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Research Article

Assessment of Cilantro in Relation to Nutrients (Iron and Zinc) Application

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ABSTRACT

Human beings face various disorders due to dietary nutrient imbalance Hidden hunger appeared as a prominent issue in least developed nations and is responsible for affecting over three billion lives across the globe. Mineral supplementation and fortification of vegetable crops can address the issue of inadequate nutrition availability. Current study was focused on assessing the nutritional profile of vegetables after supplementation of iron and zinc. Seed of coriander (cilantro) was were directly sown in the trays (2 inches deep). A total of eighteen treatment units were established, comprising nutrient treatments (Fe and Zn) as well as a control. Three concentrations of each nutrient, applied as foliar as basal method, triplicated were evaluated. The young plants was analyzed for different attributes like physical and biochemical indices (Total soluble solids, Vitamin C, acidity, carotenoids, chlorophyll contents, lipophilic antioxidants (LPA), starch contents, amino acids, carotenoids, flavonoids, phenolic contents. The results indicated that supplementation of 200ppm Zn and Fe @ 1.5mM concentration is optimal for maintaining the normal growth of plants. Thus, it could be proposed that the growth of cilantro under 200ppm Zn, and Fe @1.5mM increased the intake of these nutrients and other beneficial compounds for human health.

Keywords: Micronutrient, Flavonoid, TSS, Nutriention, Coriander

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INTRODUCTION

Mineral deficiency is posing a great threat to human health, globally. Coping with hidden hunger can be accomplished to a certain extent by providing mineral biofortified vegetables, which is gaining consumer acceptability with the passage of time. Biofortification is basically strengthening nutrient profile of produce by adding essential nutrients to it. These nutrients are essential and important for human beings to perform their day-to-day task, efficiently. People have become more aware of the advantages of mineral fortified produce and prefer to enhance mineral availability through food rather than through medicines. Biofortification with nutrients like iron and zinc can help to combat hidden hunger (Kumari et al., 2022). Malnutrition is rising at alarming rate, particularly in underdeveloped nations, affecting more than three billion people across the world. (Carvalho et.al, 2013; Hoekenga, 2014). Deficiency of nutrients and vitamins results in various negative effects on human health as well as their economics, so bio fortified crops mitigate negative effects (Prasad et al, 2015). Nutrient deficiency negatively impacts human health and biofortified crops can negatively impact these effects and proves to be a better alternative to medicines. Microgreens are among the versatile crops with less growing area but highly nutritious profiles (Mir et al., 2017), giving them ideal status for biofortification studies. In current circumstances, people are consuming diet with an average mineral profile, lacking introduction of some exotic crops (Genc et al., 2009). Cilantro (*Coriandrum sativum*) is a basic ingredient used for garnishing and widely used for its distinct taste and flavor. It is mostly consumed in raw form which indicates its direct consumption in green form. Iron and Zinc are the essential nutrients for metabolic processes but required in less quantities. However, these nutrients are ranked 5th and 6th as disease causing factors due to their less provision in human diet (Kumar et al, 2012; Sarwar et al., 2013)). Iron is a basic constituent of blood and oxygen carrier in the body. Human diet, deficient in iron is a main cause of anemia, particularly in children and adult females. Zn is equally important for plants and animals, for being a structural constituent and regulatory co-factor in a number of enzymes and proteins involved in many biochemical pathways. However, millions of hectares of cropland are affected by Zn deficiency, and approximately one third of the human population suffers from an inadequate intake of Zn (Murgia et al., 2012). The objectives of this study was to determine the influence of micronutrients (Fe and Zn) on yield and nutrient profile of cilantro. Second objective of this study was to optimize the dose and application method of nutrient fortification

MATERIALS AND METHODS

In this study, cilantro (*Coriandrum sativum*) seeds were obtained from a certified agency and directly sown in trays that were 2 inches deep and lined with foil. The cilantro plants were grown in a growth room under optimal temperature conditions of 14-18°C. The trays were filled with a media containing, 35% sand, 28% silt and 37% clay, along with a moderate amount of organic matter. The experiment was conducted in the growth room of the Department of Horticulture at the University of Layyah. In addition to the control treatment, the study involved two distinct experimental nutrient treatments including iron (Fe) and zinc (Zn), applied in three different concentrations. Each treatment was replicated three times, with each replication having one tray. In total, there were 18 trays, including both foliar and basal applications. The plants were irrigated as needed throughout the experiment. After the initial sowing, 1st Application of nutrients (foliar and basal) was provided on germination stage, with subsequent 2nd and 3rd applications after germination and a week before harvesting.

Table 1. Treatment details of nutrients applied to cilantro.

Nutrient	Application method	Concentration
No nutrient	Foliar & Basal	Control (distilled water)
Fe	Foliar & Basal	Fe_1 (1mM)
		Fe_2 (1.5mM)
		Fe_3 (2mM)
Zn	Foliar & Basal	Zn_1 (100ppm)
		Zn_2 (150ppm)
		Zn_3 (200ppm)

Plant Analysis of Fresh Samples of Cilantro

Measuring scale was used to assess shoot and root length (cm). Weighing balance (PA-413 manufactured by Chaus Corporation, USA) was used for determining fresh and dry weight (g) of cilantro plants. Number of leaves per plant were counted and averaged. A product of leaf length and width was taken to assess leaf area (cm^2).

Total soluble solid (TSS) were determined through digital refractometer. Titration method was adopted for ascorbic acid estimation.

Total flavonoid contents were measured, following aluminum chloride colorimetric method involving UV-Vis spectrophotometer (WE6000). The calibration plot (Y = 0.0162x + 0.0044, R2 = 0.999) was used to calculate total flavonoid contents. Sample and standard readings were made using a spectrophotometer (WE6000) at 765 nm, to measure total phenolic compounds. Absorbance was recorded with help of UV-VIS spectrophotometer (WE6000) for amino acid estimation using ninhydrin reagent. The lipophilic antioxidant activity (LAA) was measured with the 2,20 - azinobis 3-ethylbenzothiazoline-6-sulfonic acid ABTS method by UV–Vis spectrophotometry. After measuring absorbance at 734nm for 30mints, ABTS % were calculated by using formula

ABTS %= (AB-AA/AB) X 100
AB =absorbance of ABTS radical + methanol
AA= absorbance of ABTS radical + sample extract

Total carotenoid contents was determined by noticing absorbance of sample using UV-VIS spectrophotometer (WE6000), prepared by grinding leaf sample and centrifuging with 80% acetone (10 mL) at 12000 rpm for 5 min. Same sample were read at 645 nm and 663 nm for estimation of chlorophyll a and b.

Statistical Analysis

The growth room experiments followed the completely randomized design (CRD) factorial with three replications. The data collected was evaluated by Analysis of Variance (ANOVA) and treatment means were compared using Tuckey test, at 1% level of significance to separate treatment means, using Statistix 8.1 analytical software (McGraw-Hill 2008).

RESULTS

Plant Morphology

The results regarding fresh and dry weight of cilantro in response to iron and zinc supplementation in cilantro are statistically significant. Comparison of treatment means showed that Fe concentration @1mM resulted in the maximum average fresh weight (8g) and maximum average dry weight (2.08g) respectively. Maximum average fresh weight (6.79g) and dry weight (1.46g) was recorded in foliar application method followed by 5.35g and 1.20g in basal application method (Table 2). Comparison of treatment means further indicated that foliar application of Fe was more effective in enhancing plant biomass than basal application. Statistical analysis of the interaction between treatment and application method for fresh and dry biomass revealed that the highest fresh weights (9 g for foliar and 7 g for basal application) and dry weights (2.43 g for foliar and 1.72 g for basal application) were recorded with Fe applied at 1 mM (Table 3) Similarly, maximum average plant fresh weight (8.31g) and maximum average dry weight (1.65g) were measured, when Zn was applied @ 200ppm. Maximum average fresh weight (6.71g) and dry weight (1.20g) was recorded in foliar application method followed by 5.30g and 0.78g in basal application method (Table 4). Statistical analysis exhibited that comparison of treatment and method interaction means of Fresh and dry weight showed that maximum fresh weight (9.2g and 7.4g) and dry weight (2.10g and 1.21g) in foliar and basal applications were measured Zn @ 200ppm while minimum fresh weight (3.96g) and dry weight (0.44g) was measured in control (distill water) treatment (Table 5).

Comparison of treatment means showed that Fe (1mM) concentration performed best regarding shoot and root length (8.93cm and 5.11cm) (Table 2). However, a significant result was evaluated in treatment*method interaction which shows that longest shoot length (10.06cm and 7.8cm) was measured in 1mM concentration of Fe in foliar and basal methods while interaction was non-significant regarding root length in cilantro respectively (Table 3). Zinc applied at conc. of 200 ppm performed best regarding shoot and root length (7.70cm and 4.71cm). However, a significant difference was evaluated in treatment and method interaction which shows that longest shoot length (8.96cm and 6.43cm) was measured in foliar and basal method in cilantro in 200ppm Zn concentration while root length illustrated non-significant results. (Table 5).

The interaction between treatment and application method was not significant for leaf number, yet it was significant for leaf area in response to iron application (Table 4).

Foliar and basal applications of zinc significantly differed in terms of leaf number, with foliar application producing a higher leaf count (4.00) compared to basal application (3.41) (Table 4). This highlights that foliar nutrient application more effectively promotes leaf development. Analysis of treatment means showed that Zn applied at 200 ppm (T3) resulted in the highest number of leaves (4.50) and largest leaf area (21.46 cm²). However, no significant interaction between treatment and application method was observed (Table 5).

Biochemical Attributes

TSS (◦Brix) and Ascorbic acid (mg)

In the current experiment, Comparison of treatment means showed that (1mM) Fe concentration performed best concerning TSS and ascorbic acid (11.38 ◦Brix and 13.83 mg) followed by 1.5mM concentration with treatment means 9.48 and 11.33 (Table 2). Statistically, comparison test of TSS and ascorbic acid for interaction of treatment and application methods shows that maximum TSS (12.53 and 10.23◦Brix) and ascorbic acid (15 and 12.66 mg) in foliar and basal applications were measured in Fe @1mM (Table 3). Comparison of treatment means indicated that

Zn applied at 200 ppm produced the highest TSS (10.83 °Brix) and ascorbic acid content (11.38 and 14.66 mg) (Table 4). Maximum TSS (8.84◦Brix) and ascorbic acid (11.75 mg) was evaluated in foliar method as compare to basal method (7.93 and 8.83). Statistically, Comparisons Test of TSS and ascorbic acid for Treatment*Method interaction (Table 5) showed that maximum TSS (11.33 and 9.76◦Brix) and ascorbic acid (17 and 12.33 mg) in foliar and basal applications were measured (200ppm Zn) while minimum TSS (6.43◦Brix) and ascorbic acid (7 mg) was measured in control (distill water) treatment.

Table 2. Effect of Iron supplementation on cilantro vegetative and biochemical analysis.

Parameters (Vegetative)	**Concentration means**				**Application Methods means**	
	T_0 (control)	**T_1(1mM)**	**T_2(1.5mM)**	**T_3(2mM)**	**Foliar**	**Basal**
Fresh weight (g)	3.96 d	8a	6.75 b	5.56 c	6.79 a	5.35 b
Dry weight (g)	0.443 (d)	2.080(a)	1.67(b)	1.136 (c)	1.463(a)	1.205 (b)
Shoot length (cm)	4.066(d)	8.93 (a)	7.55(b)	6.45 (c)	7.50(a)	6.00(b)
Root length (cm)	2.93 (c)	5.11 (a)	4.55(ab)	4.25 (b)	3.98 (b)	4.44(a)
No. of leaves per plant	2.33 (c)	4.83(a)	3.66 (b)	3.00 (bc)	3.66	3.2
Leaf area (cm^2)	15.80 ab	20.66 a	18.96 ab	13.56 b	19.6	14.9
(Biochemical Attributes)						
TSS (◦Brix)	6.43 (d)	11.38 (a)	9.48 (b)	7.81 (c)	9.45 (a)	8.10 (b)
Ascorbic acid (mg)	7.00 (c)	13.83 (a)	11.33(b)	7.16 (c)	10.83 (a)	8.83 (b)
Phenols (mg /g f.w)	34 a	32.33 ab	29.33b	24.83c	29.5	30.7
LAA (μM trolox g^{-1}f.w.)	22.90 (c)	27.50(bc)	37.3 (a)	31.8 (b)	32.058 (a)	27.725 (b)
Amino acids (nmol/g)	24.23(bc)	30.96 (a)	26.50 (b)	21.16 (c)	26.87 (a)	24.55 (b)
Flavonoids (mg)	10.70 (c)	14.53 (a)	12.01 (b)	10.70 (c)	12.36 (a)	11.60 (b)
Carotenoids (μg $g^{-1)}$	4.21 (c)	4.89(a)	5.04 (a)	4.51 (b)	4.90(a)	4.90(b)
Chlorophyll a (mg/g/F. wt)	0.35 (c)	0.61(b)	0.81 (a)	0.63 (b)	0.72 (a)	0.485 (b)
Chlorophyll b (mg/g/F. wt)	0.283 (c)	0.35 (bc)	0.55(a)	0.43 (b)	0.46 (a)	0.34(b)

Phenols (mg 100 g^{-1} FW) and Lipophilic Antioxidant Activity (μM trolox g^{-1} FW)

Analysis of variance for data pertaining to phenols in response to Fe application regarding treatment means was highly significant while interaction of treatment and methods of application was non-significant. Effect of iron supplementation on LAA was significant regarding treatment means and application method while interactive results were non-significant. Comparison of treatment means showed that maximum phenolic contents (34 mg) were noted in control treatment followed by Fe @1Mm (32mg). Maximum LAA were measured in foliar method (32.05 μM trolox) in contrast to basal method (27.7 μM trolox) given in Table 2. However, interaction between treatments (Fe conc.) and method in cilantro was assessed non-significant (Table 3).

Table 3. Concentration and application methods interaction in response to iron.

Parameter	**Foliar**				**Basal**			
	T_0	**T_1**	**T_2**	**T_3**	**T_0**	**T_1**	**T_2**	**T_3**
Fresh weight (g)	3.96 e	9.00 a	7.60 b	6.59 bc	3.93 e	7.00bc	5.90cd	4.53de
Dry weight (g)	0.44 d	2.43a	1.83b	1.14c	0.40 d	1.72 b	1.52 bc	1.13 c
Shoot length(cm)	4.06 e	10.06a	8.63 ab	7.23bcd	4.06 e	7.80bc	6.46cd	5.66de
Root length (cm)	2.93	4.73	4.20	4.06	2.90	5.50	4.91	4.43
No. of leaves	2.33	5.33	4	3	2.33	4.33	3.33	3

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Leaf area (cm^2)	15.8 bc	25.26a	23.4 ab	13.8 c	15.2 c	16.0ac	14.4 abc	13.26 c
TSS (◦Brix)	6.43	12.53	10.40	8.46	6.40	10.23	8.56	7.16
Ascorbic acid (mg)	7.00 de	15 a	13 ab	8.33cd	6.5de	12.66b	9.66c	6 e
Phenols (mg /g f.w)	34	31.66	28.6	23.6	33	33	30	26
LAA (μM trolox g^{-1} f.w.)	22.90	31.6	40.33	33.33	22.85	23.33	34.33	30.33
Amino acids (nmol/g)	24.23	33.26	27	23	24.20	28.66	26	19.33
Flavonoids (mg)	10.70d	15.86a	12.33bc	10.56d	10.65d	13.20b	11.7bcd	10.83cd
Carotenoids (μg $g^{-1)}$	4.21c	5.46a	5.54a	4.38bc	4.10c	4.33bc	4.55bc	4.65b
Chlorophyll a (mg/g/F. wt)	0.35 e	0.79b	1.10a	0.65bc	0.32e	0.44de	0.53cde	0.62bcd
Chlorophyll b (mg/g/F. wt)	0.28c	0.37bc	0.67a	0.51ab	0.26c	0.32c	0.43bc	0.35bc

Analysis of variance for phenolic content in response to zinc application revealed highly significant differences among treatment means, application methods, and their interaction. In contrast, the effect of Zn supplementation on leaf antioxidant activity (LAA) was significant for treatment means only, while the application method and treatment × method interaction were non-significant. Comparison of treatment means showed that the highest phenolic content (47.5 mg) and LAA (40.66 μM Trolox) were recorded in 200 ppm Zn, whereas the lowest phenolic content (32.16 mg) was observed in 100 ppm Zn and the lowest LAA (22.90 μM Trolox) in the control treatment (Table 4). Foliar application of zinc resulted in higher phenols (41.41 mg) and LAA (33.05 μM Trolox) compared to basal application (33.91 mg and 29.55 μM Trolox, respectively) (Table 4). The interaction between treatments and application method (Table 5) showed that the maximum phenolic contents were obtained at 200 ppm Zn application (54.33 mg for foliar, 40.66 mg for basal). However, the interaction effect for LAA was non-significant.

Table 4. Effect of Zinc supplementation on cilantro vegetative and biochemical analysis**.**

Parameters (Vegetative)	**Concentration means**				**Application Methods means**	
	T_0 (control)	**T_1(100ppm)**	**T_2(150ppm)**	**T_3(200ppm)**	**Foliar**	**Basal**
Fresh weight (g)	3.96 (d)		6.58 (b)	8.31 (a)	6.71 (a)	5.30 (b)
Dry weight (g)	0.44 (d)	0.79 (c)	1.09(b)	1.65 (a)	1.20 (a)	0.78 (b)
Shoot length (cm)	4.06 (c)	5.60 (b)	6.26 (b)	7.70 (a)	6.94 (a)	4.87 (b)
Root length (cm)	2.93 (c)	3.51 (bc)	3.86 (b)	4.71 (a)	3.43 (b)	4.08 (a)
No. of leaves	2.33 (b)	3.83(a)	4.16 (a)	4.50(a)	4.00 (a)	3.41 (b)
Leaf area (cm^2)	15.80 b	16.43 ab	19.4 ab	21.4 a	19.66	16.8
Bio chemical						
TSS (◦Brix)	6.43 (d)	7.23 (d)	9.03 (b)	10.83 (a)	8.83 (a)	7.93 (b)
Ascorbic acid (mg)	7.00 (c)	8.16 (c)	11.33 (b)	14.66 (a)	11.75 (a)	8.83 (b)
Phenols (mg /g f.w)	34.00 (b)	32.00 (b)	37.00 (b)	47.00 (a)	41.41 (a)	33.91 a
LAA (μM trolox g-f.w.)	22.90 (c)	29.16 (b)	32.50 (b)	40.66 (a)	33.05 (a)	29.55 b
Amino acids (nmol/g)	24.23 (a)	25.33 (a)	26.66 (a)	30.16 (a)	27.14	26.05
Flavonoids (mg)	10.70 (d)	11.73 (c)	13.96 (b)	15.71 (a)	13.55 (a)	12.50 b
Carotenoids (μg $g^{-1)}$	4.21 (d)	4.64 (c)	5.15 (b)	5.55 (a)	5.18 (a)	4.60 (b)
Chlorophyll a (mg/g/F. wt)	0.35 (c)	0.52 (b)	0.55 (b)	0.80 (a)	0.57	0.54
Chlorophyll b (mg/g/F. wt)	0.28 (c)	0.36 (b)	0.39 (b)	0.53 (a)	0.41	0.37

Amino Acids (mmol g-1 FW), Flavonoids (mg) and Carotenoids (mg g-1 FW)

Statistically, analysis of variance exhibited highly significant results regarding Amino acids, flavonoids and carotenoids while interactive results of treatment (Fe) and methods of application in amino acids were non-significant. Comparison of treatment means showed that Fe @ 1mM concentration performed best regarding amino acids and flavonoids (30.96 mmol g^{-1} and 14.53 mg) while maximum carotenoids (5.04 mg) were quantified in Fe @1.5mM concentration (Table 2). Foliar application method gave maximum results regarding amino acids, flavonoids and carotenoids (26.87 mmol g^{-1}FW, 12.36 mg and 4.90 mg g^{-1} FW) in comparison to basal method (24.55 mmol g^{-1}FW, 11.60 mg and 4.43 mg g^{-1} FW). A significant difference was evaluated in treatment and method interaction of flavonoids and carotenoids while a non-significant difference was assessed in amino acids (Table 3). Maximum flavonoids (15.8 and 13.2 mg) and amino acids (33.2 and 28.6 mmol g^{-1}FW) were recorded in Fe @1mM concentration while maximum carotenoids (5.54 and 4.68 mg g^{-1} FW) were measured in Fe @ 1.5mM concentration in foliar and basal applications. However, least results regarding flavonoids and carotenoids (10.7 mg and 4.21 mg g^{-1} FW) were measured in control treatment in foliar and basal respectively. Comparison of treatment means indicated that Zn applied at 200 ppm produced the highest levels of flavonoids, carotenoids, and amino acids (15.71 mg, 5.55 mg g^{-1} FW, and 30.16 mmol g^{-1}FW, respectively). Foliar application resulted in higher flavonoid (13.55 mg) and carotenoid (5.18 mg g^{-1} FW) content compared to basal Zn application (12.50 mg and 4.6 mg g^{-1} FW) (Table 4). The interaction between treatment and application method was significant for flavonoids and carotenoids but non-significant for amino acids. The highest flavonoid (16.70 mg for foliar and 14.73 mg for basal) and carotenoid (6.17 mg g^{-1} FW for foliar and 4.93 mg g^{-1} FW for basal) levels were observed in the 200 ppm Zn treatment.

Chlorophyll "a"and "b" (mg/g/FW)

Comparison of treatment means showed that Fe applied at 1.5 mM resulted in the highest chlorophyll a and chlorophyll b contents (0.81 and 0.55 mg/g/FW, respectively) (Table 2).

Evaluation of application methods indicated significant differences, with foliar application producing higher chlorophyll a and b contents (0.723 and 0.46 mg/g/FW) compared to basal application (0.485 and 0.348 mg/g/FW) (Table 2). Analysis of the interaction between treatment and application method (Table 3) revealed that the maximum chlorophyll a and b contents were recorded in the 1.5 mM Fe treatment for both foliar (1.10 and 0.67 mg/g/FW) and basal applications (0.62 and 0.43 mg/g/FW), while the lowest values were found in the control treatment (0.35 and 0.28 mg/g/FW) (Table 3). The analysis of comparison of treatment (Zn) means showed significant results regarding chlorophyll a but non-significant results regarding chlorophyll b. Zn @ 200ppm concentration performed best regarding chlorophyll a (0.803 mg/g/FW), chlorophyll b (0.538 mg/g/FW) followed by Zn 150ppm (0.55 and 0.393 mg/g/FW). Minimum chlorophyll "a" and "b" contents (0.35 and 0.28 mg/g/FW) were evaluated in control treatment. Comparison test of application method illustrated non-significant results in both application methods. Maximum chlorophyll a, and chlorophyll b contents (0.579 and 0.411 mg/g/FW) were assessed in foliar method as compared to basal method (0.540 mg/g/FW and 0.377 mg/g/FW) given in (Table 4).

Interaction effect between treatments and method shows that maximum chlorophyll a (0.810 mg/g/FW and 0.796 mg/g/FW), chlorophyll b (0.563 and 0.513 mg/g/FW) were measured in 200ppm concentration in foliar and basal applications respectively while minimum chlorophyll contents (0.35 and 0.28 mg/g/FW) were measured in control (distilled water) treatment (Table 5).

Table 5. Concentration and application method interaction in response to zinc supplementation on vegetative and biochemical analysis of cilantro.

Parameter	Foliar				Basal			
	T_0	T_1	T_2	T_3	T_0	T_1	T_2	T_3
Fresh weight (g)	3.96	5.80 c	7.90ab	9.20a	3.93	4.56cd	5.26cd	7.4b
Dry weight (g)	0.44	1.08 b	1.19b	2.10 a	0.40	0.50 c	0.99b	1.21 b
Shoot length (cm)	4.06	6.90 b	7.83 ab	8.96 a	4.06	4.30 c	4.70 c	6.43 b
Root length (cm)	2.93	3.02 cd	3.50bcd	4.26ab	2.90	4.00abc	4.23abc	5.16a
No. of leaves	2.33c	4 a	4.66a	5 a	2.33c	3.66ab	3.66ab	4 a
Leaf area (cm^2)	15.8	18	21.5	23.3	15.2	14.8	17.2	19.6
TSS (◦Brix)	6.43	7.80cd	9.76b	11.33a	6.40	6.66de	8.30c	10.33ab
Ascorbic acid (mg)	7.00 de	9.33cd	13.66ab	17 a	6.5 de	7d	9cd	12.33bc

Phenols (mg /g FW)	34 a	35 bcd	42.33 b	54.33a	33 a	29.33d	31.66cd	40.6bc
LAA (µM trolox g^{-1} FW)	22.90	30.6	35	43.6	22.85	27.6	30	37.6
Amino acids (nmol/g)	24.23	26	27.3	31	24.20	24.6	26	29.3
Flavonoids (mg)	10.70d	12 cd	14.7b	16.7 a	10.65d	11.4d	13.16 c	14.73 b
Carotenoids (µg $g^{-1)}$	4.21c	4.74c	5.58b	6.17a	4.10c	4.54 cd	4.71c	4.93c
Chlorophyll a (mg/g/FW)	0.35 e	0.62 b	0.53bc	0.81 a	0.32e	0.43cd	0.58bc	0.79 a
Chlorophyll b (mg/g/FW)	0.28	0.41	0.38	0.56	0.26	0.31	0.40	0.51

DISCUSSION

Among the factors influencing cilantro production, nutrient availability represents the principal limitation affecting vegetative and reproductive growth. In this context, biofortification offers a strategic approach to enhance nutrient availability and uptake within the plant system (Pal et al., 2025), thereby improving growth performance while simultaneously increasing the nutritional quality of fresh cilantro through targeted enrichment of essential minerals during critical growth stages. In the current work, results show that basal application of Fe did not provide as good results as compare to foliar application. Biomass production and biochemical profiling of cilantro plants indicated a positive response to foliar iron (Fe) application, resulting in significant improvements in plant biomass and associated biochemical analysis. The results are consistent with the findings of Tiffin, (1970) who concluded that basal application of iron limit the transport of iron in the xylem tissues of plants which lead to poor movement of Fe into young leaves and it causes photo destruction of citrate leading to production of nondialyzable form of iron which possess inactivation of iron in the leaves (Bienfait and Scheffers, 1992). Diana and Nehru (2014) also found higher results in the attributes of coriander upon applying Fe. Maximum concentrations of iron in the leaves and leaf tips resulted in enhanced photosynthesis and more chlorophyll formation (Nadim et al., 2012). Iron plays a crucial role as a catalyst in enzymatic reactions involved in plant metabolism, promoting the synthesis of photosynthates and thereby supporting enhanced plant growth. In addition to its role in chloroplast RNA metabolism, iron is essential at multiple stages of biosynthetic pathways, facilitating the production and accumulation of key biomolecules, which ultimately contributes to improved overall growth (Diana & Nehru, 2014). The application of Fe enhanced catalytic activity, promoting the breakdown of complex molecules into simpler forms such as glucose, amino acids, and fatty acids. This improvement in metabolic processes was reflected in better seed germination and increased root and shoot elongation in coriander seedlings (Santosh, 2012).

Present experiment also investigated the effect of zinc biofortification on cilantro (coriander). High concentration of Zn @ 200ppm proposed excellent results. In increased the phenolic contents, amino acids and plant biomass. Zn also increased the chlorophyll contents, the results are in agreement with the findings of (Barrameda et al., 2017) who indicated that if 100–200 ppm Zn concentration is applied, it is optimum dose to maintain the normal growth of plants and it also boosted concentration of zinc in the edible parts of B. *oleracea*. Any further increase of Zn supply induced an accumulation of total amino acids, and increased the enzymatic activities involved in sulfur assimilation and synthesis of phenols, finally it resulted in a foliar accumulation of glucosinolates and phenolic contents. Similar results were observed in the study of Meena et al. (2016) who further stated that application of zinc might have enhanced the availability and smooth supply of nutrients for plant's metabolic system and photosynthetic activity resulting in optimum growth and development of the crop. In addition to that, zinc is essential in tryptophan synthesis, which is a component of some proteins, and it is a compound required for production of growth hormones (auxins) like indole-acetic acid. Zinc is an essential component of carbonic anhydrase, various dehydrogenases, and plays a key role in auxin synthesis, all of which contribute to enhanced plant growth. The results of the present study are consistent with the findings of Said-Al Ahl and Mahmoud (2010), Salmasi et al. (2012) and Abbas (2013). Further, the vital role of zinc in chlorophyll formation, regulating auxin concentration and its regulatory effect on most of the physiological and metabolic processes of plants might have helped the plants to absorb greater amount of nutrients from the soil. Zinc-mediated improvements in photosynthesis and metabolic functions enhanced assimilates production and their partitioning to seeds, leading to higher seed nutrient concentrations, in agreement with the observations of Upadhyay et al. (2012). The application of zinc exerted remarkable positive effects on meristematic activity and apical growth, resulting in substantial improvements in plant height, number of branches per plant, and dry matter accumulation at all growth stages. As a vital component of enzymes involved in nitrogen assimilation, zinc plays a central role in chlorophyll formation, significantly boosting chlorophyll content in leaves. This enhanced chlorophyll, combined with greater nutrient uptake, likely amplified photosynthesis and carbohydrate production, ensuring efficient translocation of assimilates to all plant parts, particularly to the panicle. These findings underscore zinc's exceptional ability to promote vegetative growth and overall plant vigor and are in agreement with the observations of Lal et al. (2014).

CONCLUSIONS

Human dietary deficiencies are a significant concern, particularly in least developed nations, where hidden hunger affects over three billion people. This study investigates the nutritional enhancement of vegetables, specifically coriander (cilantro), through mineral supplementation of iron (Fe) and zinc (Zn). Eighteen treatment units were established, involving various nutrient concentrations applied both foliar and as a basal method. A total of three concentrations for each mineral were tested. Key physical and biochemical indices such as total soluble solids, Vitamin C, acidity, carotenoids, chlorophyll, lipophilic antioxidants, starch, amino acids, flavonoids, and phenolic contents were analyzed in young plants. Results revealed that a supplementation of 200 ppm Zn and Fe at a concentration of 1.5 mM is optimal for supporting cilantro growth, thereby enhancing the availability of essential nutrients and beneficial compounds for human health.

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AUTHOR CONTRIBUTIONS

All the authors contributed equally to this research.

COMPETING OF INTEREST

No conflicts of interest have been disclosed by the authors.

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