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Agronomic Biofortification of Iron and Zinc and its Effect on Growth, Yield and Quality of Wheat Crop

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ABSTRACT: Micronutrient deficiencies in soil, as it not only leads to declining crop yields but also contributes to poor quality of produce, leading to dietary micronutrient deficiencies in human beings. In many micronutrient-deficient regions, wheat is the dominant staple food making up >50% of the diet. Agronomic biofortification with application of microbial inoculants and fertilizers to improve the nutritional quality of foods is a new approach being used to improve the nutrient content of a variety of staple crops. The present field experiments were conducted during *rabi* 2021-22 and *rabi* 2022-23 at research farm of Soil Science and Agricultural Chemistry, VNMKV, Parbhani to evaluate the iron and zinc solubilizing microbes as novel tool for biofortification in wheat. Experiment consists of thirty-six treatment combinations which includes four iron and zinc solubilizing inoculants (Control, *Pseudomona striata, Pseudomona fluorescens* and *Bacillus megaterium*), three levels of iron sulphate (0, 20, and 40 kg $FeSO_4$ ha^{-1}) and three levels of zinc sulphate (0,20, and 40 kg $ZnSO_4$ ha^{-1}) which were replicated twice in factorial complete randomized block design. The results indicated significant effect of microbial cultures and graded levels of $FeSO_4$ and $ZnSO_4$ on plant height, number of leaves, number of tillers and leaf area and total chlorophyll content of leaves of wheat crop. Microbial inoculants especially *Pseudomona striata* and iron and zinc level upto 40 kg ha^{-1} each found effective on growth parameters. The significant effect of microbial inoculants and graded levels of iron sulphate and zinc sulphate was seen on grain yield and straw yield of wheat. Highest grain and straw yield reported with *Pseudomona striata* i.e 2968 kg ha^{-1} grain yield and 5331 kg ha^{-1} straw yield. Further, 40 kg $FeSO_4$ reported maximum grain yield (2975 kg ha^{-1}) and straw yield (5612 kg ha^{-1}). Similarly, 40 kg $ZnSO_4$ ha^{-1} observed higher grain yield (2971 kg ha^{-1}) and straw yield (5530 kg ha^{-1}). Quality of wheat grains was also influenced by application of *Pseudomona striata* and 40 kg zinc and iron sulphate each ha^{-1}.

Keywords: microbial inoculants, wheat, iron sulphate, zinc sulphate, *Pseudomona*.

INTRODUCTION

Plants require a variety of nutrients for optimum growth and metabolism. Some of the micronutrients play a vital role in balanced crop nutrition and physiological functions and are therefore essential for plant growth and crop production. The common micronutrients important for plant metabolic activities are iron, zinc, copper, boron and manganese, (Uchida, 2000). Deficiency of any one of these micronutrients in the soil could retard plant growth. Most of the soils in world are deficient in micronutrients due to harvesting of micronutrients from the soil by growing of high-yield crops, increased use of NPK fertilizers containing lesser amounts of micronutrients and less use of organic manures and compost. Among the different micronutrients, zinc and iron are important for healthy growth, reproduction and metabolism of crop plants. Zinc serves as an important component in a variety of enzymatic reactions, redox reactions and metabolic processes (Gandhi *et al.*, 2014). Zinc has been reported to perform many critical functions in biological systems, including protection of structural and functional integrity of photosynthesis, biomass production, chlorophyll formation, nodulation, lipid and protein metabolism, carbohydrate synthesis (Thenua *et al*., 2014; Yu *et al*., 2017). Zinc is also required for the synthesis of phytohormones like auxins and cytokinins, which help in growth regulation and stem elongation in plants (Hussain *et al*., 2015). Iron is essential for chlorophyll biosynthesis, nitrogen fixation, DNA replication, reactive oxygen species (ROS) scavenging, and electron transport chain in both mitochondria and chloroplasts (Nouet *et al*., 2001; Yruela, 2013). Mostly, the zinc and iron deficiencies are caused by a diet deficient in micronutrients or their non-bioavailability (Welch and Graham 2004).

Widely cultivated modern wheat cultivars with a high-yield capacity are poor sources of micronutrients, especially Zn and Fe, for meeting daily requirements of humans. In addition, wheat is rich in antinutritional compounds such as phytic acid and phenolic compounds that reduce biological availability of Zn and Fe in the human digestive tract (Welch and Graham 2004). Generally, grain Zn and Fe concentrations in commercial wheat cultivars is less. The low concentrations are not adequate for human nutrition in diets with wheat constituting the main source of essential minerals. Hence, such wheat-based diets consumed over a period of time can result in micronutrient malnutrition and related severe health complications. Among the strategies applied for reducing the prevalence of Fe and Zn deficiency problem in human populations, enrichment (biofortification) of food crops with Fe and Zn through agricultural approaches is a widely applied strategy (Pfeiffer and McClafferty 2007; Borg *et al*., 2009; Cakmak *et al*., 2010a). Agronomic biofortification (e.g., fertilizer applications) represent complementary and cost-effective agricultural approaches to the problem (Cakmak, 2008; White and Broadley 2009).

MATERIAL AND METHOD

The present investigations were conducted at research farm of Department of Soil Science and Agricultural Chemistry, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani. Geographically, Parbhani district. Experiment consist of thirty six treatment combinations which includes four iron and zinc solubilizing cultures (Control, *Pseudomona striata, Pseudomona fluorescens,* and *Bacillus megaterium*), three levels of iron sulphate (0, 20 and 40 kg $FeSO_4$ ha^{-1}) and three levels of zinc sulphate (0, 20 and 40 kg $ZnSO_4$ ha^{-1}) replicated twice. Seed inoculation was done with *Pseudomona striata*, *Pseudomona fluorescens,* and *Bacillus megaterium* as seed treatment before sowing. The crop variety used was NIAW-1994. The recommended dose of chemical fertilizers was applied @ 100:50:50 N and P_2O_5 and K_2O kg ha^{-1} through urea, SSP and MOP. A basal dose of fertilizer was applied as per treatment at the time of sowing to wheat. Irrigation was given as per crop need. The recommended package of practices was followed. The grain and straw yields were recorded from net plot area at maturity stage of the crop. For recording biometric observations five plants were randomly selected from the plot and were marked.

RESULT AND DISCUSSION

Effect of iron and zinc solubilizing microbial inoculants and levels of iron and zinc sulphate on growth parameters of wheat. The results show that microbial inoculants and levels of iron sulphate and zinc sulphate significantly influences growth attributes like plant height, number of leaves, number of tillers and leaf area and chlorophyll content of wheat crop.

Plant height (cm): Data with respect to plant height (cm) as influenced by iron and zinc solubilizing microbial inoculants and graded levels of iron sulphate and zinc sulphate depicted in Table 1. Periodical plant height was measured at various growth stages of wheat crop. Microbial inoculants influenced on plant height and ranged between 28.02-33.88, 52.38-58.32 and 54.45-59.75 cm at tillering, flowering and harvest stage of wheat crop. Maximum plant height noted with application of *Pseudomona striata* i.e. 33.88, 58.32 and 59.75 cm at tillering, flowering and harvest stage respectively. Further, plant height of wheat crop influenced by levels of $FeSO_4$ and $ZnSO_4$ and maximum plant height noted up to 40 kg ha^{-1}. The maximum plant was found in plots receiving 40 kg $FeSO_4$ ha^{-1} i.e. 33.61-58.60-60.19 cm at tillering, flowering and harvesting stage respectively. The lower plant height was recorded with control treatment (29.54, 54.47 and 55.98 cm at tillering, flowering and harvest stage respectively). Furthermore, Levels of zinc sulphate influenced on plant height and highest plant height found with 40 kg $ZnSO_4$ ha^{-1} i.e., 33.38-58.64-60.18 cm at tillering, flowering and harvesting stage respectively. Lower plant height was reported in control treatment (29.80, 54.65 and 55.84 cm at tillering, flowering and harvest stage respectively).

The reason for the increase in growth parameter like plant height may be due to certain plant growth hormones and secondary metabolites produced by various microbial inoculants like *Pseudomona* species and *Bacillus megaterium*. Production of plant growth regulators by the microorganisms is another important mechanism often associated with growth stimulation. Various PGPR involved in the synthesis of auxins in pure culture in soil and hence can play important roles in the growth and development of crop plants. The growth promotion in wheat might be due to greater availability of nutrient through organic and biological sources by enhancing the cambium activity of root hair, root proliferation and cell development in the root surface area resulting in better absorption of water and nutrients (Shanmugaiah *et al.* 2009). Also the steady supply of iron sulphate and zinc sulphate increases growth parameter like plant height in growth development stages of wheat crop. These results are incompliance with the findings of Waghmare *et al*. (2019) reported that significantly highest plant height was recorded in *Pseudomonas striata* X $ZnSO_4$ 30 kg ha^{-1} treatment and lowest plant height was recorded in without microbial culture and zinc application. Our results are also concurring with the findings of Hafeez *et al*. (2021) reported that soil applied zinc and iron significantly improves the growth and yield parameters of both wheat cultivars in both seasons and wheat cultivars. The combined application of zinc and iron at 10 and 12 kg ha^{-1} respectively produced highest plant height while minimum plant height was noted in control treatment.

Number of leaves: The number of leaves in wheat crop at various growth stages was significantly influenced by various microbial inoculants and graded levels of $FeSO_4$ and $ZnSO_4$. The data pertained in Table 1 shows that number of leaves increased significantly due to microbial inoculants over control. Levels of $FeSO_4$ and $ZnSO_4$ increased number of leaves up to 40 kg $FeSO_4$ and $ZnSO_4$ ha^{-1} significantly. The numerically highest number of leave was noticed with *Pseudomona striata* i.e. 13.27 at tillering. stage, 18.04 at flowering stage and 12.26 at harvest stage of wheat crop. The lower number of leaves was noticed in control treatment (10.86, 14.56 and 9.91 at tillering stage, flowering stage and harvest stage respectively. Moreover, significant effect of graded levels of iron sulphate also found in both seasons. For levels of iron sulphate significantly highest number of leaves was found in 40 kg $FeSO_4$ ha^{-1} which was 13.58 at tillering stage, 17.86 at flowering stage and 12.19 at harvest stage in pooled mean respectively. Less number of leaves recorded with control treatment (10.68 at tillering stage, 14.69 at flowering stage and 9.16 at harvest stage respectively). Similarly, the significant effect of zinc sulphate was found on number of leaves for both seasons. For levels of zinc sulphate the highest number of leaves was found in 40 kg $ZnSO_4$ ha^{-1} which was 13.52 at tillering stage, 18.76 at flowering stage and 12.52 at harvest stage. Lower number of leaves for levels of zinc was observed in control treatment (10.46 at tillering stage, 13.71 at flowering stage 8.50 at harvest stage).

The increased growth response of plants caused by inoculation of various microbial isolates depends on their ability of the bacterial sp. to survive and develop in the rhizosphere. A possible mechanism for increased plant growth is an increase in nutrient transfer from soil to root. Shete (2020) reported that highest number of leaves was found in RDF + 25 soil application of $ZnSO_4$ ha^{-1} + 25 kg soil application of $ZnSO_4$ ha^{-1} (13.67, 28.33 and 24.33 at 30 DAS, 60 DAS and at harvest respectively) and lower number of leaves were noted in control treatment in pearl millet crop. Moreover, Shanmugaiah *et al.* (2009) revealed that reason for the increase in growth parameters may be due to certain plant growth hormones and secondary metabolites produced by *P. fluorescens* and *Trichoderma harzianum* which are known to have increased growth rate.

Number of tillers: The number of tillers at various growth stages was significantly influenced by different microbial inoculants and graded levels of $FeSO_4$ and $ZnSO_4$ (Table 1). The significantly highest number of tillers was recorded with treatment receiving inoculation of *Pseudomona striata* (M_1) i.e., 3.22, 4.18 and 4.02 at tillering, flowering and harvest stage respectively. In graded levels of $FeSO_4$ and $ZnSO_4$ significantly highest number of tillers was noted up to 40 kg $FeSO_4$ and $ZnSO_4$ ha^{-1}. For graded levels of iron sulphate the maximum number of tillers was reported in 40 kg $FeSO_4$ ha^{-1} i.e. 3.01-4.22-4.05 at tillering, flowering and harvest stage respectively. Similarly For graded levels of zinc sulphate the maximum number of tillers was noted in 40 kg $ZnSO_4$ ha^{-1} i.e. 3.06-4.32-4.07 at tillering, flowering and harvest stage respectively. Our experimental results are also in agreement with the findings of Anshumala Kujur and Syed Ismail (2022) reported significant effect of graded levels of iron up to 60 mg $FeSO_4$ kg^{-1} soil was observed and siderophore producing microbe's culture particularly *Azospirillum lipoferum* was noted on all growth attributes such as plant height. Shete (2020) the maximum number of tillers was observed in RDF + 25 soil application of $ZnSO_4$ ha^{-1} + 25 kg soil application of $ZnSO_4$ ha^{-1} and lower number of leaves were noted in control treatment in pearl millet crop reported. Also Waghmare *et al*. (2019) noticed that *Pseudomonas striata* + 30 kg $ZnSO_4$ ha^{-1} showed higher plant height, leaf count, dry matter yield per plant and leaf area index than the other treatments in spinach. Furthermore, Verma (2018) reported that under nutrient management treatments application of NPK + 25 kg $ZnSO_4$ ha^{-1} as basal dose + $FeSO_4$ 1 % solution sprayed at tillering stage recorded more number of tillers at tillering.

Leaf area (cm^2): The leaf area at various growth stages depicted in Table 1 was significantly influenced by different microbial inoculants and graded levels of $FeSO_4$ and $ZnSO_4$ and results also revealed that, the leaf area was increased during growth stages and age of crop. Significantly increased in leaf area (13.85, 20.00 and 25.47 cm^2 at tillering, flowering and milk dough stage of wheat crop respectively) in treatment receiving inoculation of *Pseudomona striata* (M_1). The lowest leaf area was found in control plots (11.50, 16.00 and 21.62 cm^2 at tillering, flowering and milk dough stage of wheat crop respectively. Scrutiny of the data further revealed the graded levels of $FeSO_4$ and $ZnSO_4$ also influenced leaf area of wheat at all the growth stages. In iron sulphate 40 kg $FeSO_4$ ha^{-1} reported maximum leaf area i.e. 14.01, 19.31 and 25.41 cm^2 at tillering, flowering and milk dough stage respectively. For levels of zinc sulphate leaf area was influenced upto 40 kg ha^{-1} and highest leaf area reported with 40 kg $ZnSO_4$ ha^{-1} i.e. 14.02, 19.47 and 25.59 cm^2 at tillering, flowering and milk dough stage respectively.

The steady supply of Fe and Zn from fertilizer and solubilizing microbes plays a crucial role during photosynthesis, and also acts as an important metal which helps in electron transfer process, transition metal which participates in plant growth, development, and metabolic processes, because it is the structural and functional part of several biological molecules, such as heme, cytochrome and hydrogenase. Thus, balanced amount of Fe promotes the photosynthetic machinery, which further induces better plant growth and development. Similarly, constant supply of zinc through zinc sulphate and zinc solubilizing microbial inoculants play important role in structural, functional, or regulatory cofactor of several enzymes which interns gives better plant growth and development of wheat crop. Our results are also corroborating with the findings of Ali *et al.* (2021) found the foliar application of 3 kg ha^{-1} Zn ha significantly enhanced leaf area of wheat crop.

Total chlorophyll content (mg g^{-1}): It was evident from data given in Table 1. that total chlorophyll content was influenced by microbial inoculants and $FeSO_4$ and $ZnSO_4$. The total chlorophyll content influenced by microbial inoculants which ranged between 2.30-2.45 mg g^{-1} at tillering stage, 2.51-2.70 mg g^{-1} at flowering stage and 2.75-2.85 mg g^{-1} at milk dough stage. The maximum total chlorophyll content noted in plots treated with microbial inoculants than control treatment. Maximum total chlorophyll content reported in *Pseudomona striata* i. e. 2.45, 2.70 and 2.95 mg g^{-1} at tillering, flowering and milk dough stage respectively. The iron sulphate upto 40 kg ha^{-1}also influenced on total chlorophyll content ranged from 2.22-2.55, 2.45-2.79 and 2.68-3.04 mg g^{-1} at tillering, flowering and milk dough stage respectively. Highest total chlorophyll content reported with 40 kg $FeSO_4$ ha^{-1} i.e. 2.55, 2.79 and 3.04 mg g^{-1} at tillering, flowering and milk dough stage respectively. Further, he zinc sulphate upto 40 kg ha^{-1}also influenced on total chlorophyll content from 2.29-2.52, 2.51-2.77 and 2.74-3.03 at tillering, flowering and milk dough stage respectively. Highest total chlorophyll content reported with 40 kg $ZnSO_4$ ha^{-1} i.e. 2.52, 2.77 and 3.03 mg g^{-1} at tillering, flowering and milk dough stage respectively.

Microbial inoculants continuous rise in photosynthetic pigments as a result of improved gas exchange potential brought on by lower stomatal resistances and higher transpiration flux. A larger leaf area results in more stomata on every leaf and a higher rate of photosynthetic activity. Nutrients uptake, disease resistance and photosynthetic efficiency may all be improved by PGPR strains colonizing plant roots and establishing chemical communication as well as systemically altering the expression of several plant genes. PGPR therapy raises the chlorophyll content of plants, which speeds up photosynthesis and improves plant health in general. Organic acids and amino acids like methionine and histidine are known to increase the absorption of nutrients Vaid *et al*. (2014). Moreover, the application of micronutrients like iron and zinc whether soil or foliar application leads in increase in chlorophyll content. Obtained results are confirmed with Kandoliya *et al*. (2018) concluded that Fe and Zn applications either as soil or foliar application increased the total chlorophyll content of wheat.

Table 1: Effect of microbial inoculants and graded levels of iron sulphate and zinc sulphate on plant height (cm), number of tillers, number of leaves, leaf area (cm^2) and total chlorophyll content (mg g^{-1}) of wheat crop at growth stages (Pooled data of two years)

Treatment	Plant height (cm)			Number of tillers			Number of leaves			Leaf area(cm^2)			Total chlorophyll content (mg g^{-1})		
	At till stage	At flow stage	At harvest stage	At till stage	At Flow stage	At harvest stage	At till stage	At flow stage	At harvest stage	At till stage	At flow stage	At milk dough stage	At till stage	At flow stage	At milk dough stage
Microbial inoculants (M)															
M0 (Control)	28.02	52.38	54.45	2.20	3.30	3.17	10.86	14.56	9.91	11.50	16.00	21.62	2.30	2.51	2.75
M1 (*Pseudomona striata*)	33.88	58.32	59.75	3.22	4.18	4.02	13.27	18.04	12.26	13.85	20.00	25.47	2.45	2.70	2.95
M2 (*Pseudomona fluorescens*)	32.03	57.94	59.08	2.73	3.72	3.41	12.29	15.91	10.03	12.15	17.31	23.83	2.39	2.60	2.85
M3 (*Bacillus megaterium*)	32.03	57.33	58.85	2.73	3.76	3.71	12.06	16.34	10.11	12.23	17.79	23.78	2.41	2.66	2.91
SE ±	0.39	0.78	0.82	0.11	0.096	0.117	0.37	0.22	0.25	0.25	0.26	0.42	0.042	0.037	0.040
CD at 5%	0.78	1.59	1.67	0.23	0.195	0.238	0.76	0.45	0.51	0.50	0.53	0.84	0.085	0.075	0.082
Levels of $FeSO_4$ (Fe)															
Fe0 ($FeSO_4$ 0 kg ha^{-1})	29.54	54.47	55.98	2.41	3.26	3.10	10.68	14.69	9.16	10.97	16.08	21.67	2.22	2.45	2.68
Fe1 ($FeSO_4$ 20 kg ha^{-1})	31.32	56.41	57.92	2.73	3.74	3.58	12.10	16.09	10.37	12.31	17.94	23.94	2.39	2.62	2.87
Fe2 ($FeSO_4$ 40 kg ha^{-1})	33.61	58.60	60.19	3.01	4.22	4.05	13.58	17.86	12.19	14.01	19.31	25.41	2.55	2.79	3.04
SE±	0.33	0.68	0.71	0.10	0.08	0.10	0.32	0.19	0.22	0.21	0.23	0.36	0.036	0.032	0.035
CD at 5 %	0.68	1.38	1.45	0.20	0.17	0.21	0.66	0.39	0.45	0.43	0.46	0.73	0.073	0.065	0.071
Levels of $ZnSO_4$ (Zn)															
Zn0 ($ZnSO_4$ 0 kg ha^{-1})	29.80	54.65	55.84	2.41	3.23	3.18	10.46	13.71	8.50	10.72	15.93	21.68	2.29	2.51	2.74
Zn1($ZnSO_4$ 20 kg ha^{-1})	31.30	56.19	58.07	2.69	3.68	3.48	12.38	16.17	10.71	12.56	17.93	23.76	2.35	2.58	2.83
Zn2 ($ZnSO_4$ 40 kg ha^{-1})	33.38	58.64	60.18	3.06	4.32	4.07	13.52	18.76	12.52	14.02	19.47	25.59	2.52	2.77	3.03
SE ±	0.33	0.68	0.71	0.10	0.08	0.10	0.32	0.19	0.22	0.21	0.23	0.36	0.036	0.032	0.035
CD at 5%	0.68	1.38	1.45	0.20	0.17	0.21	0.66	0.39	0.45	0.43	0.46	0.73	0.073	0.065	0.071

Table 2: Effect of microbial inoculants and graded levels of iron sulphate and zinc sulphate on yield and quality parameter (Pooled data of two years).

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Test weight (g)
Microbial inoculants (M)			
M0 (Control)	2554	4818	40.56
M1 (*Pseudomona striata*)	2968	5331	43.65
M2 (*Pseudomona fluorescens*)	2708	5066	42.28
M3 (*Bacillus megaterium*)	2644	5135	42.69
SE ±	33.52	55.43	0.54
CD at 5%	68.09	112.60	1.10
Levels of $FeSO_4$ (Fe)			
Fe0 ($FeSO_4$ 0 kg ha^{-1})	2487	4651	39.54
Fe1 ($FeSO_4$ 20 kg ha^{-1})	2693	5002	42.18
Fe2 ($FeSO_4$ 40 kg ha^{-1})	2975	5612	45.15
SE±	29.03	47.10	0.47
CD at 5 %	58.97	97.51	0.95
Levels of $ZnSO_4$ (Zn)			
Zn0 ($ZnSO_4$ 0 kg ha^{-1})	2497	4707	40.10
Zn1($ZnSO_4$ 20 kg ha^{-1})	2687	5026	42.26
Zn2 ($ZnSO_4$ 40 kg ha^{-1})	2971	5530	44.53
SE ±	29.03	47.10	0.47
CD at 5%	58.97	97.51	0.95

Effect of iron and zinc solubilizing microbial inoculation and levels of iron sulphate and zinc sulphate on yield attributes of wheat crop

Iron and zinc solubilizing microbial inoculation and levels of iron sulphate and zinc sulphate significantly influenced on grain yield of grain and straw yield of wheat crop

Grain yield (kg ha^{-1}): The microbial inoculants and graded levels of iron and zinc sulphate significantly and positively influence the grain of wheat crop in both the years and in pooled data (Table 2). Microbial inoculants positively influenced on grain yield which ranged between 2554-2968 kg ha^{-1}. The higher grain yield was noted plots inoculated with *Pseudomona striata* (M_1) over control i.e. 2968 kg ha^{-1}. Further, significant increase in the grain yield of wheat due graded levels of iron and zinc sulphate as compared to control treatment observed. Grain yield of wheat influenced with graded levels of iron sulphate up to 40 kg ha^{-1} ranged between 2487-2975 kg ha^{-1}. The highest grain yield was noted in plots treated with 40 kg $FeSO_4$ kg ha^{-1} (2975 kg ha^{-1}). Similarly, the grain yield influenced with application of zinc sulphate which ranged between 2497-2971 kg ha^{-1}. Maximum yield was noted in plots treated with 40 kg $ZnSO_4$ ha^{-1} (2971 kg ha^{-1}).

Straw yield (kg ha^{-1}): Data narrated in Table 2 related to straw yield of wheat was significantly influenced due to microbial cultures and graded levels of iron sulphate and zinc sulphate. The significantly maximum straw yield was recorded in treatment with inoculation of *Pseudomona striata* (M_1) i.e., 5331 kg ha^{-1}. Further, graded levels of iron and zinc in the form of $FeSO_4$ and $ZnSO_4$ also significantly influenced straw yield of wheat. The significantly highest straw yield was noted in the application of 40 kg $FeSO_4$ (5612 kg ha^{-1}) and $ZnSO_4$ ha^{-1} (5530 kg ha^{-1}).

Increase in grain yield might be due to the effect of increased in different yield attributes, increase in photosynthetic activity due to higher chlorophyll content and closely related to the potential to produce fertile tillers, which also influences directly the number of spikes produced per unit area and also rhizosphere is the soil environment where the plant root is available and is a zone of maximum microbial activity resulting in a confined nutrient pool in which essential macro and micronutrients are extracted which increased in nutrient content in plant due to the application of Zn and Fe (Choudhary *et al*., 2014). The results are conformity with findings of Ingole *et al*. (2023) revealed that inoculation with *Pseudomonas striata* along with RDF of NPK followed by *Trichoderma viride* and *Bacillus megaterium* were found considerably effective in enhancing growth, yield and maintaining quality of guava crop. Further, significantly highest grain yield (4786 kg ha^{-1}) was received for the treatment T_{12} (RDF + Soil application of $ZnSO_4$ @ 10 kg ha^{-1} + $FeSO_4$ @ 20 kg ha^{-1}) which was almost 38.2 per cent higher as compared to control treatment (N-P-K: 120-60-60 kg ha^{-1}) reported by Kandoliya *et al*., (2018). Moreover, Habib (2009) showed that foliar application of Zn and Fe (alone or together) has significant effect on wheat yield. The above findings were in agreements with the results obtained in present experiment.

Effect of iron and zinc solubilizing microbial inoculants and levels of iron sulphate and zinc sulphate on quality parameter of wheat

Test weight (g): Data presented in Table 2 related to test weight of wheat seed was influenced by iron and zinc solubilizing microbial inoculants and levels of iron sulphate and zinc levels sulphate. The significant effect of microbial inoculants found on test weight of wheat. The highest test weight reported in *Pseudomona striata* i.e. 43.65 g which was at par with *Bacillus megaterium*

42.69 g. The lowest test weight reported in control treatment (40.56 g). Scrutiny of the data further revealed that levels of iron and zinc sulphate also influenced on test weight of wheat seed. For levels of iron sulphate the higher test weight reported in 40 $FeSO_4$kg ha^{-1} (45.15 g) and for zinc levels the higher test weight noted in 40 $ZnSO_4$kg ha^{-1} (44.53). The experimental results are agreement with findings of Moreover, Shete (2020) reported that significant increase in grain weight due to application of micronutrients as compare to RDF and control and concluded that maximum test weight (18.50 g) was recorded with RDF + soil application of 25 kg $FeSO_4$ ha^{-1} + 25 kg $ZnSO_4$ ha^{-1} in pearl millet crop.

CONCLUSIONS

From the results it can be concluded that application of microbial inoculants particularly *Pseudomona striata* and 40 kg $FeSO_4$ kg ha^{-1} and 40 kg $FeSO_4$ kg ha^{-1} significantly increases growth parameters like plant height, number of tillers, number of leaves, leaf area and chlorophyll content. Also, significant increase in yield and quality parameter with application of *Pseudomona striata* and 40 kg $FeSO_4$ ha^{-1} and 40 kg $FeSO_4$ ha^{-1} along with recommended dose of fertilizers.

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