [1]. Rice is the most important food crop for more than two billion people in Asia, providing 27 percent of dietary energy and 20 percent of overall dietary protein [2]. In the 2022/23 crop year, about 520.4 million metric tons of rice were consumed worldwide and it is expected to increase to 852 million tonnes by 2035. It is a predominant crop in the lowland ecosystem. Asia is considered the "rice bowl" of the world, producing and consuming more than 90 per cent of the world's rice, but India and China contribute more than half of the world's rice. Rice occupies an area of about 163 million hectares globally with production and productivity of 769 million tonnes and 4717 kg ha⁻¹, respectively. India ranks first in acreage (45.77 million hectares) and second in production (186.50 million metric tonnes) after China [3].

Rice production worldwide has increased to 751.9 million tons [4] with 90% of it produced and consumed in developing nations. However, around 870 million people worldwide suffer from chronic malnutrition [5] with the great majority of them living in underdeveloped nations where rice is strongly linked to food security and political stability. As a result, enhancing rice micronutrient status is critical for addressing crucial nutrition and health issues affecting large populations, particularly in poor or developing nations. Iron and zinc are two micronutrients that are necessary for plant growth and human health. Iron and zinc deficiencies are the sixth and fifth largest health risk factors in developing nations, respectively [6,7], resulting in high mortality rates. As a result, resolving these dietary inadequacies will take time. Furthermore, polished rice contains just 2 mg kg⁻¹ iron and 12 mg kg⁻¹ zinc on average [8] but human Zn and Fe intake recommendations are 12–15 and 10–15 mg, respectively [9]. More than half of the world's population suffers from Fe and Zn deficiency, which can damage immunological

function and affect human growth and development [10].

Zinc is an important micronutrient that plays a role in biological metabolism. It is gaining attention around the world as a result of rising reports of zinc inadequacy in food crops and humans, necessitating a food-based approach to address zinc malnutrition. Zn has a crucial role in intracellular metabolic activities as it acts as a cofactor of various enzymes [11]. These enzymes mostly act on metabolic reactions Utilized in the breakdown of starch into sugar, chlorophyll synthesis, and the production of some carbohydrates). Additionally, Zn strengthens plant tissue so it may survive in frigid conditions. Zn affects plant water relations, alters stomatal conductance and plays a role in protecting the cell from the damaging effect of reactive oxygen species [12,13]. Auxins are compounding that aid in growth control and stem elongation and they cannot be produced without zinc [14]. As a result, a lack of zinc in the soil has a negative impact on plant growth and development. Iron deficiency in rice mainly occurs under upland conditions; particularly in alkaline and calcareous soils. Sometimes severe chlorosis in rice due to Fe deficiency has led to the complete failure of rice crop. In most of the studies, foliar application of Fe has an edge over soil. Iron is easily translocated acropetally and even retranslocated basipetally after foliar application as long as 2+ Fe does not get immobilized. But Fe salts rapidly oxidize upon exposure to ambient air under field conditions. The availability of iron in the plant is involved in chlorophyll biosynthesis and the development of chloroplast and other photosynthetic apparatus. This argument was premised on the fact iron constitutes a vital component of proteins and enzymes involved in most physiological processes (photosynthesis, respiration, electron transportation, etc.) that are linked with plant productivity [15].

Every year, around 0.8 million individuals worldwide, including nearly 0.45 million children, are in danger of dying due to zinc deficiency [16]. Iron deficiency is a widespread nutritional

problem in developing countries, causing impairments of cognitive function, immune system and work capacity the increase in infant and maternal mortality represents major health complications associated with Fe deficiency and is the most common cause of anemia globally [17,18]. Iron deficiency anemia (IDA) affects 1.62 billion people worldwide, including 293 million preschool children, 56 million pregnant women and 468 million non-pregnant women, according to published statistics [19] As iron is the fourth most prevalent element on the earth's crust, it is found in abundance in soils; yet, the majority of iron in soils is unavailable for plant uptake [20].

Biofortification is an attractive concept for making full use of a plant's potential for utilization and mobilization of micronutrients and it also helps in revamping the growing conditions of the crop [21]. The biofortification method has the potential to increase the micronutrient content of food crops such as rice. This is a practical and sustainable way to address vitamin deficiencies for people whose diet is mostly rice and who do not have access to other food options, food markets, or proper healthcare [22]. Increasing the bioavailable concentration of essential elements in edible parts of the crop is defined as biofortification [23]. As compared to brown rice, milled and polished rice become lower in nutritional quality and its zinc content is reduced by 1.83 times (from 33 to 18 parts per million), whereas its iron content is reduced by 2.14 times (from 8.8 to 4.1 parts per million) to 4.75 times (from 19 to 4 parts per million), which may vary according to grain milling processes [24].

2. MATERIALS AND METHODS

The present study was conducted at the Experimental farm, Krushi Vigyan Kendra, Navsari Agricultural University, Dediapada, Narmada, Gujarat (21.6289° N, 73.5824° E) during the two consecutive *kharif* seasons of 2022 and 2023. According to agro-climatic conditions, Dediapada is placed in south Gujarat zone II (Agro-ecological situation-I). The climate of this zone is typically tropical, characterized by humid and warm monsoons with heavy rain, a moderately cold winter and a fairly hot summer. The average annual rainfall of the tract is about 1000–1250 mm. The soil in the experimental field was clay in texture, medium in organic carbon (0.52 and 0.54%) and available nitrogen (275.19 and 270.31 kg ha⁻¹), medium in available phosphorus (36.60 and 37.15 kg ha⁻¹), high in

available potassium (428.35 and 421.20 kg ha⁻¹), medium available zinc (0.64 and 0.71 mg kg⁻¹) and available Fe (7.20 and 7.46 mg kg⁻¹). The soil was found to be slightly alkaline (pH 7.2 and 7.31) with normal electrical conductivity (0.41 and 0.39 dS m⁻¹).

In order to study the “Influence of iron and zinc biofortification on growth and yield of drilled rice (*Oryza sativa* L.)” a field experiment was conducted with total ten treatments comprising T₁: Absolute control (Only RDF), T₂: Soil ZnSO₄ @ 25 kg ha⁻¹, T₃: Soil FeSO₄ @ 25 kg ha⁻¹, T₄: Soil ZnSO₄ + FeSO₄ each @ 25 kg ha⁻¹, T₅: Foliar ZnSO₄ @ 0.5% at 30 & 60 DAS, T₆: Foliar FeSO₄ @ 0.5% at 30 & 60 DAS, T₇: Foliar ZnSO₄ + FeSO₄ each @ 0.5% at 30 & 60 DAS, T₈: Soil ZnSO₄ @ 25 kg ha⁻¹ + Foliar ZnSO₄ @ 0.5% at 30 & 60 DAS, T₉: Soil FeSO₄ @ 25 kg ha⁻¹ + Foliar FeSO₄ @ 0.5% at 30 & 60 DAS, T₁₀: Soil ZnSO₄ + FeSO₄ each @ 25 kg ha⁻¹ and Foliar ZnSO₄ + FeSO₄ each @ 0.5% at 30 & 60 DAS with three replications during the *kharif* season of the years 2022 and 2023. Rice cultivar GR-16 (Tapi) was used for this experiment and it was released in 2018 from the Main Rice Research Centre Navsari, Navsari Agricultural University, Vyara. Early maturing upland rice variety GR-16 recorded 2983 kg ha⁻¹ mean grain yield in Gujarat Crop sown manually at a depth of 3-4 cm in the furrow, in which fertilizer was banded previously on each plot (Gross plot size: 5.0 m x 4.8 m and Net plot size: 4.2 m x 3.6 m) at a spacing of 30 cm x 10 cm. Seeds were covered properly with soil. After two weeks of sowing, the thinning and gap filling were carried out. The crop was grown under rainfed conditions and also irrigation was applied as per requirement. The required quantity of fertilizer was worked out as per the unit area and treatment basis (Recommended dose of fertilizer: 80-30-00 kg ha⁻¹ N-P-K). The shallow furrows were opened manually in each plot as per the treatments in dry conditions. Inorganic fertilizers, 50% nitrogen through urea and a full dose of phosphorus through SSP were applied at the basal just before sowing as a common dose to all treatments. The remaining 50% nitrogen through urea was applied at 30 days after sowing when irrigation was applied. Soil applications of Zn and Fe through ZnSO₄ and FeSO₄ were applied at the basal just before sowing as per the treatment basis. Two foliar applications of zinc sulphate and ferrous sulphate each at 0.5 percent mixed with a 0.25 percent lime solution were sprayed after 30 and 60 DAS as per the treatments. During foliar application, 400 liters in the first

spray and 500 liters in the second spray mixture ha⁻¹ was used.

2.1 Growth Parameters

The plant height of five randomly selected and tagged plants from each net plot was measured by using a wooden metre scale. The measurement was made from the base of the plant to the tip of the last fully open leaf at 30, 60, 90 DAS and at harvest expressed in centimetre (cm). The progressive tiller count was recorded at 30, 60, 90 DAS and at harvest from five randomly selected plants from each net plot and converted to tillers per plant. Leaf area per plant was worked out following the procedure given by Gomez [25].

$$\text{Leaf area (cm}^2\text{) of each leaf in middle tiller} \\ = L \times W \times 0.65$$

Where, L = Maximum length of leaf (cm)

W = Maximum width of leaf (cm)

The leaf area index (LAI) was obtained by dividing the actual leaf area obtained per hill by the ground area occupied per hill. From there, the leaf area index was calculated by the total leaf area of the plant divided by the total ground area under the plant as proposed by Watson [26]. The dry matter accumulation was recorded at 30, 60, 90 DAS and harvest for growth analysis from five plants in each gross plot was used for the estimation of dry matter. All the plants were uprooted and allowed to sun dry and finally oven dried at 65 ± 5 °C for recording constant dry weight. The weight thus obtained is expressed as dry weight plant⁻¹ (g) after dividing the total number of plants in the samples.

2.2 Yield Parameters

The number of ear bearing tillers from the net plot area with the help of 1 m² quadrat from 30 DAS to maturity at every 30 days interval *i.e.*, 30, 60, 90 DAS and at harvest and expressed as a number of tillers m⁻². The number of filled and unfilled grains in all the five selected panicles from the five labeled hills in each treatment were counted and averaged to arrive at a number of filled and unfilled grains panicle⁻¹. The length of the five randomly selected panicles (cm) from the marked hill was measured in centimeter from the base to the tip of the panicle. The weight of the panicle was measured in grams from five randomly selected panicles from net plot at the time of harvest. Thousand grain weight (test weight) counted by five grain samples were

collected at random from the net plot yield of each treatment. The grain samples were weighed and then the number of grains present in each sample was counted to arrive at the test weight (grams per 1000 grains). Grain and straw yield per plant were measured from randomly selected five plants from the net plot and the average was calculated. Grains from corresponding net plots were sun dried for 4 to 6 days and the weight of grains in each net plot area was converted and recorded as grain yield kg ha⁻¹. Straw yield from the net plot of each treatment was dried in the sun to a constant weight and after it converted to straw yield in kg ha⁻¹. The harvest index was computed by the percentage of economic yield to the biological yield of rice and it was recorded separately for each treatment.

The statistical analysis of the data of various observations recorded during the investigation was carried out under Randomized Block Design through the analysis of variance technique as described by Panse and Sukhatme [27]. The significant difference was tested by F-test at a five per cent level of significance. The standard error of mean was calculated for all the parameters however, the critical difference was calculated when the difference among treatments were found significant. Further pooled analysis variance of two year workouts to study the year effect on the treatment and their interaction [28].

3. RESULTS AND DISCUSSION

Results revealed that growth attributes of rice *i.e.* periodical plant height, number of tillers plant⁻¹, leaf area, leaf area index, dry matter accumulation plant⁻¹ and yield attributes *viz.*, productive tillers m⁻², number of filled grains panicle⁻¹, number of unfilled grains panicle⁻¹, panicle length, weight of panicle, thousand grain weight, grain yield plant⁻¹, straw yield plant⁻¹, grain yield and straw yield were significantly influenced by different treatments.

3.1 Growth Attributes

Plant height is an important expression of plant growth and offers an immediate comparison of the different treatments. Data obtained on the progressive plant height at different stages of growth at 30, 60, 90 DAS and at harvest as affected by different treatments were put to statistical analysis and the results have been summarized and presented in Table 1. Plant height at 30 DAT (day after transplanting) was

found nonsignificant. The maximum plant height was recorded under treatment of soil ZnSO₄ + FeSO₄ each @ 25 kg ha⁻¹ and Foliar ZnSO₄ + FeSO₄ each @ 0.5% at 30 & 60 DAS (T₁₀) during both years and pooled study, but it remained at par with treatments T₄, T₈, T₉, T₂ and T₃ during both year. While treatments T₄, T₈ and T₉ were found statistically at par with T₁₀ in the pooled result. Whereas, minimum plant height was recorded under treatment T₁ (Absolute control) across both the years of investigation and on a pooled basis. At 90 days after sowing (Table 1), significantly taller rice plants were observed in treatment T₁₀ and it was statistically at par with treatments T₄, T₈ and T₉ during both years. In pooled analysis, T₄ and T₈ were found to be on par with T₁₀. However, significantly lower plant height was observed during individual years of study and in pooled results under treatment absolute control (T₁). Data in Table 1 clearly indicated that plant height at harvest was recorded significantly higher in treatment Soil ZnSO₄ + FeSO₄ each @ 25 kg ha⁻¹ and Foliar ZnSO₄ + FeSO₄ each @ 0.5% at 30 & 60 DAS (T₁₀) during both years, but it remained statistically at par with treatments T₄, and T₉. However, data on pooled analysis revealed that treatments T₄ and T₈ (Soil ZnSO₄ @ 25 kg ha⁻¹ + Foliar ZnSO₄ @ 0.5% at 30 & 60 DAS) were found to be on par with T₁₀. The lowest plant height was registered with absolute control (T₁) during both years and in pooled results at all stages of crop growth.

The data recorded on the number of tillers as influenced by different treatments at 30 day intervals starting from 30 DAS to harvest have been summarized and presented in Table 2. At 30 DAS, the number of tillers plant⁻¹ was not altered due to soil and foliar application of Zn and Fe. However, foliar application of Zn and Fe and recorded a significantly higher maximum number of tillers plant⁻¹ in treatment soil ZnSO₄ + FeSO₄ each @ 25 kg ha⁻¹ and foliar ZnSO₄ + FeSO₄ each @ 0.5% at 30 & 60 DAS (T₁₀) at 60, 90 DAS and at harvest during both year and in pooled results, which remained statistically at par with T₄, T₈, T₉ and T₂. In pooled results, T₄ and T₈ were found to be on par with T₁₀. The significantly lowest number of tillers plant⁻¹ at 60, 90 DAS and at harvest, all stages of growth was observed under absolute control (T₁). The availability of nutrients to the crops at various growth stages through agrochemical sources might have increased the number of tillers. Zn

and Fe might have accelerated photosynthetic rate, thereby increasing the supply of carbohydrates, resulted in increased cell division, multiplication and elongation leading to an increased number of tillers per plant of field crop. The results were also confirmed with the findings of Ram et al. 2020 and Ugile et al. 2024.

Leaf area increased with the age of the crop up to 60 DAS and then declined in all treatments. At 30 DAS, there was no significant difference in leaf area with respect to soil and foliar application of Zn and Fe. The interaction effect was also found to be non significant. At 60 and 90 DAS (Table 3), among the different levels of soil and foliar application of Zn and Fe, application of soil ZnSO₄ + FeSO₄ each @ 25 kg ha⁻¹ and foliar ZnSO₄ + FeSO₄ each @ 0.5% at 30 & 60 DAS (T₁₀) accounted for significantly higher leaf area over absolute control (T₁) and was on par with treatments T₄, T₈, T₉ and T₂ during both years. Whereas, treatments T₄ (Soil ZnSO₄ + FeSO₄ each @ 25 kg ha⁻¹) and T₈ (Soil ZnSO₄ @ 25 kg ha⁻¹ + Foliar ZnSO₄ @ 0.5% at 30 & 60 DAS) are on par with treatment treatments T₁₀ in the pooled study.

The leaf area index is an important plant growth parameter that determines crop yield and the capacity of plants to trap solar energy for photosynthesis. The data presented in Table 4 revealed a remarkably increased leaf area index with an increase in the soil and foliar application of Zn and Fe as the crop aged up to 60 DAS. However, thereafter a decline was noticed. An examination of the data revealed that different treatments of soil and foliar application of Zn and Fe on LAI significantly influenced at all the growth stages, except at 30 DAS during 2022, 2023 and in the combined analysis. The data regarding LAI at 60 and 90 DAS presented in Table 4 showed that significantly higher LAI was recorded with treatment T₁₀, but it remained at par with treatments T₄, T₈, T₉ and T₂ during both years. However, in the case of pooled analysis, treatment T₄ and T₈ are on par with treatment T₁₀. The lower LAI at 60 DAS was obtained with treatment T₁ (Absolute control) during both years and in pooled results.

The results of the experiments on dry matter accumulation plant⁻¹ of rice depicted in Table 5. An examination of the data revealed that different treatments of soil and foliar application of Zn and Fe on dry matter accumulation plant⁻¹ significantly influenced it at all the growth stages,

except at 30 DAS during 2022, 2023 and in the combined analysis. Application of soil ZnSO₄ + FeSO₄ each @ 25 kg ha⁻¹ and foliar ZnSO₄ + FeSO₄ each @ 0.5% at 30 & 60 DAS (T₁₀) recorded significantly higher dry matter accumulation plant⁻¹ of the rice crop at 60, 90 DAS and at harvest during both years, but it remained at par with treatments T₄, T₈ and T₉ during both year. Whereas, in pooled results, it remained at par with treatments T₄ and T₈. Minimum dry matter accumulation plant⁻¹ was recorded under treatment T₁ (Absolute control).

The results presented in the above findings indicated that soil and foliar application of Zn and Fe showed a significant effect on crop growth. Among different growth parameters viz., plant height at 60, 90 DAS and at harvest, leaf area, number of tillers and dry matter accumulation plant⁻¹ at different growth stages of crop varied significantly by soil and foliar application of Zn and Fe. Most of the photosynthetic pathways depends on enzymes and coenzymes which are synthesized by micronutrients. Increasing in growth parameters due to the involvement of Zn and Fe which are involved in the synthesis of growth promoting hormones and the reduction process. Zn and Fe are essential for several enzymes that regulate metabolic activities in plants. Zn helps in auxin production, which led to higher hormonal activity at critical crop growth stages, which ultimately resulted in better crop growth parameters. While, Fe is indispensable for chlorophyll synthesis and involved in the formation of the pyrrole ring, which is a structural component of chlorophyll and iron has a stimulating effect to increase the plant height, leaf area, leaf area index, dry matter accumulation and other growth attributes. The results are similar findings with Zayed et al. [29]. Suresh S. and Salakinkop S. R. [30] Goverdhan M. [31] Kadam et al. [32] Balachandrakumar and Rao [33] Rao et al. [34] Janardhan et al. [35], Bharti et al [36] and Rao et al. [37] Ram et al. [38] and Ugile et al. [39]

3.2 Yield Attributes and Yield

The data on yield attributes and yield viz., productive tillers meter⁻², number of filled grains panicle⁻¹, number of unfilled grains panicle⁻¹, panicle length, panicle weight, 1000 grain weight, grain yield plant⁻¹, straw yield plant⁻¹, grain yield, straw yield and harvest index as influenced by soil and foliar application of Zn and Fe were presented in Tables 6, 7 and 8.

The mean data of the number of tillers meter⁻² revealed that treatment T₁₀ (Soil ZnSO₄ + FeSO₄ each @ 25 kg ha⁻¹ and Foliar ZnSO₄ + FeSO₄ each @ 0.5% at 30 & 60 DAS) produced significantly more panicles during both years and in pooled results, and was statistically equal with T₄, T₈ and T₉ in the first year. While treatments T₄, T₈, T₉ and T₂ were found statistically at par with T₁₀ during the second year. However, in pooled results, treatments T₄ (Soil Zn + Fe each @ 25 kg ha⁻¹) and T₈ (Soil ZnSO₄ @ 25 kg ha⁻¹ + Foliar ZnSO₄ @ 0.5% at 30 & 60 DAS) remained on par with T₁₀. Minimum number of tillers meter⁻² was recorded under treatment T₁ (Absolute control) (Table 6). The reason for improving the number of tillers per square meter might be due to the availability of nutrients through soil application to the rice crop Zn and Fe increase plants' tolerance to several abiotic stresses, reduce transpiration and increase nitrate reductase activity, flower longevity and hence, increase in number of tillers. Similar findings were obtained by Ugile et al. [39].

An appraisal of the data in Table 6 showed that soil and foliar application of Zn and Fe have a significant effect on the number of filled grains panicle⁻¹. An application of soil ZnSO₄ + FeSO₄ each @ 25 kg ha⁻¹ and foliar ZnSO₄ + FeSO₄ each @ 0.5% at 30 & 60 DAS (T₁₀) recorded the maximum number of filled grains panicle⁻¹ during both years and in pooled results. However, it was found to be on par with treatments T₄, T₈, T₉, T₂ and T₃ during both years. While treatments T₄, T₈ and T₉ were found statistically at par with T₁₀ in pooled results, Further, significantly the lowest number of filled grains panicle⁻¹ was recorded with the treatment of T₁ (Absolute control) during both years and in pooled results. The number of grains per panicle increased due to greater diversion of assimilates towards reproductive organs. For seed development, assimilate transfer to reproductive sinks is essential. The availability and use of assimilates may have an impact on seed set and filling. The combination of traits that contribute to yield, improved photosynthetic efficiency and improved reproductive sink ability to use incoming assimilates as a result of exogenous Zn and Fe application resulted in an increase in the number of grains per panicle. These results are in agreement with the work of Yadav et al [40] and Ugile et al. [39].

Table 1. Plant height of rice as influenced by different treatments

Treatments	At 30 DAS (cm)			At 60 DAS (cm)			At 60 DAS (cm)			At harvest (cm)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T ₁	29.88	29.53	29.70	51.98	54.23	53.11	75.56	77.03	76.30	77.05	77.91	77.48
T ₂	30.42	30.76	30.59	61.00	63.12	62.06	85.41	86.36	85.89	86.37	86.92	86.65
T ₃	30.37	30.48	30.43	60.96	61.91	61.43	84.77	85.72	85.25	85.75	86.84	86.29
T ₄	30.51	30.82	30.67	67.46	68.09	67.78	95.99	97.26	96.62	97.28	98.84	98.06
T ₅	30.18	30.20	30.19	57.34	58.31	57.82	81.85	82.01	81.93	82.05	83.12	82.58
T ₆	30.11	30.08	30.09	54.37	56.67	55.52	77.95	80.27	79.11	80.29	80.83	80.56
T ₇	30.26	30.36	30.31	57.99	59.01	58.50	83.19	84.17	83.68	84.19	85.26	84.73
T ₈	30.44	30.89	30.66	67.26	68.01	67.64	91.62	94.43	93.03	94.46	95.67	95.07
T ₉	30.43	30.78	30.61	62.26	63.89	63.08	88.01	89.74	88.88	89.79	90.93	90.36
T ₁₀	30.67	30.94	30.81	69.28	69.99	69.63	97.35	98.95	98.15	98.99	100.58	99.78
SEm±	1.22	1.25	0.87	3.39	3.37	2.39	3.99	4.15	2.88	4.12	4.26	2.96
CD at 5 %	NS	NS	NS	10.08	10.01	6.86	11.85	12.34	8.26	12.24	12.67	8.51
CV (%)	6.94	7.12	7.03	9.63	9.36	9.49	8.02	8.21	8.12	8.14	8.33	8.24
Year	SEm±	0.39		1.07			1.29			1.33		
	CD (P=0.05)	NS		NS			NS			NS		
Y x T	SEm±	1.23		3.38			4.07			4.19		
	CD (P=0.05)	NS		NS			NS			NS		

Table 2. Number of tillers per plant of rice as influenced by different treatments

Treatments	At 30 DAS			At 60 DAS			At 90 DAS			At harvest		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T ₁	3.46	3.52	3.49	7.67	7.70	7.69	7.49	7.65	7.57	7.60	7.76	7.68
T ₂	3.68	3.80	3.74	8.62	8.76	8.69	8.50	8.71	8.61	8.68	8.82	8.75
T ₃	3.63	3.76	3.69	8.45	8.59	8.52	8.33	8.54	8.43	8.51	8.65	8.58
T ₄	3.91	4.07	3.99	9.40	9.52	9.46	9.28	9.47	9.37	9.46	9.58	9.52
T ₅	3.53	3.75	3.64	7.97	8.13	8.05	7.85	8.07	7.96	8.03	8.19	8.11
T ₆	3.50	3.55	3.53	7.85	8.01	7.93	7.73	7.96	7.84	7.91	8.07	7.99
T ₇	3.58	3.70	3.64	8.13	8.28	8.20	8.01	8.22	8.12	8.19	8.34	8.26
T ₈	3.83	3.86	3.85	9.14	9.27	9.20	9.02	9.21	9.11	9.20	9.33	9.26
T ₉	3.75	3.80	3.77	8.84	8.98	8.91	8.72	8.92	8.82	8.90	9.04	8.97
T ₁₀	3.93	4.07	4.00	9.85	9.96	9.91	9.79	9.94	9.86	9.97	10.02	10.00
SEm±	0.19	0.18	0.13	0.44	0.46	0.32	0.45	0.46	0.32	0.46	0.46	0.33
CD at 5 %	NS	NS	NS	1.32	1.36	0.92	1.32	1.37	0.92	1.38	1.36	0.93
CV (%)	8.85	8.02	8.43	8.97	9.08	9.02	9.10	9.22	9.16	9.27	9.01	9.14
Year	SEm±	0.06		0.14			0.14			0.15		
	CD (P=0.05)	NS		NS			NS			NS		
Y x T	SEm±	0.18		0.45			0.45			0.46		
	CD (P=0.05)	NS		NS			NS			NS		

Table 3. Leaf area of rice as influenced by different treatments

Treatments		Leaf Area (cm ² plant ⁻¹)								
		At 30 DAS			At 60 DAS			At 90 DAS		
		2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T ₁		124	126	125	976	980	978	714	729	722
T ₂		131	136	133	1097	1115	1106	811	831	821
T ₃		130	134	132	1075	1094	1084	794	814	804
T ₄		140	145	142	1196	1211	1204	885	903	894
T ₅		126	134	130	1014	1033	1024	749	770	760
T ₆		125	127	126	999	1019	1009	738	759	749
T ₇		128	132	130	1034	1053	1043	764	785	774
T ₈		137	138	137	1162	1178	1170	860	879	869
T ₉		134	136	135	1124	1142	1133	832	851	841
T ₁₀		140	145	143	1253	1268	1260	934	948	941
SEm±		6.71	6.26	4.59	56.59	58.14	40.56	42.45	44.04	30.58
CD at 5 %		NS	NS	NS	168.13	172.74	116.44	126.14	130.85	87.79
CV (%)		8.85	8.02	8.43	8.97	9.08	9.02	9.10	9.22	9.16
Year	SEm±	2.05			18.14			13.68		
	CD (P=0.05)	NS			NS			NS		
Y x T	SEm±	6.49			57.37			43.25		
	CD (P=0.05)	NS			NS			NS		

Table 4. Leaf area index of rice as influenced by different treatments

Treatments		At 30 DAS			At 60 DAS			At 90 DAS		
		2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T ₁		0.41	0.42	0.42	3.25	3.27	3.26	2.38	2.43	2.41
T ₂		0.44	0.45	0.44	3.66	3.72	3.69	2.70	2.77	2.74
T ₃		0.43	0.45	0.44	3.58	3.64	3.61	2.65	2.71	2.68
T ₄		0.47	0.48	0.47	3.99	4.04	4.01	2.95	3.01	2.98
T ₅		0.42	0.45	0.43	3.38	3.44	3.41	2.50	2.57	2.53
T ₆		0.42	0.42	0.42	3.33	3.40	3.36	2.46	2.53	2.50
T ₇		0.43	0.44	0.43	3.45	3.51	3.48	2.55	2.62	2.58
T ₈		0.46	0.46	0.46	3.87	3.93	3.90	2.87	2.93	2.90
T ₉		0.45	0.45	0.45	3.75	3.81	3.78	2.77	2.84	2.80
T ₁₀		0.47	0.48	0.48	4.17	4.23	4.20	3.11	3.16	3.14
SEm±		0.02	0.02	0.02	0.19	0.19	0.14	0.14	0.15	0.10
CD at 5 %		NS	NS	NS	0.56	0.58	0.39	0.42	0.44	0.29
CV (%)		8.85	8.02	8.43	8.97	9.08	9.02	9.10	9.22	9.16
Year	SEm±	0.01			0.06			0.05		
	CD (P=0.05)	NS			NS			NS		

Treatments		At 30 DAS			At 60 DAS			At 90 DAS		
		2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Y x T	SEm±	0.02			0.19			0.14		
	CD (P=0.05)	NS			NS			NS		

Table 5. Dry matter accumulation per plant of rice as influenced by different treatments

Treatments		At 30 DAS			At 60 DAS			At 90 DAS			At harvest (g plant-1)		
		2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T ₁		2.22	2.28	2.25	12.04	12.01	12.02	18.72	19.22	18.97	20.65	20.88	20.76
T ₂		2.29	2.30	2.30	13.25	13.62	13.43	22.28	22.68	22.48	24.16	24.90	24.53
T ₃		2.28	2.35	2.31	12.53	13.37	12.95	21.36	21.79	21.57	23.36	23.49	23.43
T ₄		2.39	2.41	2.40	14.23	14.76	14.50	24.47	26.57	25.52	25.92	26.28	26.10
T ₅		2.26	2.31	2.28	12.40	12.60	12.50	19.71	19.91	19.81	22.38	22.29	22.34
T ₆		2.21	2.25	2.23	12.25	12.33	12.29	19.60	19.73	19.66	21.70	21.54	21.62
T ₇		2.24	2.29	2.27	12.47	13.26	12.87	19.79	20.95	20.37	22.79	23.27	23.03
T ₈		2.38	2.40	2.39	13.98	14.56	14.27	23.77	24.32	24.04	25.52	25.96	25.74
T ₉		2.30	2.39	2.35	13.50	13.91	13.71	22.95	23.39	23.17	25.23	25.53	25.38
T ₁₀		2.44	2.42	2.43	15.30	15.67	15.48	25.93	26.98	26.46	26.34	27.62	26.98
SEm±		0.06	0.10	0.06	0.67	0.65	0.47	1.18	1.11	0.81	1.15	1.14	0.81
CD at 5 %		NS	NS	NS	2.00	1.93	1.34	3.52	3.31	2.33	3.41	3.39	2.32
CV (%)		4.75	7.23	6.14	8.82	8.26	8.54	9.39	8.55	8.97	8.34	8.18	8.26
Year	SEm±	0.03			0.21			0.36			0.36		
	CD (P=0.05)	NS			NS			NS			NS		
Y x T	SEm±	0.08			0.66			1.15			1.14		
	CD (P=0.05)	NS			NS			NS			NS		

Table 6. Number of productive tillers, number of grains per panicle and number of unfilled grains per panicle of rice as influenced by different treatments

Treatments	Productive tillers (m-2)			No. of filled grains panicle ⁻¹			No. of unfilled grains panicle ⁻¹		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T ₁	232	246	239	125.8	127.5	126.6	10.3	9.8	10.0
T ₂	274	283	278	142.6	145.0	143.8	8.2	8.8	8.5
T ₃	267	276	272	139.6	142.1	140.9	8.6	9.3	9.0
T ₄	307	309	308	153.5	162.9	158.2	7.2	7.5	7.3
T ₅	248	262	255	132.4	134.3	133.4	9.3	9.7	9.5
T ₆	244	258	251	129.5	131.7	130.6	10.1	9.7	9.9
T ₇	255	266	260	135.7	134.7	135.2	9.0	9.3	9.2
T ₈	295	300	298	149.1	157.0	153.0	7.3	7.8	7.6
T ₉	282	290	286	148.1	153.5	150.8	7.6	8.3	8.0
T ₁₀	319	324	321	160.1	166.0	163.1	7.1	7.0	7.1
SEm±	13.07	13.99	9.57	6.94	8.05	5.32	0.46	0.46	0.32
CD at 5 %	38.83	41.56	27.48	20.63	23.92	15.26	1.35	1.37	0.93
CV (%)	8.32	8.61	8.47	8.49	9.59	9.07	9.31	9.15	9.23
Year	SEm±	4.28		2.38			0.14		
	CD (P=0.05)	NS		NS			NS		
Y x T	SEm±	13.54		7.52			0.46		
	CD (P=0.05)	NS		NS			NS		

Table 7. Panicle length, panicle weight, 1000 grain weight, grain and straw yield per plant of rice as influenced by different treatments

Treatments	Panicle length (cm)			Panicle weight (g)			1000 grain weight (g)			Grain yield plant ⁻¹ (g)			Straw yield plant ⁻¹ (g)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T ₁	22.07	21.56	21.82	1.75	1.76	1.75	25.32	25.81	25.57	7.54	7.70	7.62	13.28	13.35	13.32
T ₂	25.48	26.35	25.92	2.39	2.56	2.48	27.67	27.83	27.75	8.78	9.04	8.91	15.42	15.59	15.51
T ₃	24.38	25.36	24.87	2.31	2.49	2.40	27.36	27.52	27.44	8.50	8.55	8.52	14.85	15.01	14.93
T ₄	28.40	29.47	28.93	3.25	3.22	3.24	28.45	28.61	28.53	9.37	9.55	9.46	16.47	16.67	16.57
T ₅	23.89	24.52	24.20	2.05	2.01	2.03	26.29	26.45	26.37	8.13	8.10	8.12	14.04	14.17	14.10
T ₆	23.58	23.53	23.55	1.97	1.89	1.93	25.99	26.14	26.07	7.89	7.94	7.91	13.63	13.83	13.73
T ₇	24.24	24.98	24.61	2.20	2.29	2.25	26.71	26.87	26.79	8.29	8.45	8.37	14.34	14.48	14.41
T ₈	27.00	28.31	27.66	2.82	2.88	2.85	28.30	28.46	28.38	9.28	9.43	9.35	16.37	16.56	16.47
T ₉	25.80	26.85	26.32	2.52	2.56	2.54	28.08	28.24	28.16	9.19	9.27	9.23	16.16	16.36	16.26
T ₁₀	29.96	30.43	30.19	3.43	3.54	3.49	28.97	29.13	29.05	9.48	10.06	9.77	16.63	17.11	16.87
SEm±	1.28	1.45	0.97	0.14	0.14	0.10	1.45	1.51	1.05	0.43	0.47	0.32	0.80	0.83	0.58
CD at 5 %	3.80	4.32	2.78	0.41	0.42	0.28	NS	NS	NS	1.28	1.41	0.92	2.38	2.47	1.66
CV (%)	8.69	9.63	9.19	9.56	9.81	9.69	9.21	9.50	9.36	8.66	9.33	9.01	9.18	9.41	9.30
Year	SEm±			0.43			0.47			0.14			0.26		
	CD (P=0.05)			NS			NS			NS			NS		
Y x T	SEm±			1.37			1.48			0.45			0.82		
	CD (P=0.05)			NS			NS			NS			NS		

Table 8. Grain and straw yield of rice as influenced by different treatments

Treatments	Grain yield (kg ha ⁻¹)			Straw yield (kg ha ⁻¹)			Harvest index		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T1: Absolute control (Only RDF)	2435	2454	2445	4235	4301	4268	36.58	36.32	36.45
T2: Soil ZnSO ₄ @ 25 kg ha ⁻¹	2816	2869	2842	4927	5030	4979	36.38	36.37	36.37
T3: Soil FeSO ₄ @ 25 kg ha ⁻¹	2729	2744	2737	4776	4812	4794	36.36	36.49	36.42
T4: Soil ZnSO ₄ + FeSO ₄ each @ 25 kg ha ⁻¹	2988	3039	3013	5229	5328	5278	36.54	36.43	36.49
T5: Foliar ZnSO ₄ @ 0.5% at 30 & 60 DAS	2588	2661	2624	4528	4666	4597	36.42	36.35	36.38
T6: Foliar FeSO ₄ @ 0.5% at 30 & 60 DAS	2523	2552	2538	4415	4477	4446	36.37	36.32	36.34
T7: Foliar ZnSO ₄ + FeSO ₄ each @ 0.5% at 30 & 60 DAS	2678	2727	2703	4686	4783	4735	36.37	36.35	36.36
T8: Soil ZnSO ₄ @ 25 kg ha ⁻¹ + Foliar ZnSO ₄ @ 0.5% at 30 & 60 DAS	2952	3006	2979	5165	5270	5217	36.45	36.36	36.40
T9: Soil FeSO ₄ @ 25 kg ha ⁻¹ + Foliar FeSO ₄ @ 0.5% at 30 & 60 DAS	2916	2963	2940	5103	5196	5149	36.47	36.32	36.40
T10: Soil ZnSO ₄ + FeSO ₄ each @ 25 kg ha ⁻¹ and Foliar ZnSO ₄ + FeSO ₄ each @ 0.5% at 30 & 60 DAS	3003	3067	3035	5288	5384	5336	36.21	36.29	36.25
SEm±	129.98	135.30	93.81	231.40	237.69	165.86	1.82	1.89	1.31
CD at 5 %	386.20	402.02	269.29	687.56	706.24	476.13	NS	NS	NS
CV (%)	8.15	8.35	8.25	8.29	8.36	8.33	8.63	8.98	8.81
Year	SEm±			74.18			0.59		
	CD (P=0.05)			NS			NS		
Y x T	SEm±			234.57			1.85		
	CD (P=0.05)			NS			NS		

Results of this experiment revealed that various treatments of soil and foliar application of Zn and Fe significantly influenced the number of unfilled grains panicle⁻¹. As far as the number of unfilled grains panicle⁻¹ is concerned, all the treatments under study significantly differ from each other and being minimum in treatment T₁₀ over absolute control treatment T₁ which was statistically at par with treatments T₄, T₈, T₉ and T₂ during first years. While, in the case of second and in pooled results treatment treatments T₄, T₈ and T₉ were found statistically at par with T₁₀.

Significantly higher panicle length (Table 7) was recorded with treatment T₁₀ (Soil ZnSO₄ + FeSO₄ each @ 25 kg ha⁻¹ and Foliar ZnSO₄ + FeSO₄ each @ 0.5% at 30 & 60 DAS), but being at par with treatment T₄ (Soil ZnSO₄ + FeSO₄ each @ 25 kg ha⁻¹) and T₈ (Soil ZnSO₄ @ 25 kg ha⁻¹ + Foliar ZnSO₄ @ 0.5% at 30 & 60 DAS) during the first year and pooled study. However, in second year treatments T₄, T₈, T₉ and T₂ at par with T₁₀. However, in pooled study, treatments T₄ and T₈ were found statistically equal with T₁₀. The increase in panicle length might be attributed to the beneficial role of Zn and Fe in improving photosynthetic activity and plant nutrition. The reason for increasing the panicle length might be due to the highly availability of Fe and Zn to rice which increased dry matter and plant assimilates, which directly reflects in the number of tillers plant⁻¹ and also higher panicle length. Similarly, results were published by Tripathy and Sahoo [41] and Ugile et al. [39].

A perusal of the data presented in Table 7 revealed that soil ZnSO₄ + FeSO₄ each @ 25 kg ha⁻¹ and foliar ZnSO₄ + FeSO₄ each @ 0.5% at 30 & 60 DAS (T₁₀) recorded significantly higher weight of panicle compared to the remaining treatments except Soil ZnSO₄ + FeSO₄ each @ 25 kg ha⁻¹ (T₄). However, significantly light weight were found with treatment absolute control (T₁) during both consecutive years and in combined results.

The data presented in Table 7 indicated that the differences in test weight were non-significant due to soil and foliar application of Zn and Fe. However, treatment T₁₀ recorded a higher value of test weight.

Data in Table 7 revealed that grain yield plant⁻¹ of rice as influenced by soil and foliar application of Zn and Fe varied significantly during both years and in pooled results. Further, data revealed that

soil ZnSO₄ + FeSO₄ each @ 25 kg ha⁻¹ and foliar ZnSO₄ + FeSO₄ each @ 0.5% at 30 & 60 DAS (T₁₀) recorded significantly higher grain yield plant⁻¹ and remained statistically at par with treatments T₄, T₈, T₉, T₂, T₃ and T₇. While in the second year and in pooled analysis T₄, T₈, T₉ and T₂ were found at par with the T₁₀. It was also noted that absolute control (T₁) recorded the significantly lowest grain yield plant⁻¹ during both years as well as in the pooled analysis.

The sum of the mean data indicated that various treatments lead to a significant increase in straw yield plant⁻¹ in rice during an individual year, as well as in pooled analysis (Table 8). Treatment T₁₀ recorded significantly higher straw yield plant⁻¹ and remained statistically at par with treatments T₄, T₈, T₉, T₂, T₃ (Soil FeSO₄ @ 25 kg ha⁻¹) and T₇ during both years. However, treatment T₄, T₈, T₉ and T₂ treatments was found to be statistically equal to T₁₀ in pooled analysis. Absolute control (T₁) gave the lowest straw yield plant⁻¹ g plant⁻¹, respectively) during both years as well as in the pooled analysis.

The grain yield is the net result of various agronomic inputs influencing growth and yield attributing characteristics that are altered by the surrounding environment during the life cycle of the crop. A critical examination of the data presented in Table 8. Clearly indicated that rice grain yield was significantly influenced by soil and foliar application of Zn and Fe. Results of grain yield recorded at harvest of the crop as influenced by soil and foliar application of Zn and Fe for the years of 2021, 2022 and on a pooled basis, are presented in Table 8. A perusal of the data showed that the effect of soil and foliar application of Zn and Fe was found to be significant during both the years of experimentation and pooled analysis on the grain yield of rice. Data revealed that significantly higher grain yields (3003, 3067 and 3035 kg ha⁻¹, respectively) were obtained under the treatment soil ZnSO₄ + FeSO₄ each @ 25 kg ha⁻¹ and foliar ZnSO₄ + FeSO₄ each @ 0.5% at 30 & 60 DAS (T₁₀) during both years and over the pooled results. However, it remained significantly at par with treatments T₄, T₈, T₉, T₃ and T₇ during both years. Wherein, in pooled analysis, T₄ (Soil ZnSO₄ + FeSO₄ each @ 25 kg ha⁻¹), T₈ (Soil ZnSO₄ @ 25 kg ha⁻¹ + Foliar ZnSO₄ @ 0.5% at 30 & 60 DAS), T₉ (Soil FeSO₄ @ 25 kg ha⁻¹ + Foliar FeSO₄ @ 0.5% at 30 & 60 DAS) and T₂

(Soil ZnSO₄ @ 25 kg ha⁻¹) treatments were found to be statistically equal with T₁₀. The significantly lowest grain yield (2435, 2454 and 2445 kg ha⁻¹, respectively) was observed under absolute control. The trend of treatments to produce grain yield was T₁₀>T₄>T₈>T₉>T₂>T₃>T₇>T₅>T₆>T₁₀.

Data obtained on the straw yield of summer rice as influenced by different treatments have been statistically analyzed and presented in Table 8. The data revealed that soil and foliar application of Zn and Fe significantly increased the straw yield of rice during both years as well as in pooled analysis. Among the different treatments examined, significantly higher straw yield (5288, 5384 and 5336 kg ha⁻¹, respectively) was recorded under the treatment soil ZnSO₄ + FeSO₄ each @ 25 kg ha⁻¹ and foliar ZnSO₄ + FeSO₄ each @ 0.5% at 30 & 60 DAS (T₁₀) during both the years and in the pooled results and it remained at par with treatments T₄, T₈, T₉, T₂, T₃ and T₇ during both years. However, treatments T₄, T₈, T₉ and T₂ treatments were found to be statistically equal to T₁₀ in pooled analysis. Absolute control (T₁) gave the lowest straw yield (4235, 4301 and 4268 kg ha⁻¹, respectively) during both years as well as in the pooled analysis.

A critical examination of the data (Table 8) indicated that various soil and foliar applications of Zn and Fe during both years and in the pooled analysis had no significant effect on the harvest index.

From the findings mentioned above, soil and foliar application of Zn and Fe showed significant effect on yield attributing characters and yield of drilled rice. Increase in productive tillers meter⁻², number of filled grains panicle⁻¹, number of unfilled grains panicle⁻¹, panicle length (cm), panicle weight (g), 1000 grain weight (g), grain yield plant⁻¹ (g plant⁻¹), straw yield plant⁻¹ (g plant⁻¹), grain yield (kg ha⁻¹) and straw yield (kg ha⁻¹) was noticed as a result of soil and foliar application of Zn and Fe. Zn and Fe are part of the photosynthesis, assimilation and translocation of photosynthates from source to sink. The increase in yield due to zinc and iron application may be attributed to their role in various physiological processes and improvement in growth components better partitioning of carbohydrates from leaf to reproductive parts resulting in increasing yield. It could be ascribed to its improvement in metallo

enzymes system regulatory function and growth promoting auxin production especially during the enrichment process to last for a longer time and release the nutrients slowly in the soil system in such a way that nutrients are protected from fixation and made available to the plant root system throughout the crop growth and resulting in yield attributes and yield of rice. These results are in confirmation with Zayed et al. [29] Suresh S. and Salakinkop S. R. [30] Goverdhan M. [31] Kadam et al. [32] Balachandrakumar, V. and Rao [33] Rao et al. [34] Janardhan et al. [35] Bharti et al. [36], Rao et al. [37] and Ugile et al. [39,42]

4. CONCLUSION

In the light of the results obtained from two years investigation, it can be concluded that, to obtain better growth and yields of drilled rice cv. GR 16 (Tapi), the crop should be fertilized with soil ZnSO₄ + FeSO₄ each @ 25 kg ha⁻¹ and foliar ZnSO₄ + FeSO₄ each @ 0.5% at 30 & 60 DAS along with RDF and soil ZnSO₄ + FeSO₄ each @ 25 kg ha⁻¹ along with RDF.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

All Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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