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Studies on the Effect of Biofortification through Micronutrients Fortified Organics on the Soil Properties, Yield and Quality of Brinjal in Coastal Soil

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ABSTRACT

Numerous multi-micronutrient fertilizers (MMF) have been developed during recent years to address the micronutrient deficiencies in crops but still micronutrient deficiency occurs in both soil and human beings. Biofortification is one of the techniques, which deliver the targeted element in edible part of the plants to overcome the malnutrition and hidden-hunger in burgeoning population. Based on the fact, the present field study was undertaken to study the effect of biofortification through micronutrients fortified organics on the performance of brinjal in coastal soil. The various treatments evaluated were T_1 – Control (100% NPK/RDF alone), T_2 – RDF + FYM @ 12.5 t ha^{-1}, T_3 – RDF + Vermicompost (VC) @ 12.5 t ha^{-1}, T_4 – RDF + FYM + $ZnSO_4$ @ 25kg ha^{-1} + $FeSO_4$ @ 25 kg ha^{-1} SA (soil application), T_5 – RDF + VC + $ZnSO_4$ @ 25 kg ha^{-1} + $FeSO_4$ @ 25 kg ha^{-1} SA, T_6 – RDF + FYM + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA (foliar application), T_7 – RDF + VC + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA, T_8 - RDF + Zn + Fe Fortified FYM (MNFFYM)@ 6.25 t ha^{-1}, T_9-RDF + Zn + Fe Fortified VC (MNFVC) @ 6.25 t ha^{-1}, T_{10} - RDF + MNFFYM @ 6.25 t ha^{-1} + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA and T_{11} - RDF + MNFVC @ 6.25t ha^{-1} + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA. The treatments were studied under Randomized Block Design (RBD) with three replications and using Annamalai brinjal as test crop. Among that treatments, combined application of recommended dose of fertilizer (RDF) + micronutrients fortified vermicompost (MNFVC) @ 6.25 t ha^{-1} through soil application along with foliar application of $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% at pre flowering stage (PFS) and at flowering stage (FS) recorded the highest growth, yield characters, yield and quality of brinjal. This treatment also recorded the significant higher nutrients availability and nutrients uptake by brinjal in coastal soil.

Keywords Biofortification, Zinc, Iron, Brinjal, Coastal soil.

INTRODUCTION

Micronutrient deficiencies lead to hidden hunger which distress more than two billion individuals or one in three people, globally (Finkelstein *et al.* 2015 and Kurdekar *et al.* 2023). These deficiencies

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occur when intake and absorption of vitamins and minerals are inadequate to sustain decent health and development (Sumithra *et al*. 2013). In past 50 years, agricultural research in developing countries has focused only on increased crop production. However, there has not been an equal growth in the production of non-staples that are high in micronutrients, such as vegetables, legumes, and animal products (Gould 2017). Agriculture is currently undergoing a transition from generating large amounts of food crops to providing enough nutrient-rich food crops. This will help in fighting hidden hunger especially in poor and developing countries, where diets are subject to micronutrient-poor staple food crops (Uikey *et al.* 2018). Biofortification refers to enhanced nutrition in food crops with increased bioavailability to the human that are developed and grown by using transgenic techniques, conventional plant breeding, or agronomic practices. Although biofortified foods are a relatively new development, their marketability, accessibility to healthcare systems, and lack of knowledge about the long-term health advantages of these nutritional supplements are some of their drawbacks (Rudkowska 2013, Gogoi *et al*. 2014). Therefore, biofortification of many crop kinds offers a long-term and sustainable alternative for providing people with crops that are high in micronutrients. Economically, purchasing biofortified crops has no cost compared to purchasing fortificants and adding them to the food supply during processing. It also offers long-term cost benefits with sustainable methods for reducing hidden hunger (Diksha and Sharma 2020).

Brinjal (*Solanum melongena* L.) or eggplant is one of the most common, popular and principle vegetable crop grown in India and other parts of the world. The brinjal is of much important in the warm areas of Far East, being grown extensively in India and other Asian countries like Bangladesh, Pakistan and Philippines. China, Turkey, Japan, Egypt, Indonesia, Iraq, Italy, Syria, and Spain are additional big producers of brinjal. Brinjal occupies third position amongst vegetable crops grown in India, it covers 680.0 thousand hectare with a productivity of 18.70 t ha^{-1} and produces 12706.0 thousand tonnes in India in 2014-2015.

Zinc (Zn) is involved in most plant growth functions and produce auxin in plant system. Zinc forms enzyme systems which regulates plant life. Yet zinc is the most common micronutrient deficiency in agriculture today. Zinc deficiency can limit yields of corn, beans, wheat, cotton, sorghum, fruits and vegetables. The deficiency of zinc indicates leaf discoloration, stunting reduced height, brown spots on upper leaves, distorted leaves, Interveinal chlorosis which spread later to younger leaves (Bhuvaneswari *et al.* 2020).

Iron (Fe) is more important in plant biochemical reactions which can directly or indirectly increase the performance of crops (Zarghamnejad *et al.* 2015). Fe has a number of important functions within plants, including photosynthesis, respiration and chlorophyll synthesis (Dhakar and Singh 2015). Further, many of metabolic pathways and enzymes are activated by iron. It is suggested to play an important role in growth by stimulating cell division. All plants need a continuous supply of iron during growth because it is not translocate from the mature to developing leaves and is classified as an immobile nutrient element. Many plants are exposed to iron deficiency which is the result of its effects on reduced nutritional quality and poor yields (Rout and Sahoo 2015).

Many investigators reported the stimulating effect of applied zinc (Zn) and iron (Fe) combined with NPK fertilization rates which can contribute to improve vegetative growth, yield components and fruit yield of brinjal. In general, abiotic stressors such as salt, acidity, waterlogging, and sandy texture are present in coastal soils. Salinity is the main factor responsible for poor yield of crops in such regions. Therefore, proper understanding about the nature, properties and prevailing constraints related to diverse group of coastal soils is necessary to undertake better management practices to improve the productivity and quality of such low productive soils (Ray *et al.* 2014). By the way biofortification of brinjal with zinc and iron fortified organic manures has a promising positive effect on brinjal in coastal soil.

MATERIALS AND METHODS

In the coastal areas of Tamilnadu, the deficiency of both macro and micronutrients especially zinc and iron are the most common in coarse textured coastal soils. Micronutrients are essential mineral elements required for both plant and human health. However, micronutrients are often lacking in soils, crop, and food. Micronutrients are therefore used as fertilizer to increase crop productivity, especially when the application of conventional NPK fertilizers is not efficient. Hence, bio fortification increases the concentration of target mineral in edible parts of crops by the use of mineral fertilizers along with zinc and iron fortified organic manures to increase the micronutrients content, yield and quality of brinjal as well as improved the dietary intake of target minerals. Hence the present study was carried out to study the effect of bio fortification of brinjal with zinc and iron fortified organic manures in coastal soil. The field experiment was carried out in a farmer's field at Perampattu coastal village, near Chidambaram taluk, Cuddalore district, Tamil Nadu, during February- May 2022. The experimental soil had the following characteristics like, pH–8.37, EC–1.58 dS m^{-1}, organic carbon 2.31 g kg^{-1}, 135.56 kg ha^{-1} of alkaline $KMnO_4$ – N; 9.45 kg ha^{-1} of Olsen–P and 157.30 kg ha^{-1} of NH_4OAc-K. The available zinc (0.69 mg kg^{-1}) and iron content (3.87 mg kg^{-1}) of soil is below the critical level. The various treatments evaluated were T_1 – Control (100% NPK/RDF alone), T_2 – RDF + FYM @ 12.5 t ha^{-1}, T_3 – RDF + Vermicompost (VC) @ 12.5 t ha^{-1}, T_4 – RDF + FYM + $ZnSO_4$ @ 25kg ha^{-1} + $FeSO_4$ @ 25 kg ha^{-1} SA (soil application), T_5 – RDF + VC + $ZnSO_4$ @ 25 kg ha^{-1} + $FeSO_4$ @ 25 kg ha^{-1} SA, T_6 – RDF + FYM + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA (foliar application), T_7 – RDF + VC + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA, T_8 - RDF + Zn + Fe Fortified FYM (MNFFYM)@ 6.25 t ha^{-1}, T_9-RDF + Zn + Fe Fortified VC (MNFVC)@ 6.25 t ha^{-1}, T_{10} - RDF + MNFFYM @ 6.25 t ha^{-1} + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA and T_{11} - RDF + MNFVC @ 6.25 t ha^{-1} + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA. The treatments were arranged in Randomized Block Design (RBD) with three replications by using brinjal var. Annamalai brinjal as a test crop. A fertilizer dose of 100:50:25 kg N: P_2O_5: K_2O ha^{-1} was followed and applied through urea, super phosphate and muriate of potash, respectively as per the treatment. Required quantities of $ZnSO_4$ and $FeSO_4$ were applied either through soil or/ and foliar as per the treatment schedule. Calculated quantities of micronutrients (Zn and Fe) fortified organic manures like micronutrients fortified farm yard manure (MNFFYM) and micronutrients fortified vermicompost (MNFVC) were applied to the soil as per treatment schedule. Foliar application of $ZnSO_4$ and $FeSO_4$ @ 0.5% at Pre Flowering Stage (PFS) and at Flowering Stage (FS) was given as per the treatment schedule. Various growth components like plant height, number of branches $plant^{-1}$, dry matter production (DMP) and yield components viz., number of fruits $plant^{-1}$ and single fruit weight, fruit and stover yield were recorded at harvest stage. The fruit and stover samples were collected at different critical stages. The plant samples were then shade dried and kept in oven for 72 hrs at 65°C. After taking weight, the plant samples were powdered in the Willey mill and analyzed for the content of N, P, K, Zn and Fe. The total uptake of individual nutrient was computed by multiplying the respective nutrient content with DMP. In Brinjal fruits analysis, the quality parameters of like Ascorbic acid content, protein content, total soluble solids (TSS) and titrable acidity was noted. The soil samples were collected at different stages and analyzed for available N, P, K, Zn and Fe using standard procedure of Jackson (1973).

RESULTS AND DISCUSSION

Growth, yield characters, yield and quality of brinjal

Growth characters

Application of different micronutrients fortified organic manures along with micronutrient fertilization favorably increased the growth characters of brinjal in coastal saline soil. Among the various treatments, the treatment (T_{11}), combined application of recommended dose of fertilizer (RDF) + micronutrients fortified vermicompost (MNFVC) @ 6.25 t ha^{-1} through soil application along with foliar application of $ZnSO_4$ + $FeSO_4$ @ 0.5% at pre flowering stage (PFS) and at flowering stage (FS) recorded the highest growth characters viz., plant height (123.56 cm) and DMP (844.25 kg ha^{-1}). This was followed by the application of individual micronutrient (zinc or iron) either soil or foliar alone along recommended NPK (without fortification) significantly increased growth, quality yield characters and yield of brinjal as compared to control. The foliar application of $ZnSO_4$ @ 0.5% +

Table 1. Effect of biofortification of brinjal with zinc and iron fortified organic manures on growth, yield characters, yield and quality of brinjal.

Treatments	Plant height (cm)	Dry matter production (kg ha^{-1})	No. of fruits $plant^{-1}$	Single fruit weight (g)	Fruit yield (t ha^{-1})	Stover yield (t ha^{-1})	Ascorbic acid (mg 100 g^{-1})	Crude protein (%)
T_1 – Control (100% NPK/RDF alone)	91.36	701.55	13.38	33.48	14.69	5.22	4.74	3.286
T_2 – RDF + FYM @ 12.5 t ha^{-1}	97.35	715.48	14.47	34.63	15.28	5.46	5.34	3.426
T_3 – RDF + Vermicompost (VC) @ 12.5 t ha^{-1}	101.22	728.43	15.32	35.62	15.79	5.64	6.03	3.576
T_4 – RDF + FYM + $ZnSO_4$ @ 25kg ha^{-1} + $FeSO_4$ @ 25 kg ha^{-1} SA (soil application)	104.55	741.37	16.31	36.53	16.26	5.83	6.73	3.756
T_5 – RDF + VC + $ZnSO_4$ @ 25 kg ha^{-1} + $FeSO_4$ @ 25 kg ha^{-1} SA	107.05	755.23	17.33	37.62	16.67	6.01	7.44	3.946
T_6 – RDF + FYM + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA (foliar application)	109.51	768.50	18.44	38.77	17.25	6.2	8.19	4.076
T_7 – RDF + VC + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA	112.50	781.56	19.32	39.86	17.91	6.38	8.81	4.226
T_8 – RDF + Zn + Fe Fortified FYM (MNFFYM)@ 6.25 t ha^{-1}	115.37	805.11	20.27	40.85	18.42	6.54	9.53	4.406
T_9– RDF + Zn + Fe Fortified VC (MN-FVC) @ 6.25 t ha^{-1}	118.04	819.47	21.36	41.73	18.91	6.72	10.19	4.566
T_{10} – RDF + MNFFYM @ 6.25 t ha^{-1} + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA	120.97	831.51	22.48	42.84	19.44	6.91	10.94	4.716
T_{11} – RDF + MNFVC @ 6.25t ha^{-1} + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA	123.56	844.25	23.37	43.79	19.89	7.11	11.56	4.876
SEd	**1.11**	**5.50**	**0.30**	**0.35**	**0.17**	**0.08**	**0.17**	**0.05**
CD (p = 0.05)	**2.35**	**11.55**	**0.65**	**0.74**	**0.36**	**0.15**	**0.48**	**0.11**

$FeSO_4$ @ 0.5% twice at flowering and pre flowering stage along with recommended dose of NPK and vermicompost (T_7) recorded a plant height of 112.50 cm and DMP of 781.56 kg ha^{-1}. This was followed by treatments arranged in descending order like T_6>T_5>T_4>T_3> and T_2.The lowest growth parameters of brinjal was noticed in treatment T_1 - Control (100% NPK/RDF alone).

The increase in growth parameters may be due to application of major and micro nutrients through foliar sprays along with fortified organics increased the photosynthetic activity, chlorophyll formation, nitrogen metabolism and auxin contents in the plants which ultimately improving the plant height. Further, the increased growth parameters of brinjal due to application of zinc and iron the increased the rates of photosynthesis and photosynthates supply for maximum branches growth or change in endogenous auxin in turn in apical dominance. These findings are in agreement with the findings of Amalia *et al*. (2020) and Bana *et al.* (2022), (Table 1).

Yield characters

The brinjal responded well to the application of zinc and iron along with fortified vermicompost and FYM. The significant influence of recommended NPK along with Zn and Fe enriched organics in increasing the yield characters of brinjal was well documented in the present study.

The yield characters realized under the nutrient poverished coastal saline soil, the highest no. of fruits $plant^{-1}$ (23.37) and single fruit weight (43.79 g) was recorded with combined application of recommended dose of fertilizer (RDF) + micronutrients fortified vermicompost (MNFVC) @ 6.25 t ha^{-1} through soil application along with foliar application of $ZnSO_4$ + $FeSO_4$ @ 0.5% at pre flowering stage (PFS) and at flowering stage (FS) (T_{11}). This was followed by the treatments T_{10}, (RDF + MNFFYM @ 6.25 tha^{-1} + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA), T_9 (RDF + Zn + Fe Fortified VC (MNFVC)@ 6.25tha^{-1}) and T_8 (RDF + Zn + Fe Fortified FYM (MNFFYM)@ 6.25t ha^{-1}) which recorded the no. of fruits plant^{-1} of 23.37, 22.48, 21.36 and single fruit weight of 43.79, 42.84, 41.73 g of brinjal, respectively. This was followed by the application of zinc and iron alone or without fortification treatments T_7, (RDF + VC + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA), T_6 (RDF + FYM + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA), T_5 (RDF + VC + $ZnSO_4$ @ 25kg ha^{-1} + $FeSO_4$ @ 25kg ha^{-1} SA) and T_4 (RDF + FYM + $ZnSO_4$ @ 25kg ha^{-1} + $FeSO_4$ @ 25 kg ha^{-1} SA) which recorded the lowest yield characters as compared to above said treatments (fortification). The lowest yield characters were recorded with the application of RDF alone or with organics treatments such as T_2 – RDF + FYM @ 12.5 t ha^{-1}, T_3 – RDF + Vermicompost (VC) @ 12.5 t ha^{-1} and T_1 (RDF alone/control).

The combined application of recommended dose of fertilizer (RDF) + micronutrients fortified vermicompost (MNFVC) @ 6.25 t ha^{-1} through soil application along with foliar application of $ZnSO_4$ + $FeSO_4$ @ 0.5% at pre flowering stage (PFS) and at flowering stage (FS) recorded the higher yield parameters of brinjal. This might be due to better synthesis of cytokine with optimum supply of zinc and iron resulting in more yield characters. The findings are in accordance with Bhuvaneswari *et al.* (2020).

Yield of brinjal

Among the various treatments, the treatment (T_{11}), combined application of recommended dose of fertilizer (RDF) + micronutrients fortified vermicompost (MNFVC) @ 6.25 t ha^{-1} through soil application along with foliar application of $ZnSO_4$ + $FeSO_4$ @ 0.5% at pre flowering stage (PFS) and at flowering stage (FS) recorded a fruit and stover yield of 19.89 and 7.11 t ha^{-1}. This was followed by the treatments which received zinc and iron either fortification or combination with foliar spray. The treatment T_{10}, (RDF + MNFFYM @ 6.25 t ha^{-1} + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA), T_9 (RDF + MNFVC @ 6.25 t ha^{-1}) and T_8 (RDF + MNFFYM @ 6.25 t ha^{-1}) which recorded the fruit yield of 19.89, 19.44, 18.91 t ha^{-1} and stover yield of 6.91, 6.72, 6.54 t ha^{-1} of brinjal, respectively.

This was followed by the treatments (without fortification) arranged in descending order like T_7>T_6>T_5>T_4>T_3>T_2 and T_1. The highest fruit and stover yield was recorded by the treatment T_{11} which was 35.39 and 36.20% increase over control or 100% NPK alone (without micronutrients, BF and organics). The control treatment T_1, 100% NPK alone recorded a lower fruit (14.69 t ha^{-1}) and stover (5.22 t ha^{-1}) yield of brinjal.

Present findings are in accordance with Manimegala and Gunasekaran (2020) who found significantly higher fruit yield and stover yield of brinjal under increased with peat: Vermicompost: Sand with 100% drip fertigation. Further, foliar application of zinc and iron enhanced the fruit and stover yield in the present study could be due to adequate and continuous nutrient availability through soil and foliar nutrition promotes the supply of assimilates to sink thus influences the higher yield of brinjal.

Quality characters

The effect due to the application of zinc and iron fortified organic manures in enhancing the quality parameters of brinjal were significant. The treatment (T_{11}), combined application of recommended dose of fertilizer (RDF) + micronutrients fortified vermicompost (MNFVC) @ 6.25 t ha^{-1} through soil application along with foliar application of $ZnSO_4$ + $FeSO_4$ @ 0.5% at pre flowering stage (PFS) and at flowering stage (FS) recorded the highest ascorbic acid and crude protein content of 11.56 mg 100 g^{-1} and 4.876%, respectively. This was followed by the next best treatments T_{10}, (RDF + MNFFYM @ 6.25tha^{-1} + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA), T_9 (RDF + MNFVC @ 6.25 t ha^{-1}) and T_8 (RDF + MNFFYM @ 6.25 t ha^{-1}) which recorded the ascorbic acid content of 10.94, 10.19, 9.53 mg 100 g^{-1} and crude protein content of 4.716, 4.566, 4.406 % of brinjal, respectively. This was followed by the treatments (without fortification) arranged in descending order like T_7>T_6>T_5>T_4>T_3>T_2 and T_1.\

The combined application of recommended dose of fertilizer (RDF) + micronutrients fortified vermicompost (MNFVC) @ 6.25 t ha^{-1} through soil application along with foliar application of $ZnSO_4$ + $FeSO_4$ @ 0.5% at pre flowering stage (PFS) and at flowering stage (FS) registered the highest Quality parameters like ascorbic acid and crude protein content. This could be due the fact that the soil used was saline condition and application of micronutrients through fortified vermicompost decreased the soil pH and increased availability of Zn as well as it affect the concentration of vitamin C and the amount of antioxidative compounds in solanaceous crops. These findings are in accordance with Singh *et al.* (2020).

Major nutrients availability in coastal saline soil

The availability of major nutrients in coastal saline soils are very low due to poor crop residues and microbial activity and leaching of nutrients associated with poor structure and low use efficiency of applied nutrients. In the present study, the application of fortified micronutrients along with foliar spray exerted favorable influence on increasing the nutrients availability in soil. (Table 2.).

The nutrients availability in the soil significantly increased at all the stages of brinjal growth. Among the various treatments, the highest available N (168.74 kg ha^{-1}), P (10.69 kg ha^{-1}) and K (198.26 kg ha^{-1}) at harvest stage was recorded with the combined application of recommended dose of fertilizer (RDF)

Table 2. Effect of biofortification of brinjal with zinc and iron fortified organic manures on major nutrients availability in coastal saline soil.

Treatments	Alkaline $KMnO_4$-N (kg ha^{-1})			Olsen-P (kg ha-1)			NH_4OAc-K (kg ha-1)		
	FS	FFS	HS	FS	FFS	HS	FS	FFS	HS
T_1 – Control (100% NPK/RDF alone)	140.61	118.01	121.67	9.65	9.08	8.93	169.45	144.64	114.54
T_2 – RDF + FYM @ 12.5 t ha^{-1}	145.10	121.30	126.69	9.80	9.33	9.15	175.84	151.13	122.63
T_3 – RDF + Vermicompost (VC) @ 12.5 t ha^{-1}	149.62	126.62	131.74	9.71	9.51	9.30	180.26	160.65	138.65
T_4 – RDF + FYM + $ZnSO_4$ @ 25kg ha^{-1} + $FeSO_4$ @ 25 kg ha^{-1} SA (soil application)	154.08	133.98	135.83	10.04	9.90	9.53	184.61	165.08	144.68
T_5 – RDF + VC + $ZnSO_4$ @ 25 kg ha^{-1} + $FeSO_4$ @ 25 kg ha^{-1} SA	158.59	141.29	141.94	10.16	10.05	9.74	189.94	171.64	152.74
T_6 – RDF + FYM + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA (foliar application)	163.15	146.65	145.12	10.28	10.19	9.88	194.31	179.21	157.81
T_7 – RDF + VC + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA	167.59	151.09	150.33	10.89	10.63	10.11	199.63	185.83	162.83
T_8 – RDF + Zn + Fe Fortified FYM (MNFFYM)@ 6.25 t ha^{-1}	172.18	158.48	155.44	11.02	10.81	10.25	203.02	191.42	174.92
T_9 – RDF + Zn + Fe Fortified VC (MNFVC) @ 6.25 t ha^{-1}	176.60	163.90	159.48	11.17	11.01	10.36	209.23	197.03	185.25
T_{10} – RDF + MNFFYM @ 6.25 t ha^{-1} + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA	170.84	168.18	164.67	11.93	11.36	10.56	215.39	204.11	191.01
T_{11} – RDF + MNFVC @ 6.25t ha^{-1} + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA	181.35	173.59	168.74	12.09	11.62	10.69	220.54	210.54	198.26
SEd	**2.09**	**2.02**	**1.88**	**0.04**	**0.04**	**0.05**	**2.04**	**2.02**	**1.87**
CD (p = 0.05)	**4.39**	**4.25**	**3.95**	**0.10**	**0.09**	**0.10**	**4.29**	**4.25**	**3.94**

+ micronutrients fortified vermicompost (MNFVC) @ 6.25 t ha^{-1} through soil application along with foliar application of $ZnSO_4$ + $FeSO_4$ @ 0.5% at pre flowering stage (PFS) and at flowering stage (FS) (T_{11}). This was followed by treatments T_{10}, (RDF + MNFFYM @ 6.25t ha^{-1} + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA), T_9 (RDF + MNFVC @ 6.25tha^{-1}) and T_8 (RDF + MNFFYM @ 6.25t ha^{-1}).

Available major nutrients were increased with micronutrient application without fortified treatments viz., T_7 – RDF + VC + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA, T_6 – RDF + FYM + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA (foliar application), T_5 – RDF + VC + $ZnSO_4$ @ 25 kg ha^{-1} + $FeSO_4$ @ 25 kg ha^{-1} SA, T_4 – RDF + FYM + $ZnSO_4$ @ 25 kg ha^{-1} + $FeSO_4$ @ 25 kg ha^{-1} SA (soil application). The lowest nutrient availability in soil was noticed in treatments which supplied organics alone and RDF alone viz., T_3 – RDF + Vermicompost (VC) @ 12.5 t ha^{-1}, T_2 – RDF + FYM @ 12.5 t ha^{-1} and T_1 – Control.

Addition of micronutrient as zinc and iron increased the nitrogenase activity thereby the availability of N is increased. Further, the addition of organics stimulated the growth and activity of microorganisms, which increased the nutrient release and the effect was further enhanced by the addition of nitrogenous fertilizer. Increased N availability in the soil could be due to the synergistic effect by application of zinc and iron along with organic manures (Haider *et al.* 2020).

The increased Olsen-P content due to addition of zinc and iron nutrition along with organics might be due to role played by organics in dissolution of native phosphorus compounds to the active pool besides mineralization as they contained appreciable content of phosphorus. Further, the availability of K increased with zinc and iron along with organics addition in soil due to the stimulatory effect of zinc and iron on K along with the favorable influence of organics helping in the mobilization and release of K from clay and organic complexes. The present findings are in accordance with the earlier reports of Choudhary *et al.* (2014) and Kumar (2016).

Zinc and iron availability in coastal saline soil

The available Zn and Fe in the soil was significantly increased due to the fortified micronutrients application (zinc + iron) along with foliar spray at all the critical stages like flowering, fruit formation and at harvest stages of brinjal. Among the treatments the treatment T_{11}, combined application of recommended

Table 3. Effect of biofortification of brinjal with zinc and iron fortified organic manures on zinc and iron availability in coastal saline soil.

Treatments	DTPA-Zinc (mg kg^{-1})			DTPA-Iron (mg kg^{-1})		
	FS	FFS	HS	FS	FFS	HS
T_1 – Control	0.85	0.61	0.22	0.84	0.55	0.71
T_2 – RDF + FYM @ 12.5 t ha^{-1}	1.22	1.01	0.52	1.09	0.92	0.94
T_3 – RDF + Vermicompost (VC) @ 12.5 t ha^{-1}	1.58	1.20	0.74	1.74	1.42	1.01
T_4 – RDF + FYM + $ZnSO_4$ @ 25kg ha^{-1} + $FeSO_4$ @ 25 kg ha^{-1} SA (soil application)	1.70	1.29	0.79	1.82	1.56	1.08
T_5 – RDF + VC + $ZnSO_4$ @ 25kg ha^{-1} + $FeSO_4$ @ 25kg ha^{-1} SA	1.79	1.37	0.84	1.90	1.64	1.15
T_6 – RDF + FYM + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA(foliar application)	1.90	1.45	0.89	2.01	1.71	1.23
T_7 – RDF + VC + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA	1.98	1.56	0.95	2.11	1.79	1.31
T_8 - RDF + Zn + Fe Fortified FYM (MNFFYM)@ 6.25t ha^{-1}	2.06	1.64	1.01	2.19	1.87	1.38
T_9-RDF + Zn + Fe Fortified VC (MNFVC)@ 6.25tha^{-1}	2.15	1.71	1.06	2.27	1.94	1.46
T_{10} - RDF + MNFFYM @ 6.25tha^{-1} + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA	2.23	1.78	1.12	2.35	2.03	1.45
T_{11} - RDF + MNFVC @ 6.25t ha^{-1} + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA	2.33	1.87	1.18	2.45	2.12	1.63
SEd	0.032	0.030	0.024	0.033	0.030	0.028
CD (p = 0.05)	0.069	0.063	0.049	0.071	0.062	0.060

dose of fertilizer (RDF) + micronutrients fortified vermicompost (MNFVC) @ 6.25 t ha^{-1} through soil application along with foliar application of $ZnSO_4$ + $FeSO_4$ @ 0.5% at pre flowering stage (PFS) and at flowering stage (FS) recorded the highest available DTPA zinc (1.18 mg kg^{-1}) and iron (1.63 mg kg^{-1}) content in soil at harvest stage. This was followed by the next best treatments T_{10}, (RDF + MNFFYM @ 6.25 t ha^{-1} + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA), T_9 (RDF + MNFVC @ 6.25 t ha^{-1}) and T_8 (RDF + MNFFYM @ 6.25t ha^{-1}). This was followed by the treatments (without fortification) arranged in descending order like $T_7>T_6>T_5>T_4>T_3$ and T_2. The control treatment T_1, recorded the lowest DTPA Zn and Fe content of 0.22 and 0.71mg kg^{-1} at harvest, respectively. Higher zinc and iron content of soil might be due to organic acids released during the decomposition of organic materials which might have reacted with soil thereby increasing the availability. These results are in agreement with the findings of Thingujam *et al*. (2016). (Table 3).

Major nutrients uptake by brinjal

The major uptake of brinjal at all the critical stages of crop growth and in fruit and stover was significantly increased with the Zn and Fe fertilization. Application of recommended dose of NPK + RDF+ MNFVC @ 6.25 t ha^{-1} + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA significantly increased the uptake of major nutrients by brinjal (Table 4).

Application of zinc and iron through fortification recorded the higher nutrients uptake than soil application or foliar spray alone. Among the treatments evaluated the treatment T_{11}, combined application of recommended dose of fertilizer (RDF) + micronutrients fortified vermicompost (MNFVC) @ 6.25 t ha^{-1} through soil application along with foliar application of $ZnSO_4$ + $FeSO_4$ @ 0.5% at pre flowering stage (PFS) and at flowering stage (FS) recorded the highest N uptake of 42.19 kg ha^{-1}, P uptake of 6.89 kg ha^{-1} and K uptake of 17.25 kg ha^{-1} by fruit. This was followed

Table 4. Effect of biofortification of brinjal with zinc and iron fortified organic manures on major nutrients uptake by brinjal.

Treatments	Nitrogen (kg ha^{-1})				Phosphorus (kg ha^{-1})				Potassium (kg ha^{-1})			
	FS	FFS	Fruit	Stover	FS	FFS	Fruit	Stover	FS	FFS	Fruit	Stover
T_1 –Control	8.09	13.03	17.57	12.32	1.12	2.14	2.74	4.32	14.03	19.05	6.85	16.15
T_2 –RDF + FYM @ 12.5 t ha^{-1}	9.53	15.55	19.79	15.12	1.37	2.52	3.01	4.91	15.72	21.34	8.04	18.49
T_3 –RDF + Vermicompost (VC) @ 12.5 t ha^{-1}	10.02	17.24	22.18	17.09	1.59	2.89	3.39	5.54	17.55	23.67	8.97	20.88
T_4 –RDF + FYM + $ZnSO_4$ @ 25kg ha^{-1} + $FeSO_4$ @ 25 kg ha^{-1} SA (soil application)	12.09	19.81	24.45	19.82	1.96	3.37	3.72	6.06	19.17	26.09	9.99	23.46
T_5 –RDF + VC + $ZnSO_4$ @ 25 kg ha^{-1} + $FeSO_4$ @ 25 kg ha^{-1} SA	13.06	21.37	26.71	20.67	2.21	3.70	3.95	6.75	20.96	28.46	11.06	26.08
T_6 – RDF + FYM + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA(foliar application)	15.12	23.03	28.92	22.63	2.54	4.15	4.27	7.25	22.57	30.94	11.87	28.63
T_7–RDF + VC + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA	16.07	25.68	31.25	24.61	2.75	4.47	4.51	7.86	24.24	33.31	12.98	31.32
T_8 - RDF + Zn + Fe Fortified FYM (MNFFYM) @ 6.25 t ha^{-1}	18.01	27.39	33.56	26.42	3.14	4.98	4.89	8.45	26.06	35.53	14.18	33.86
T_9-RDF + Zn + Fe Fortified VC (MNFVC)@ 6.25t ha^{-1}	19.22	29.59	35.96	28.68	3.36	5.46	5.16	9.08	27.91	37.88	15.11	36.58
T_{10} - RDF + MNFFYM @ 6.25t ha^{-1} + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA	21.03	31.04	38.91	31.68	4.73	6.87	6.17	10.19	29.22	39.81	16.24	39.65
T_{11} - RDF + MNFVC @ 6.25t ha^{-1} + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA	22.94	33.22	42.19	33.66	5.12	7.39	6.89	10.88	31.11	42.02	17.25	42.33
SEd	0.58	0.66	0.99	0.75	0.07	0.12	0.08	0.20	0.58	0.98	0.31	1.08
CD (p = 0.05)	0.83	1.29	2.09	1.59	0.16	0.27	0.17	0.42	1.22	2.07	0.66	2.27

Table 5. Effect of biofortification of brinjal with zinc and iron fortified organic manures on zinc and iron uptake by brinjal.

Treatments	Zinc (g ha^{-1})				Iron (g ha^{-1})			
	FS	FFS	Fruit	Stover	FS	FFS	Fruit	Stover
T_1 – Control	151.02	166.04	105.48	70.78	105.23	120.43	136.58	84.65
T_2 – RDF + FYM @ 12.5 t ha^{-1}	164.61	182.63	119.07	81.37	117.82	135.02	150.77	93.84
T_3 – RDF + Vermicompost (VC) @ 12.5 t ha^{-1}	179.75	200.67	134.11	92.41	129.86	150.06	166.21	104.28
T_4 – RDF + FYM + $ZnSO_4$ @ 25kg ha^{-1} + $FeSO_4$ @ 25 kg ha^{-1} SA (soil application)	202.11	221.43	151.87	103.17	143.63	166.83	182.38	115.45
T_5 – RDF + VC + $ZnSO_4$ @ 25 kg ha^{-1} + $FeSO_4$ @ 25kg ha^{-1} SA	221.32	238.27	168.71	113.01	158.47	181.67	197.29	125.36
T_6 – RDF + FYM + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA(foliar application)	234.41	255.39	185.83	121.13	171.62	198.82	214.34	136.41
T_7 – RDF + VC + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA	250.42	271.41	201.85	132.15	185.64	214.84	231.22	146.28
T_8 - RDF + Zn + Fe Fortified FYM (MNFFYM) @ 6.25t ha^{-1}	264.55	290.54	215.98	140.28	199.77	229.97	246.25	156.31
T_9 - RDF + Zn + Fe Fortified VC (MNFVC) @ 6.25 t ha^{-1}	281.09	304.08	229.52	150.82	213.31	244.51	260.29	166.35
T_{10} - RDF + MNFFYM @ 6.25t ha^{-1} + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA	293.14	329.13	245.43	161.25	225.74	259.61	275.88	179.94
T_{11} - RDF + MNFVC @ 6.25t ha^{-1} + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA	313.28	346.27	267.57	182.39	247.88	281.75	297.61	198.67
SEd	**4.84**	**5.89**	**5.27**	**3.38**	**4.78**	**6.50**	**6.31**	**4.11**
CD (p = 0.05)	**10.17**	**12.37**	**11.07**	**7.11**	**10.04**	**13.67**	**13.27**	**8.64**

by the treatments (without fortification) arranged in descending order like T_7>T_6>T_5>T_4>T_3 and T_2. The lowest NPK uptake of 17.57, 2.74 and 6.85 kg ha^{-1} by fruit was noticed in control (T_1).

The highest nitrogen uptake was recorded in treatment T_{11} this is because of the fact that the micronutrient is involved in nitrogen fixation and translocation into plant parts which might have increased the N content of plants. The higher nitrogen absorption may also be due to stimulatory or positive effect of zinc and iron on nitrogen uptake. Further, the alkaline $KMnO_4$ - N content of soil was also high for the above treatments. This might have naturally resulted in enhanced absorption of N by the crop ultimately leading to higher N uptake. The higher uptake of P might be attributed to the increased availability of phosphorus content in the soil was also high owing to the phosphate anions released from insoluble phosphate complexes in soil produced by the treatments (Mishra *et al.* 2017 and Suryanto *et al.* 2017). Increased K uptake might be due to better plant growth leading to higher uptake of nutrients and further on the stimulatory effect of Zn + Fe in absorption of potassium. These results are in accordance with the findings of Barman *et al.* (2014) and Elayaraja *et al.* (2023).

Zinc and iron uptake by brinjal

The uptake of zinc and iron by brinjal at all the growth stages as well as by fruit and stover was also significantly increased with zinc and iron fertilization through fortification. Among the various treatments, treatment T_{11}, combined application of recommended dose of fertilizer (RDF) + micronutrients fortified vermicompost (MNFVC) @ 6.25 t ha^{-1} through soil application along with foliar application of $ZnSO_4$ + $FeSO_4$ @ 0.5% at pre flowering stage (PFS) and at flowering stage (FS) registered the highest uptake Zn and Fe uptake of 267.57 and 297.61 g ha^{-1} by fruit. This was followed by treatments T_{10}, (RDF+ MNFFYM @ 6.25 t ha^{-1} + $ZnSO_4$ @ 0.5% + $FeSO_4$ @ 0.5% FA), T_9 (RDF+ MNFVC @ 6.25 t ha^{-1}) and T_8(RDF+MNFFYM @ 6.25t ha^{-1}). This was followed by the treatments T_8> T_7>T_6 >T_5>T_4 >T_3 and T_2. The treatment T_1, application of 100% NPK alone (without Zn and Fe) recorded the lowest Zn and Fe uptake of

(105.48 and 136.58 g ha^{-1}) by fruit and (70.78 and 84.65 g ha^{-1}) by stover (Table 5).

The increased Zn and Fe uptake by brinjal was significant with application of zinc + iron along with organics might be due to the decomposition process of added organic material in the soil. During the decomposition process, a number of organic acids are released which solubilized the nutrients in the soil matrix (Elayaraja *et al.* 2023). Increased micronutrients uptake with the application of NPK and organics were already reported by Bana *et al.* (2022).

CONCLUSION

The study concluded that the beneficial effect on application of recommended dose of NPK fertilizer (RDF) + Zn and Fe fortified vermicompost @ 6.25 t ha^{-1} along with the foliar application of $ZnSO_4$ and $FeSO_4$ @ 0.5% significantly enhanced the growth, yield and quality of brinjal. This treatment also registered the significantly higher nutrients availability and uptake by brinjal in coastal saline soil.

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REFERENCES

Amalia L, Budiasih R, Ria ER, Widodo RW, Kuswati U (2020) Fermented compost and N-fertilizer for enhancing the growth and productivity of purple eggplant on vertisols. *Open Agric* 5 (1): 898–904. https://doi.org/10.1515/opag-2020-0084

Bana RS, Jat GS, Grover M, Bamboriya SD, Singh D, Bansal R (2022) Foliar nutrient supplementation with micronutrient-embedded fertilizer increases biofortification in eggplant fruit and soil biological activity while enhancing plant productivity. *Sci Rep* 12 (1): 1-16.

Barman M, Shukla LM, Datta SP, Rattan RK (2014) Effect of applied lime and boron on the availability of nutrients in an acid soil. *J Plant Nutr* 37: 357-373.

Bhuvaneswari R, Nayana NL, Srinivasan S, Karthikeyan P, Suganthi S (2020) Response of humic acid and zinc fertilization on the yield characters of brinjal (*Solanum melongena* L.) *Plant Archives* 20(1): 1332-1334.

Choudhary GL, Rana KS, Bana RS, Prajapat K (2014) Soil microbial properties, growth and productivity of pearlmillet (*Pennisetum glaucum* L.) as influenced by moisture management and zinc fortification under rainfed conditions. *Afr J Microbiol Res* 8: 3314–3323.

Dhakar S, Singh Y (2015) Studies on the effect of inorganic fertilizers and plant growth regulator on growth and yield of brinjal (*Solanum melongena* L.). *Ind J Basic Appl Med Res* 1(2): 27-39.

Diksha M, Sharma DP (2020) Effect of Different Plant Growth Regulators, Micronutrients and Photothermal Regimes on Growth, Phenological and Yield Characters of Brinjal (*Solanum melongena* L.). *Int J Curr Microbiol App Sci* 9(10): 3241-3249.

Elayaraja D, Jawahar S, Sureka K, Kamaleshwaran R (2023) Biofortification of Zinc and Iron through Fortified Organics Along with NPK Levels on the Quality, Nutrient Uptake and Productivity of Brinjal in Coastal Saline Soil. *Int J Plant and Soil Sci* 35(18): 1989-1998. https://doi.org/10.9734/ijpss/2023/v35i183484.

Finkelstein J, Mehta S, Udipi S, Padmini G, Sarah VL, Michael JW, Laura EM, Eric M, Jere H (2015) A randomized trial of iron-biofortified pearl millet in school children in India. *J Nutr* 145(7): 1576-1581.

Gogoi S, Das MR, Bora P, Mazumder N (2014) Effect of foliar application of nutrients on fruit and seed production of brinjal (*Solanum melongena* L.). *Ind J Assam Agricultural Sci* 2 (1-2): 23 -27.

Gould J (2017) Nutrition: A world of insecurity. *Nature* 544(7651): S6.

Haider MU, Hussain M, Farooq M, Nawaz A (2020) Zinc Nutrition for improving the productivity and grain biofortification of mungbean. *J Soil Sci Plant Nutr* 20 (3): 1321–1335.

Kumar V (2016) Use of integrated nutrient management to enhance soil fertility and crop yield of hybrid cultivar of brinjal (*Solanum melongena* L.) under field conditions. *Adv Plants Agric Res* 4(2): 1–9. https://doi.org/10.15406/apar.2016.04.00130

Kurdekar AK, Banu AM, Das H, Sudha Rani K, Rana S, Rai S, Pandey S (2023) A promising approach for addressing micronutrient deficiencies and enhancing nutritional quality in food crops through biofortification. *Int J Plant and Soil Sci* 35(18): 2127-2134. https://doi.org/10.9734/ijpss/2023/v35i183503

Manimegala G, Gunasekaran G (2020) Effect of vermicompost and NPK fertilizer on growth and yield components of eggplant (*Solanum melongena* L.). *Int J Sci Technol Res* 9(1): 1388–1391.

Mishra VK, Kumar S, Pandey VK (2017) Effect of organic manure and bio-fertilizers on growth, yield and quality of brinjal (*Solanum melongena* L.). *Int J Pure App Biosci* 6(1): 704-707.

NHB (National Horticulture Board), *Horticultural Statistics at a Glance* (2015).

Ray P, Meena BL, Nath CP (2014) Management of coastal soils for improving soil quality and productivity. *Popular Kheti* 2(1):

95-99.

Rout GR, Sahoo S (2015) Role of iron in plant growth and metabolism. *Rev Agrl Sci* 3 (1): 1- 24. https://doi.org/10.7831/ras.3.1

Rudkowska I, Jacques H, Weisnagel SJ, Marette A, Vohl MC (2013) Transcriptomic profiles of skeletal muscle tissue following aneuglycemic-hyperinsulinemic clamp in insulin-resistant obese subjects. Genes and Nutrition 8(1): 91-98. https://doi.org/10.1007/s12263-012-0298-2

Singh PR, Saurab K, Singh Devi (2020) Effect of Bio-fertilizers on Growth, Yield and Quality of Brinjal (*Solanum melongena* L.) cv. Kashi Uttam. *Chem Sci Rev Lett* 9(35): 786-791.

Sumithra M, Jee Hyun R, Jonathan DS, Franz FR, Klaus K, Robert EB (2013) The global hidden hunger indices and maps: An advocacy tool for action. *PLoS One* 8(6): 67860.

Suryanto A, Hamid A, Damaiyanti HRR (2017) Effectiveness of biofertilizer on growth and productivity of eggplant (*Solanum melongena* L.). *J Adv Agrl Tech* 4(4): 368- 371.

Thingujam U, Pati S, Khanam R, Pari A, Ray K, Phonglosa A, Bhattacharyya K (2016) Effect of integrated nutrient management on the nutrient accumulation and status of post-harvest soil of brinjal (*Solanum melongena* L.) under Nadia conditions (West Bengal). *Ind J Appl Nat Sci* 8(1): 321–8. https://doi.org/10.31018/jans.v8i1.794.

Uikey S, Das MP, Ramgiry P, Vijayvergiya D, Ghaday P, Ali S A, Pradhan J (2018) Effect of zinc, boron and iron on growth and phenological characters of brinjal (*Solanum melongena* L.). *Int J Curr Microbiol App Sci* 7(9): 1643-1649.

Zarghamnejad Z, kordlaghari KP, Keshavarzi K (2015) Efficacy of foliar application of ferrous and manganese sulfate on wet and dry biomass of tomato (*Lycopersicon esculentum*) in greenhouse. *Int J Biosci* 6: 437-444.