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Research Article

Effect of Iron and Zinc on Growth and Yield of Chili (Capsicum Annuum L.)

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Abstract

The research experiment titled as "The effect of iron and zinc on the growth and yield of chili (Capsicum annuum L.)" was conducted at Horticulture Research Farm, The University of Agriculture Peshawar, in summer of year 2022. There were four levels of Iron (0, 0.25, 0.5 and 0.75 %) and four levels of Zinc (0, 0.25, 0.5 and 0.75 %). The statistical design i-e Randomized Complete Block Design, with three replications and experimental units, was used. The application of Iron and Zinc on chili (Cv. P6) seedlings showed there was a significant effect on almost all the studied parameters. With respect to application of iron, the maximum branches plant-1, leaf chlorophyll content, fruit length, number of fruit plant-1, single fruit weight, root length, ascorbic acid and yield tons ha-1 were recorded for treatment of Iron application at the rate of 0.75 %, while maximum plant height was recorded when Iron was applied at the rate of 0.5 %. The results showed that in case of Zinc it significantly affected all parameters. The maximum plant height, branches number per plant, leaf chlorophyll content, number of fruits plant-1, length of fruit, single fruit weight, ascorbic acid content, length of root, and yield tons ha-1 were recorded for treatment of Zinc at 0.75 %. Maximum days to flowering and days to fruit set was recorded in untreated plants. The treatments of Iron 0.75 % and Zinc 0.75 % were found more effective for better growth and yield of chilies and are recommended for grower in Peshawar valley.

Keywords: Iron, Zinc, Chilli, Micronutrient, Growth Promoting.

1. Introduction

Chili (Capsicum annuum L.) is a well-known Solanaceae crop. It was originated in Brazil and tropical America. It has been cultivated for 6000 years. Chili belongs to the genus Capsicum and the Solanaceae family. Chili is famous all over the world. The chili crop is known for the red color pigment "Capsanthin", and the pungency is attributed to "Capsaicin". Moreover, chili is renowned for its abundance of essential vitamins, including A, C, and E. Notably, chili plays a crucial and beneficial role in boosting the national economy. However, there is room for enhancing chili productivity through effective management of diseases caused by fungal, bacterial, and viral pathogens. For instance, Phytophthora capsica causing plant root rot and Pythium species induced damping-off result in a significant mortality rate of over 60% among seedlings, both in nursery and main field settings [1].

Four species of chilies are cultivated out of 20 species. Capsicum pubescens and Capsicum pendulum, among the cultivated species, are hardly ever grown in Central and South America, whereas Capsicum annuums are grown all over the world [2]. After tomato and potato, chili is third most growing vegetable [3]. Green chili is used as vegetable, while, dry chili is used for the purpose of sauces and pickles [4]. Chili is self-pollinated crop [5]. The chromosomal number (2n) is 24. Under open pollination, however, out-crossing ranging from 2 to 96 percent has been reported [6]. Capsicum annuum and Capsicum frutescens are the two most often grown species in Pakistan. Capsicum annuum cultivars, on the other hand, are widely grown in Pakistan as a cash crop [7]. Chili is widely grown under both rainfed and irrigated conditions. India is leading in its production. Japan, Mexico, Ethiopia, Nigeria, Uganda, Turkey, Indonesia, China, Thailand and Pakistan are the main chili growing countries [8]. Pakistan currently has a total area under chilies of 63.6 thousand hectares, with an annual production of 171600 tonnes. In Pakistan the average yield of chili is 2.5 tons ha-1 [9]. Over the years, a significant rise has been observed in area, production and average yield, which could be attributed to the adoption of recommended agronomic practices and the use of high yielding and disease tolerant cultivars (Verma et al., 2004) [10]. In Pakistan, chili cultivation covered approximately 62456 hectares resulting in a total yield of 139687 tons. In the province of Punjab, chili was grown on 5778 hectares, producing 9377 tons. Similarly, in Sindh, an area of 52111 hectares yielded 123710 tons of chili. In Baluchistan, the cultivation area for chili was 4155 hectares, with a production of 6125 tons. Lastly, Khyber Pakhtunkhwa (KP) Province had chili cultivation on 412 hectares, yielding a total production of 475 tons [9]. Plant growth is enhanced by micronutrients. Micronutrients are mostly obtained through chemical fertilizers or through decomposition of municipal waste and manure from the farm, which is less readily available in the soil Nafees et al. Micronutrients like iron, zinc, manganese, copper, and boron are significant elements in plants that have unique and vital physiological roles and are required in small amounts for appropriate growth and development. Dehydrogenase, aldolase, isomerases, protease, peptidase and phosphohydrolase are just a few of the enzymes that require zinc [11].

When a plant is deficient in Zinc, the leaves and shoot tips do not fully elongate [12]. Zinc is a critical particle of enzymes and serves as a regulatory cofactor for other enzymes [13]. Biomass generation is facilitated by zinc. In addition, zinc is required for chlorophyll formation, function and fertilization of pollens [14, 15]. Hence, zinc increases blooms number and improves fruit set and cause pathogen resistance While, excessive use of zinc, on the other hand, can disturb the ionic homeostatic system, interfering with critical ion uptake and transportation, and osmotic control that results in disrupting the normal metabolic processes such as photosynthesis, transpiration and metabolic enzymatic actions and affects RNA, protein, and carbohydrate production [16]. A small amount of zinc is required for plant growth [17, 18]. Iron is a necessary component of several cellular activities in plants like respiration, chlorophyll production and photosynthesis. Plants from soil absorb the iron with very low iron solubility, especially in aerobic circumstances with a high value of pH. Therefore, plants have evolved effective iron-uptake mechanisms. Plants have sophisticated internal iron-transport mechanisms because iron is prone to precipitation and excess ionic iron is cytotoxic [19]. To find the optimum dose of zinc for good growth, yield and quality of chili and to determine the suitable iron level for maximum productivity of chili and evaluate the interaction of zinc and iron on growth and yield of chili under climate of Peshawar.

2. Materials and Methods

During the summer of 2022, an experiment titled “Effect of zinc and iron on growth and yield of chili” was conducted at the Horticulture Research Farm, The University of Agriculture Peshawar.

2.1. Experimental Design

Randomized Complete Block design was used in this study. Two factors were selected for experiment. Zinc was placed in main factor and iron was assigned in second factor. There were total 16 treatments that were repeated thrice.

2.2. Preparation of Land and Nursery Rising

The seed of chili cultivar P6 was sown in trays and regularly watered using sprinklers until they germinated to establish their nursery. Once the seedlings developed up to 5 to 6 leaves, they were transplanted into the well-prepared field on March 10, 2022. Each treatment was composed of two rows with five plants in each; the plot size was maintained at 1.98m^2, and plant to plant and row to row distances were maintained at 30 cm and 60 cm, respectively.

2.3. Preparation and Application of Iron and Zinc Solutions as Foliar Spray

Zinc source was X Zinc (18% Zn) and Iron source was Iron chelate (6% iron). The weight of iron and zinc (mg) was measured for each and every level and then dissolved in one-liter distilled water. These levels of iron and zincs were sprayed twice. First spray was done after 15 days of transplantation and second was practiced when plants entered the reproductive stage.

2.4. Studied Parameters

Plant height (cm), Branches number plant-1, Chlorophyll content (chlorophyll content was measured by SPAD meter (Konica Minolta Spad-502 plus), Days to flowering, Days to fruit set, Fruits number plant-1, Fruit length (cm) (Measured by Vernier caliper), Root length (cm), Ascorbic acid content (mg 100g-1) (ascorbic acid concentration was determined using the “Dye method), Yield (tons ha-1), Benefit cost ratio (Determination of the benefit and cost ratio involved dividing the total income by the total cost).

2.5. Statistical Analysis

The data was analyzed using the analysis of variance technique through the utilization of the computer program Statistix 8.1. To assess the mean values at probability levels of 0.01 or 0.05, the researchers employed the Least Significant Difference (LSD) test [20].

3. Results and Discussion

A study was conducted at Horticultural Research Farm, The University of Agriculture Peshawar. The researchers aimed to explore the impact of different concentrations of iron (0%, 0.25%, 0.5%, and 0.75%) and zinc (0%, 0.25%, 0.5%, and 0.75%) on chilies. Zinc and Iron significantly affected plant height, branches number per plant, chlorophyll content, days to flowering, days to fruit set, single fruit weight (g), fruit length, fruit number per plant, root length (cm), ascorbic acid content, yield in tons per hectare, and cost-benefit ratio analysis show in Tables 1 and Table present the data for these parameters, whereas the interaction between Zinc and Iron did not show any significance The detail of results obtained and relevant discussion are given below

3.1. Plant Height (cm)

The data presented in Table 1 indicates that the highest plant height (86.42 cm) was observed when Zinc was applied at a rate of 0.75%, followed by 0.5% Zn (76.42 cm). The control plots had the lowest plant height (53.75 cm). Various levels of Iron resulted in significant differences in plant height. The application of Iron at a rate of 0.5% led to the highest plant height (75.92 cm), followed by 0.75% (74.75 cm). The control plants exhibited the lowest plant height (61.75 cm).

Table 1: Plant height, No. of branches, Chlorophyll content, Days to flower, Days to fruit set and single fruit weight as affected by Zinc and Iron applications.

Treatments	Attributes					
Zinc concentrations (%)	Plant Height (cm)	No. of Branches plant^{-1}	Chlorophyll content (SPAD)	Days to Flowering	Days to fruit set	Single fruit weight
0	53.75 D	5.67 D	38.50 D	47.58 A	47.58 A	6.817 D
0.25	64.17 C	6.42 C	42.33 C	45.25 B	45.25 B	7.482 C
0.5	76.42B	7.83 B	48.83 B	43.00 C	43.00 C	8.142 B
0.75	86.42 A	8.42 A	52.50 A	40.83 D	40.83 D	8.692 A
LSD (P≤ 1%)	4.23	0.524	2.62	0.844	0.370	0.398
Iron Concentrations (%)						
0	61.75 C	5.42 D	39.33 D	46.67 A	53.17 A	7.37 C
0.25	68.33 B	6.33 C	42.92 C	44.92 B	51.08 B	7.67 B
0.5	75.92 A	7.67 B	48.08 B	43.33 C	49.33 C	7.79 B
0.75	74.75 A	8.92 A	52.50 A	41.75 D	47.33 D	8.29 A
LSD (P≤ 1%)	4.23	0.524	2.62	0.844	0.370	0.398
Interactions Zinc × Iron	NS	NS	NS	NS	NS	NS

It affects photosynthesis and metabolism. The growth and reproduction of plants depend on these reactions. Many enzymes require iron as a crucial molecular and functional component. The plant's photosynthesis was boosted by the addition of iron, which led to better vegetative growth [21]. These outcomes might be a due to the significant roles of these two nutrients in plants. Plants require zinc for auxin formation, which is a hormone to promote plant development and is related to cell division and elongation in plants. Application of zinc is also crucial for the stimulation of several enzymes, tryptophan synthesis, protein synthesis, and the creation of plant growth hormones, which result in an increase in plant height [18]. The growth rate and height of the plant increased when zinc was used in the right percentage along with optimum level of iron. The enzyme system, chlorophyll synthesis, and enzyme function all depend on iron.

3.2. Number of Branches

The mean values for Zinc application, Table 1 indicates that the highest recorded number of branches (8.42) was for a Zinc application rate of 0.75%, closely followed by 0.5% Zn (7.83). Whereas, the lowest number of branches (5.67) was observed in the control plots. Regarding mean of Iron levels, the application of Iron at a concentration of 0.75% resulted in the highest number of branches (8.92), followed by 0.5% Iron (7.67). In contrast, untreated plants displayed the lowest branches number (5.42).

Zinc is a component of many enzymes found in plant bodies. High zinc content accelerated photosynthesis, which might promote plant growth [22]. Our findings confirm the results of Shah et al. who reported a significant increase in the number of marigold branches per plant as a consequence of zinc application to the leaves [23]. Additionally, iron accelerated the production of photosynthesis, which boosted plant growth [24]. Khalaj et al. reported similar findings claiming that the foliar application of iron at the rate of 0.75% greatly improved the number of branches in chrysanthemum plants [25]. Probable reason for increased number of branches could be the increased rates of photosynthesis and photosynthates supply for maximum branches growth [26].

3.3. Leaf Chlorophyll Content (SPAD)

The mean data zinc in Table 1, the highest chlorophyll content was observed (52.50) with a 0.75% application of Zinc, closely followed by 48.83 with 0.5% application. On the other hand, the control plots displayed the lowest chlorophyll content (38.50). The various levels of Iron were observed to cause significant variations in chlorophyll content. When plants were sprayed with Iron @ 0.75%, maximum chlorophyll content was observed (52.50), followed by (48.08) with 0.5% Iron. While, the minimum chlorophyll content 39.33 was noticed in control plants.

These findings could be explained by the fact that using zinc at the right concentration stimulated the production of chlorophyll and had a protective antioxidant impact on chloroplasts, increasing the chlorophyll content in rose leaves [27]. Iron is required for maintaining chloroplast structure and function and is involved in the production of chlorophyll, so using iron in the correct concentration and application method will increase chlorophyll synthesis in leaves. The results for African marigold showed comparable trends, according to Choudhary et al. [28]. Chrysantemum plants' chlorophyll a and b concentration has increased significantly as a result of the foliar application of Fe and Zn. Given that Fe is crucial for the proper functioning of chlorophyll biosynthesis, it is possible that the positive effects of Fe and Zn on chlorophyll content come from their stimulating effects on the enzymes and pigments related to photosynthetic activity [29]. This was the case in the current research because the chlorophyll content of the treated plants increased as a result of the foliar application of Fe and Zn.

3.4. Days to Flowering

The mean values for zinc application effect, Table 1 presented that maximum days to flowering was noted (47.58) in untreated plants, followed by (45.25) with 0.25% Zn. While the minimum days to flowering (40.83) was recorded by application of Zinc at the rate of 0.75%. Significant variations were observed when different concentrations of Iron were applied. Maximum days to flowering was recorded (46.67) in untreated plants, followed by (44.92) with 0.25% Iron application. While the minimum days to flowering (41.75) was recorded by application of Iron at the rate of 0.75%.

Zinc foliar application may have increased the plant's metabolic activity, increasing cell size and length, which in turn may have accelerated photosynthesis and led to early blooming [30]. Our findings are consistent with those of Bashir et al. [31]. Who found that the foliar application of zinc to gerbera leaves at a rate of 0.6% greatly impacted the days before flowering. According to reports, the application of iron increased the plant's root system, which allowed the plant to use more water and nutrients, accelerating plant vegetative and reproductive growth [32]. In addition, iron stimulates the activity of numerous enzymes, including catalase and peroxidase. Iron plays a crucial role in the synthesis of chlorophyll, which increases the rate of photosynthesis and accelerates plant development and early flowering [33].

3.5. Days to Fruit Set

Regarding zinc application effect, Table 1 shows that maximum days to fruit set was recorded (53.58) in untreated plants, followed by 51.0 with 0.25% Zn. While the minimum days to fruit set (47.0) was recorded by application of Zinc at the rate of 0.75%. Significant variations were reported pertaining to Iron effect. Maximum days to fruit set was recorded (53.17) in untreated plants, followed by 51.08 with 0.25% Iron. While minimum days to fruit set 47.33) was recorded by application of Iron at the rate of 0.75%.

Iron and zinc foliar sprays decreased the time it took for the first blossom to open and the berries to mature, which may be because zinc is essential for the synthesis of nucleic acids and proteins as well as for the production of the plant hormone IAA. Iron activates different enzymes (catalase, peroxidase etc). The synthesis of chlorophyll, which boosts the rate of photosynthesis and, eventually, enhances plant growth, promotes early flowering and fruit set, depends heavily on Fe. Given that iron is necessary for the formation of numerous enzymes and the degradation of chlorophyll, foliar spraying with iron also reduced the number of days needed for flower and fruit growth. Gogois et al. found a substantial impact of zinc on the number of days before tomato flowers to appear. Zinc was crucial for the early fruit development of the brinjal [34, 35]. With the right zinc application, brinjal ripened fast (94 days). Through the synthesis of tryptophan and auxin, zinc enhances fruit development [36].

3.6. Single Fruit Weight (g)

While the mean of zinc effect, Table 1 indicated that maximum single fruit weight was recorded (8.69 g) for Zinc application of 0.75%, followed by 8.14 g with 0.5% Zn. While, the minimum single fruit weight (6.82 g) was noticed in control plants. Regarding Iron effect on weight of individual fruits, maximum single fruit weight was observed (8.29 g) when plants were sprayed with Iron @ 0.75%, followed by 7.79 g with 0.5% Iron application. While the minimum single fruit weight (7.38(g) was recorded in untreated plants.

Due to the enhanced leaf chlorophyll content resulting from iron application, the plant experienced improved respiration and photosynthesis rates, leading to healthier growth and ultimately an increase in the weight of the peach fruit [37]. Chloroplast structure and function depend on iron, which is also essential for the synthesis of chlorophyll [38]. It might boost the amount of leaf chlorophyll, which is associated with high photosynthates generation in plants. As a result of the transfer of these photosynthates to the sinks including fruits, the plant as a whole becomes healthy. The weight of the produce may have increased as a result. Increased cell size and intercellular space could be the cause of the rise in fruit weight and volume. Nearly 60 enzymes have been found to contain zinc, and it also plays a part in the synthesis of the growth promoter hormone (auxin), which is closely linked to an increase in the fresh weight of fruits [39]. The micronutrients' involvement in activating the photosynthesis enzymes and raising the concentration of chlorophyll, particularly chlorophyll a, may be the cause of the increase in fruit weight, fruit volume, and dry matter percentage. It caused a larger buildup of nutrients like sugars and water in the expanded cells, which increased the fruit's fresh weight and volume as well as the production of dry matter. The role that zinc and iron play in cell division, cell elongation, sugar metabolism, and the accumulation of carbohydrates and other photosynthates may be the cause of the rise in fruit weight that results from their application. These findings are consistent with those of Bhoyar et al. who found that spraying guava fruit with 0.5% zinc sulphate + 0.3% borax + 0.5% iron sulphate increased the weight and girth of the fruit. These results concur with those of Khurshid et al. who noted a rise in orange crop volume in response to iron and zinc spraying [40, 41].

3.7. Fruit length (cm)

Table 2 presented that maximum fruit length was recorded (10.12cm) for Zinc application of 0.5%, followed by 10.1cm with 0.75% Zn. While the minimum fruit length (8.15cm) was noticed in untreated plants. Significant variations in fruit length were noted for various levels of Iron. When plants were sprayed with Iron @ 0.75%, maximum fruit length was observed (9.76cm), followed by 9.48cm with 0.5% Iron. While the minimum fruit length (8.83cm) was recorded in untreated plants.

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Table 2: Fruit length, No. of fruit, Root length, ascorbic acid content, Yield and cost benefit ratio as affected by Zinc and Iron applications.

Treatments	Attributes					
Zinc concentrations (%)	Fruit length (cm)	No. of fruits plant^{-1}	Root length (cm)	Ascorbic Acid content (mg 100g^{-1})	Yield ton ha^{-1}	Cost benefit ratio
0	8.15 B	146.95 D	13.50 C	91.17 D	7.32 C	9.298 C
0.25	8.69 B	156.78 C	15.83 AB	95.58 C	9.99 B	12.93 B
0.5	10.12 A	163.04 B	17.30 B	100.42 B	10.66 AB	13.73 AB
0.75	10.1 A	171.0 A	18.36 C	106.23 A	12.17 A	15.67 A
LSD (P≤ 1%)	0.54	5.64	2.19	1.02	1.68	2.33
Iron Concentrations (%)						
0	8.83 B	152.53 D	14.21 B	92.08 D	7.67 C	9.79 C
0.25	8.96 B	156.84 C	15.33 C	96.58 C	9.52 B	12.27 B
0.5	9.48 A	158.33 B	16.86 AB	100.9 B	10.95AB	14.13 AB
0.75	9.76 A	170.07 A	18.59 A	103.8 A	11.99 A	15.43 A
LSD (P≤ 1%)	0.54	5.64	2.19	1.02	1.68	2.33
Interactions Zinc × Iron	NS	NS	NS	NS	NS	NS

Zinc and iron had a positive impact on plant growth. The rise in auxin concentration due to Zinc may have contributed to the longer fruit length. The longer fruit could also be the result of improved source-sink relationships, which could increase amount of carbohydrates synthesized in the leaf and transferred to the fruit at various phases of fruit development. The outcomes are in line with those of guava fruit research by Das et al. [42]. Similar to this, Zaiter et al. demonstrated that spraying strawberries with iron chelate improved performance by increasing the number of fruits [43]. The synthesis and function of chlorophylls are positively impacted by iron, which boosts photosynthesis. The capacity to photosynthesize and produce more food boosts generative power, and the growth of cells and the production of more food lead to an increase in length. In the current study, foliar application of micronutrients (Fe and Zn) led to an increase in fruit size, which may have been caused by an improvement in the internal physiology of developing fruit due to a better supply of the substances necessary for their proper growth and development, such as water, nutrients, and other compounds. The aforementioned results concur with Singh et al. [44]. The role zinc plays in increasing tryptophan and auxin, notably IAA, may be the cause. This led to an involvement in cell division and cell elongation as well as an increase in the fruit's growth. These findings agreed with Yadav et al. rice research [45]. The current study potentially improved the internal physiology of developing fruit by administering micronutrients via foliar application, ensuring an enhanced provision of water, nutrients, and other essential compounds vital for their proper growth and development. This would explain why the size of the fruit increased as a result [46].

3.8. Number of Fruits

Table 2 presented that maximum number of fruits was recorded (171.0) for Zinc application of 0.75%, followed by (163.04) by 0.5% Zn. While, minimum number of fruits (146.95) was noticed in control plants. Regarding iron application effect, significant variation in fruit length was observed. When plants were sprayed with Iron @ 0.75%, maximum number of fruits was observed (170.07), followed by (158.33) with 0.5%. While the minimum number of fruits (152.53) were recorded in untreated plants.

Iron chelate applied to strawberry plants boosted production by increasing the number of fruits. Iron enhances photosynthesis by having a positive effect on chlorophyll synthesis and activity. The capacity for photosynthetic production and increased food production increases the generative power, allowing the tree to store more fruits. Application of Zn and Fe greatly increased wheat grain yield, according to Zeidan et al. ([47]. Increased fruit production and seed weight may be linked to increased seed yield. The okra research done by Kumar et al. supports this finding. Fruit quantity, size, and quality may increase with Zn [48]. Zinc plays a key role in the breakdown of RNA and ribosomal components in plant cells. It also helps to promote the production of carbohydrates, proteins, and DNA. It is necessary for the creation of tryptophan, which is a building block for the growth-promoting compound IAA. Iron enhances photosynthesis, increases output, assimilates nutrients, transports them to sinks, and ultimately boosts seed yield. [39]. The crop may have more fruits due to the application of micronutrients because they improved the chlorophyll content of the leaves, photosynthetic efficiency, and translocation of metabolites from the source to sink as and when required [43]. In strawberry, Kazi et al. Singh and Saravanan and other researchers found similar findings [49, 50].

3.9. Root length (cm)

Table 2 indicates that maximum root length was recorded (18.36 cm) for Zinc application of 0.75%, followed by 17.30 cm with 0.5% Zn application. While, minimum root length (13.50 cm) was noticed in control plants. Various levels of Iron resulted in significant variations in root length. When plants were sprayed with Iron @ 0.75%, maximum root length was observed (18.59 cm), followed by16.86 cm with 0.5% Iron. While the minimum root length (14.21cm) was noticed in untreated plants.

Due to its crucial role in the formation of numerous enzymes and proteins, zinc is also regarded as one of the most significant micronutrients for plants, helping them to build and grow. By taking part in the processes of carbohydrate metabolism, it directly increases photosynthesis. It also takes part in the synthesis of several amino acids, hormones, and vital enzymes in the processes of oxidation and reduce ion reactions. It also serves as a catalyst and promoter for plant growth regulators like IAA. Auxin stimulates the development of primary roots. Primary root development depends on auxin gradient that is created by local auxin biosynthesis and transport. Normal root elongation and root gravitropic reactions depend on auxin produced in roots through the auxin pathway. Despite being an essential component of plants' mineral nutrition, iron has a negative effect in large concentrations. Iron can have both a direct and an indirect toxic impact. High iron concentrations cause a wide range of morphological and physiological changes in plants, including slowed growth, smaller leaves and shoots, elongated roots, reduced branching, destroyed cell structures, and inhibited phosphorus translocation into the leaves [38, 51].

3.10. Vitamin C (mg 100g-1)

Table 2 presented that maximum vitamin C content was recorded (106.23 mg 100mg-1) for Zinc application of 0.75%, followed by 0.5% Zinc (100.42 mg 100g-1). While the minimum vitamin C content (91.17 mg 100g-1) was noticed in control plots. Various levels of Iron showed significant variations in content of vitamin C. When plants were sprayed with Iron @ 0.75%, maximum vitamin C content was observed (103.8 mg 100g-1), followed by (100.9 mg 100g-1) with 0.5% Iron. While the minimum vitamin C content (92.08 mg 100g-1) was recorded in untreated plants.

The interaction of iron with proteins and enzymes necessary for pigment biosynthesis and photosynthetic activation, as well as their structural and functional components, may account for the increase in ascorbic acid levels (Mohammadi et al., [52]. The foliar application of these nutrients (Zn and Fe) potentially improved their absorption and translocation, which likely contributed to hasten cellular activity and/or facilitated the production of chlorophyll. As a result, photosynthesis was enhanced, potentially leading to improved chili quality. The increased availability of nutrients and the subsequent boost in cellular activity may be responsible for the observed enhancement. In another study the application of iron and sulfur significantly elevated the levels of ascorbic acid, TSS, and total sugar content in Kinnow [53]. Similarly, the application of iron sulfate and zinc sulfate resulted in enhanced growth and quality parameters, including ascorbic acid content in strawberries [54].

3.11. Yield (tons) ha-1

While comparing the mean values for zinc application effect, Table 2 indicated that maximum yield (tons) was recorded (12.17 tons ha-1) for Zinc application of 0.75%, followed by 10.66 with application of 0.5% Zinc. While the minimum yield (7.32 tons ha-1) was noticed in control plants. Various levels of Iron resulted in significant variations in yield (measured in tons). When plants were sprayed with Iron @ 0.75%, maximum yield (tons ha-1) was observed (11.99 tons ha-1), followed by 10.95 tons ha-1 with 0.5% Iron. However, minimum yield 7.67 tons ha-1 was recorded in control plants.

The increased output may be due to the more effective use of applied nutrients. Iron plays a major role in the biosynthesis of IAA, especially due to its role in the initiation of the primordial reproductive part and the distribution of photosynthetic towards them which promotes the yield. An increase in crop yield attributes increase nutrients uptake due to foliar application of $FeSO_4$, which would have resulted in enhanced grain and stover yield [55]. Iron's involvement in protein and starch synthesis as well as synthesis of chlorophyll in plants, contributed to an increase in pearl millet yield and yield attributes. Increased availability of iron to plants may have stimulated metabolic and enzymatic activity, resulting in an increase in crop development [56]. The reaction to zinc could be ascribed to better nutritional management as a result of increased Zn supply, which could have a positive effect on the development and yield of the crop. Both Solanki et al. and Singh et al. found that vegetable crops significantly responded to zinc application [57]. Zinc supplementation greatly increased the amount of dry matter in cabbage. A larger accumulation of dry matter in edible heads was due to better growth, more photosynthates translocated towards the sink, and increased dry matter production as a result of the addition of zinc. According to Solanki et al. zinc application had a significant impact on vegetable yields [57]. Zinc is essential for cellular development, differentiation, and metabolism, which results in robust plant growth and a deep root system that boosts plant productivity. This may also be because iron is necessary for the production and upkeep of chlorophyll in plants, as well as the formation of starch and protein. The increased availability of iron to plants may have speed up metabolic and enzymatic processes, boosting the crop's development. Trivedi et al. found similar results for soybean [58]. Chickpea yield characteristics were greatly improved by the addition of iron. Growth-attributing traits and yield-characteristics like pods per plant added up to the final crop's produce [59-78].

3.12. Benefit Cost Ratio (Bcr) For Fresh Pod Yield (Tons Ha-1)

The average values of the zinc-treated plants showed that the highest BCR (15.67) was observed when sprayed with 0.75% of zinc and the lowest BCR (9.29) when applied to control plants. For plants that have received iron treatment, the plants sprayed with 0.75% iron had the highest BCR

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(15.43), followed by 0.5% zinc (14.13) and control plants (9.79) with the lowest BCR.

These results indicate more profit margins for the farmers after using zinc and iron fertilizers.

4. Conclusions

Zinc at a concentration of 0.75% demonstrated suitability for chili growth and production due to its ability to give better results in the majority of the studied parameters. Iron at the rate of 0.75% exhibited superior results compared to other levels and untreated plants across the majority of the parameters examined.

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