Effects of NPK Fertilizer and Antioxidant Foliar Sprays on Turmeric (*Curcuma longa*) Growth and Yield

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Abstract:

A field experiment was conducted during the 2024 agricultural season in Diyala to study the effect of antioxidants (α-tocopherol at 150 mg L^{-1} and ascorbic acid at 150 mg L^{-1}) and the application of compound NPK fertilizer at three levels (0, 125, and 250 kg ha^{-1}) on the growth and yield of turmeric plants. The experiment was implemented as a factorial trial using a split-plot arrangement within a Randomized Complete Block Design (RCBD) with three replications. The studied traits included plant height, stem diameter, number of leaves, leaf length, and yield characteristics. The significance of differences between means was tested using Duncan's multiple range test at a 0.05 probability level.

The results showed that the foliar application of α-tocopherol and ascorbic acid (VEC) significantly enhanced plant height, stem diameter, number of leaves, leaf length, number of rhizomes, rhizome length, individual plant yield, and yield per square meter. The application of NPK fertilizer at 250 kg ha^{-1} (F2) outperformed other levels in terms of plant height, stem diameter, number of leaves, leaf length, number of rhizomes, and rhizome length.

Moreover, the interaction treatment combining foliar antioxidants and NPK fertilizer at 250 kg ha^{-1} (F2VEC) exhibited the best performance in plant height, number of leaves, leaf length, number of rhizomes, rhizome length, individual plant yield, yield per square meter, and stem diameter.

Keywords: Turmeric, antioxidants, NPK, yield, vegetative growth

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1 INTRODUCTION

1.1 Turmeric (Curcuma longa L.): Botanical Characteristics and Agronomic Responses to Antioxidants and Fertilization

Turmeric is a perennial herbaceous plant belonging to the *Zingiberaceae* family. It features large, ovate leaves with dark green upper surfaces and lighter green undersides. The flowers grow on a spike-like stem, while the rhizomes—recognizable by their distinctive yellow color—are used as a spice in traditional medicine, a natural food colorant, an anti-inflammatory and antioxidant agent, and in cosmetic applications due to their active compound, **curcumin**. This bioactive component is believed to be responsible for most of the plant's health benefits. Turmeric thrives in temperatures between 20–30°C and the soil type is sandu, Turmeric has many benefits, including being a powerful antioxidant and anti-inflammatory. It also enhances brain health and is beneficial for arthritis, intestinal inflammation, and skin inflammations (6).

1.2 Role of α-Tocopherol in Plant Growth

α-Tocopherol, a water-soluble antioxidant vitamin, protects cells from free radical damage and enhances vegetative growth by improving physiological processes such as carbon assimilation and cellular respiration. This results in increased leaf number, stem elongation, and stress tolerance, promoting growth even under suboptimal conditions (5). Akram et al. (2023) studied the effect of α-tocopherol foliar application (0 and 50 mg L^{-1}) on eggplant and found that 50 mg L^{-1} increased plant growth by 5–15%, chlorophyll content by 4–10%, and proline content by 4–6%. Similarly, AL katia et al. (2020) tested two α-tocopherol levels (100 and 200 mg L^{-1}) on tomato plants, with 200 mg L^{-1} significantly improving fruit number, plant yield, and total productivity.

1.3 Ascorbic Acid and Its Physiological Impact

Ascorbic acid (vitamin C) plays a vital role in plant growth and development by regulating cell division and elongation, thus promoting tissue growth—particularly in roots, leaves, and buds. It also mitigates damage to membranes, proteins, and DNA, enhancing overall cell health (Al-Hajjari, 2017).

Manal (2019) examined ascorbic acid foliar sprays (0, 2, and 3 g L^{-1}) on tomato plants and found that 2 g L^{-1} maximized plant height and leaf chlorophyll content. Fateh et al. (2019) reported that foliar application of ascorbic acid (100, 200, and 300 mg L^{-1}) on sweet pepper improved yield and fruit firmness, with 300 mg L^{-1} producing the highest per-plant yield.

1.4 Fertilization and Its Influence on Turmeric Growth

Fertilization is a critical factor in turmeric cultivation, as this rhizomatous plant requires balanced nutrition—particularly nitrogen—to ensure optimal rhizome production. Proper fertilization enhances leaf growth, boosting photosynthetic efficiency and leading to higher rhizome yield in terms of both number and weight (8). Akpan et al. (2021) evaluated the effect of NPK (15:15:15) fertilizer at two levels (120 and 400 kg ha^{-1}) on turmeric

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growth. The higher dose (400 kg ha^{-1}) significantly improved plant height, leaf number, leaf length, leaf width, and dry matter content. Similarly, Ekugha et al. (2021) tested four NPK levels (0, 50, 150, and 300 kg ha^{-1}) on ginger and found that 300 kg ha^{-1} resulted in the highest individual and total plant yield.

1.5 Study Objectives

This study aimed to investigate the effects of compound fertilizer and selected antioxidants on the growth and yield of turmeric (Curcuma longa L.).

1.6 Research Problem

Due to the absence of previous studies on turmeric cultivation in the study area, this research sought to evaluate the feasibility of successful turmeric production in Iraq while mitigating high temperature stress through the application of antioxidants.

2 MATERIALS AND METHODS

A factorial experiment was conducted during the 2024 growing season, beginning on February 25, in a private field in Bani Saad district, Diyala. The field was divided into three replications, with each replication containing 12 experimental units. Each unit consisted of 10 plants, totaling 36 experimental units. A split-plot design within a Randomized Complete Block Design (RCBD) was employed, with fertilizer treatments assigned to main plots and antioxidant treatments to sub-plots.

2.1 Experimental Factors

First factor: Soil application of NPK compound fertilizer (20:20:20) at three levels (0, 125, and 250 kg ha-1), modified from the recommendations of (11).

Second factor: Foliar application of antioxidants (ascorbic acid and α-tocopherol) with four treatments:

1. Control (distilled water spray)
2. Ascorbic acid at 150 mg L-1
3. α-Tocopherol at 150 mg L-1
4. Combined ascorbic acid and α-tocopherol at the same concentrations above, modified from Essam (2014).

2.2 Field Preparation

Indian turmeric rhizomes were obtained from a commercial market and initially planted in small pots containing peat moss and sand within a plastic tunnel. When plants reached adequate height, they were transplanted to the permanent field on June 5, 2024. Due to extreme high temperatures, an iron frame structure covered with plastic and shade cloth was constructed over the field, along with a desert cooling system to protect plants during July and August. Temperature and humidity sensors were installed to monitor and maintain optimal environmental conditions.

2.3 Measured Parameters

2.3.1 Vegetative growth characteristics:

- Plant height (cm $plant^{-1}$): Measured from soil surface to plant apex using measuring tape for five randomly selected plants per experimental unit at season end.
- Main stem diameter (mm): Measured at soil level using Vernier calipers for five random plants per unit.
- Leaf number (leaves $plant^{-1}$): Counted for five random plants per unit.
- Leaf length (cm): Measured using measuring tape for five random plants per unit.

2.3.2 Yield characteristics:

- Rhizome number (rhizomes $plant^{-1}$): Counted for five random plants per unit.

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- Rhizome length (cm): Measured from base to tip for ten rhizomes per unit.
- Yield per plant (g plant^{-1}): Total rhizome weight from five random plants per unit.
- Yield per square meter (g m^{-2}): Calculated by dividing yield per hectare values by 10,000.

3 Results and Discussion

3.1 Plant Height (cm plant^{-1})

The data presented in Table 1 indicate a significant effect of antioxidant treatments on plant height. Plants treated with VEC exhibited the tallest height (79.12 cm), whereas those in the control treatment (V0) showed a reduced height of 54.43 cm. Additionally, NPK fertilizer had a significant influence on this trait, with F2 producing the tallest plants (76.69 cm), compared to the control (F0) at 60.14 cm. A significant interaction was observed between foliar antioxidants and soil-applied NPK fertilizer, where the F2VEC combination achieved the maximum plant height (85.48 cm), while the untreated control (F0V0) recorded the lowest height (43.50 cm).

Table 1: Effect of Antioxidant Foliar Spray and Compound Fertilizer Application on Turmeric Plant Height (cm plant^{-1})

NPK Levels	Control (0 mg L^{-1}) (V_0)	Ascorbic Acid (150 mg L^{-1}) (Vc)	α-Tocopherol (150 mg L^{-1}) (Ve)	Ascorbic Acid + α-Tocopherol (150 mg L^{-1} each) (Vec)	NPK Levels Mean
F_0	43.50 f	65.34 cde	60.07 de	71.68 bc	60.14 C
F_1	55.75 e	70.17 bcd	65.27 cde	80.20 ab	67.85 B
F_2	64.06 cde	80.22 ab	77.02 ab	85.45 a	76.69 A
Antioxidant Means	**54.43 C**	**71.91 B**	**67.45 B**	**3.12**	

Notes: Means followed by the same letter are not significantly different according to Duncan's multiple range test at $P \leq 0.05$.

Whereas (for Tables 1 – 9):

- **F** refers to NPK fertilizer levels:
  - F_0 : No fertilizer (control), F_1 : 125 kg ha^{-1}, F_2 : 250 kg ha^{-1}.
- **V** refers to antioxidant treatments:
  - V_0 : No spray (control), **Vc**: Ascorbic acid (vitamin C, 150 mg L^{-1}), **Ve**: α-Tocopherol (vitamin

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E, 150 mg L^{-1}), **Vec**: Combined vitamins C + E (150 mg L^{-1} each).

- **Vc**: Vitamin C (ascorbic acid).
- **Ve**: Vitamin E (α-tocopherol).
- **Vec**: Combined vitamins C and E.

Key to Abbreviations (Tables 1 – 9):

- **NPK**: Nitrogen-Phosphorus-Potassium compound fertilizer.

3.2 Stem Diameter (mm)

The results in Table 2 reveal significant differences among antioxidant treatments in stem diameter. The VEC treatment yielded the thickest stems (17.55 mm), whereas the control (V0) had the thinnest (12.91mm). Similarly, NPK fertilization significantly affected stem diameter, with F2 producing the highest value (16.98 mm) compared to the control (F0) at 13.37 mm. The interaction between antioxidants and NPK was also significant, with F2VEC showing the thickest stems (19.20 mm),

Table 2: Effect of Antioxidant Foliar Spray and Compound Fertilizer Application on Turmeric Stem Diameter (mm)

NPK Levels	Control (0 mg L^{-1}) (V_0)	Ascorbic Acid (150 mg L^{-1}) (Vc)	α-Tocopherol (150 mg L^{-1}) (Ve)	Ascorbic Acid + α-Tocopherol (150 mg L^{-1} each) (Vec)	NPK Levels Mean
F_0	10.50 f	14.60 cde	12.53 ef	15.86 bc	13.37 B
F_1	13.00 de	15.80 bc	14.66 cde	17.60 ab	15.28 AB
F_2	15.23 bcd	17.43 ab	16.06 bc	19.20 a	16.98 A
Antioxidant Means	**12.91 D**	**15.96 B**	**14.42 C**	**17.55 A**	

while the untreated control (F0V0) recorded the lowest (10.50 mm).

3.3 Number of Leaves (leaves plant^{-1})

Table 3 demonstrates significant effects of antioxidant treatments on leaf count. The VEC treatment produced the highest number of leaves (20.59 leaves plant^{-1}), whereas the control (V0) had the lowest (13.15 leaves plant^{-1}). NPK fertilization also significantly influenced leaf count, with F2 yielding the highest number (18.64 leaves plant^{-1}) compared to the control (F0) at 14.29 leaves plant^{-1}. A significant interaction was observed, with F2VEC producing the maximum leaf count (23.26 leaves plant^{-1}), while the untreated control (F0V0) had the fewest (11.34 leaves plant^{-1}).

ISSN 2072-3857

Table 3: Effect of Antioxidant Foliar Spray and Compound Fertilizer Application on Turmeric Leaf Number (leaves plant^{-1})

NPK Levels	Control (0 mg L^{-1}) (V_0)	Ascorbic Acid (150 mg L^{-1}) (Vc)	α-Tocopherol (150 mg L^{-1}) (Ve)	Ascorbic Acid + α-Tocopherol (150 mg L^{-1} each) (Vec)	NPK Levels Mean
F_0	11.34 h	14.16 efg	13.44 fgh	18.22 bc	14.29 C
F_1	12.56 gh	16.55 cde	15.34 def	20.27 b	16.18 B
F_2	15.55 def	18.31 bc	17.45 cd	23.26 a	18.64 A
Antioxidant Means	**13.15 C**	**16.34 B**	**15.41 B**	**20.59 A**	

Notes: Means followed by the same letter are not significantly different according to Duncan's multiple range test at $P \leq 0.05$.

3.4 Leaf Length (cm)

The results in Table 4 indicate significant differences among antioxidant treatments in leaf length. The VEC treatment resulted in the longest leaves (43.25 cm), whereas the control (V0) had the shortest (17.30 cm). NPK fertilization also significantly affected leaf length, with F2 producing the longest leaves (32.35 cm) compared to the control (F0) at 24.73 cm. The interaction between antioxidants and NPK was significant, with F2VEC yielding the longest leaves (38.60 cm), while the

ISSN 2072-3857

Table 4: Effect of Antioxidant Foliar Spray and Compound Fertilizer Application on Turmeric Leaf Length (cm)

NPK Levels	Control (0 mg L^{-1}) (V_0)	Ascorbic Acid (150 mg L^{-1}) (Vc)	α-Tocopherol (150 mg L^{-1}) (Ve)	Ascorbic Acid + α-Tocopherol (150 mg L^{-1} each) (Vec)	NPK Levels Mean
F_0	14.23 f	27.96 cde	26.30 de	30.43 bcd	24.73 B
F_1	15.43 f	29.46 bcd	28.30 bcde	33.73 abc	26.73 B
F_2	22.23 e	35.06 ab	33.50 abc	38.60 a	32.35 A
Antioxidant Means	**17.30 C**	**29.36 B**	**30.83 AB**	**34.25 A**	

Notes: Means followed by the same letter are not significantly different according to Duncan's multiple range test at $P \leq 0.05$.

ntreated control (F0V0) recorded the shortest (14.23 cm).

Biochemical Interpretation

α-Tocopherol (Vitamin E) enhances vegetative growth by mitigating stress-induced metabolic disruptions, improving water uptake efficiency, and increasing indole-3-acetic acid (IAA) levels, which promote cell division and elongation. This explains the observed increases in plant height, stem diameter, and leaf number (Tables 1, 2, and 3).

Ascorbic acid (Vitamin C) contributes to cell proliferation, elongation, and stem thickening, leading to greater leaf expansion and total leaf area (Barth et al., 2006). NPK fertilizer promotes vegetative growth due to its balanced nitrogen content, which supports protein and amino acid synthesis, thereby enhancing plant metabolic activity (2).

3.5 Number of Rhizomes (rhizomes $plant^{-1}$)

The results in Table 5 indicate significant differences among antioxidant treatments in rhizome number. Plants treated with VEC exhibited the highest rhizome count (14.44 rhizomes $plant^{-1}$), while the control (V0) recorded the lowest (8.22 rhizomes $plant^{-1}$). NPK fertilization also significantly influenced rhizome production, with F2 yielding the highest number (13.08 rhizomes $plant^{-1}$) compared to the control (F0) at 9.08 rhizomes $plant^{-1}$. A significant interaction was observed between antioxidants and NPK, where the F2VECcombination produced the maximum rhizome count (15.33 rhizomes $plant^{-1}$), whereas the untreated control (F0V0) had the lowest (5.00 rhizomes $plant^{-1}$).

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Table 5: Effect of Antioxidant Foliar Spray and Compound Fertilizer Application on Turmeric Rhizome Number (rhizomes plant^{-1})

NPK Levels	Control (0 mg L^{-1}) (V_0)	Ascorbic Acid (150 mg L^{-1}) (Vc)	α-Tocopherol (150 mg L^{-1}) (Ve)	Ascorbic Acid + α-Tocopherol (150 mg L^{-1} each) (Vec)	NPK Levels Mean
F_0	5.00 e	9.00 cde	9.00 cde	13.33 abc	9.08 C
F_1	8.66 de	11.33 abcd	10.66 bcd	14.66 ab	11.33 B
F_2	11.00 abcd	13.66 ab	12.33 abcd	15.33 a	13.08 A
Antioxidant Means	8.22 C	11.33 B	10.66 B	14.44 A	

Notes: Means followed by the same letter are not significantly different according to Duncan's multiple range test at $P \leq 0.05$.

3.6 Rhizome Length (cm)

Data in Table 6 demonstrate significant effects of antioxidant treatments on rhizome length. The VEC treatment resulted in the longest rhizomes (6.84 cm), while the control (V0) showed the shortest (4.88 cm). NPK fertilization also significantly increased rhizome length, with F2producing the longest rhizomes (6.86 cm) compared to the control (F0) at 4.47 cm. The interaction between antioxidants and NPK was significant, with F2VEC achieving the maximum rhizome length (8.20 cm), while the untreated control (F0V0) recorded the shortest (3.50 cm).

ISSN 2072-3857

Table 6: Effect of Antioxidant Foliar Spray and Compound Fertilizer Application on Turmeric Rhizome Length (cm)

NPK Levels	Control (0 mg L^{-1}) (V_0)	Ascorbic Acid (150 mg L^{-1}) (Vc)	α-Tocopherol (150 mg L^{-1}) (Ve)	Ascorbic Acid + α-Tocopherol (150 mg L^{-1} each) (Vec)	NPK Levels Mean
F_0	3.50 f	5.16 de	3.96 ef	5.26 cde	4.47 C
F_1	5.10 de	6.63 bc	5.00 de	7.06 ab	5.95 B
F_2	6.06 bcd	7.20 ab	6.00 bcd	8.20 a	6.86 A
Antioxidant Means	4.88 B	6.33 A	4.98 B	6.84 A	

Notes: Means followed by the same letter are not significantly different according to Duncan's multiple range test at $P \leq 0.05$.

3.7 Plant Yield (g $plant^{-1}$)

Results in Table 7 reveal significant effects of antioxidant treatments on plant yield. The VEC treatment produced the highest yield (272.77 g $plant^{-1}$), whereas the control (V0) yielded the lowest (221.11 g $plant^{-1}$). NPK fertilization also significantly enhanced yield, with F2recording the highest value (282.33 g $plant^{-1}$) compared to the control (F0) at 210.91 g $plant^{-1}$. The interaction between antioxidants and NPK was significant, with F2VEC yielding the highest production (298.33 g $plant^{-1}$), while the untreated control (F0V0) had the lowest (165.00 g $plant^{-1}$).

ISSN 2072-3857

Table 7: Effect of Antioxidant Foliar Spray and Compound Fertilizer Application on Turmeric Yield (g plant^{-1})

NPK Levels	Control (0 mg L^{-1}) (V_0)	Ascorbic Acid (150 mg L^{-1}) (Vc)	α-Tocopherol (150 mg L^{-1}) (Ve)	Ascorbic Acid + α-Tocopherol (150 mg L^{-1} each) (Vec)	NPK Levels Mean
F_0	82.66 i	117.13 gh	108.93 h	127.63 efg	109.09 C
F_1	123.76 fg	143.03 bcd	136.90 cde	152.13 ab	138.95 B
F_2	131.00 def	153.66 ab	145.33 bc	162.93 a	148.23 A
Antioxidant Means	**112.47 D**	**137.94 B**	**130.38 C**	**147.56 A**	

Notes: Means followed by the same letter are not significantly different according to Duncan's multiple range test at $P \leq 0.05$.

3.8 Yield per Square Meter (kg m^{-2})

Data in Table 8 show significant differences among antioxidant treatments in yield per square meter. The VEC treatment resulted in the highest yield (1.136 kg m^{-2}), while the control (V0) recorded the lowest (0.920 kg m^{-2}). NPK fertilization significantly increased yield, with F2 producing the highest value (1.175 kg m^{-2}) compared to the control (F0) at 0.876 kg m^{-2}. The interaction between antioxidants and NPK was significant, with F2VEC achieving the maximum yield (1.242 kg m^{-2}), whereas the untreated control (F0V0) had the lowest (0.687 kg m^{-2}).

ISSN 2072-3857

Table 8: Effect of Antioxidant Foliar Spray and Compound Fertilizer Application on Turmeric Yield per Square Meter (kg m^{-2})

NPK Levels	Control (0 mg L^{-1}) (V_0)	Ascorbic Acid (150 mg L^{-1}) (Vc)	α-Tocopherol (150 mg L^{-1}) (Ve)	Ascorbic Acid + α-Tocopherol (150 mg L^{-1} each) (Vec)	NPK Levels Mean
F_0	0.687 g	0.971 e	0.825 f	1.020 de	0.876 C
F_1	0.978 e	1.119 c	1.020 de	1.145 bc	1.065 B
F_2	1.096 cd	1.218 ab	1.145 bc	1.242 a	1.175 A
Antioxidant Means	0.920 C	1.103 A	0.996 B	1.136 A	

Notes: Means followed by the same letter are not significantly different according to Duncan's multiple range test at $P \leq 0.05$.

Biochemical Interpretation

α-Tocopherol (Vitamin E) plays a critical role in protecting plant cells from oxidative stress, enhancing growth, elongation, and sustainability (Table 2). Ascorbic acid (Vitamin C) improves carbon assimilation by promoting sugar production, which is translocated to rhizomes, increasing their weight, length, and number (Tables 5, 6, and 7). Consequently, this leads to higher per-plant yield and yield per square meter (5).

The NPK fertilizer boosts yield due to increased nitrogen, phosphorus, and potassium uptake, enhancing leaf area and overall photosynthetic efficiency, thereby improving total plant productivity (10).

4 CONCLUSION

The combined application of antioxidants (α-tocopherol and ascorbic acid) and optimized NPK fertilization significantly enhances turmeric growth, physiological efficiency, and yield. These findings highlight the importance of integrated nutrient and antioxidant management in maximizing turmeric productivity.

ISSN 2072-3857

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