DOI: 10.21088/ijps.2348.9677.12125.2

Indian Journal of Plant and Soil
Volume 12 Number 1 January - June 2025

ORIGINAL ARTICLE

Synergistic Effects of Triacontanol and Silicon Dioxide on Growth and Productivity of Turmeric *(Curcuma longa L.)*

Princy Tyagi[1], Akbar Ali[2], Krishan Kant[3], Shalu Gupta[4], Navneet Kaur[5], Mukta Satsangi[6], Parnika Jindal[7]

HOW TO CITE THIS ARTICLE:

Princy Tyagi, Akbar Ali, Krishan Kant et. al, Synergistic eEffects of Triacontanol and Silicon Dioxide on Growth and Productivity of Turmeric (Curcuma longa L.). Ind J Plant Soil. 2025;12(1): 17-26.

ABSTRACT

Curcuma longa L. (family Zingiberaceae), one of the earliest spices cultivated in Southeast Asia, has been used for centuries as a natural remedy for chronic diseases. This study investigated the effects of triacontanol (TRIA) and silicon dioxide (SiO_2) on turmeric's development, biochemistry, and yield attributes. An experiment using a randomized block design (RBD) applied eight spray treatments at 5-day intervals: (T-0) DDW (control), (T-1) 1 ppm TRIA, (T-2) 2 ppm TRIA, (T-3) 4 ppm TRIA, (T-4) 200 ppm SiO_2, (T-5) 1 ppm TRIA + 200 ppm SiO_2, (T-6) 2 ppm TRIA + 200 ppm SiO_2, and (T-7) 4 ppm TRIA + 200 ppm SiO_2. Key results revealed that treatment T-7 (4 ppm TRIA + 200 ppm SiO_2) produced the highest shoot length per plant (18.93% increase) and fresh weight (68.53% increase), whereas T-3 (4 ppm TRIA) yielded the maximum root length per plant (45.45%), number of leaves per plant (38.88%), leaf area (48.54%), and rhizome length (73.33%). Biochemically, T-3 showed the highest total chlorophyll content (10.97% increase), while T-7

AUTHOR'S AFFILIATION:

[1] MSc Botany, Plant physiology and Biochemistry Lab, Department of Botany, Dayalbagh Educational Institute (Deemed to be University), Agra 282005, India.

[2] Assistant Professor, Plant physiology and Biochemistry Lab, Department of Botany, Dayalbagh Educational Institute (Deemed to be University), Agra 282005, India.

[3] Research Scholar, Plant physiology and Biochemistry Lab, Department of Botany, Dayalbagh Educational Institute (Deemed to be University), Agra 282005, India.

[4] Research Scholar, Plant physiology and Biochemistry Lab, Department of Botany, Dayalbagh Educational Institute (Deemed to be University), Agra 282005, India.

[5] Research Scholar, Plant physiology and Biochemistry Lab, Department of Botany, Dayalbagh Educational Institute (Deemed to be University), Agra 282005, India.

[6] Research Scholar, Plant physiology and Biochemistry Lab, Department of Botany, Dayalbagh Educational Institute (Deemed to be University), Agra 282005, India.

[7] Research Scholar, Plant physiology and Biochemistry Lab, Department of Botany, Dayalbagh Educational Institute (Deemed to be University), Agra 282005, India.

CORRESPONDING AUTHOR:

Akbar Ali, Assistant Professor, Plant physiology and Biochemistry Lab, Department of Botany, Dayalbagh Educational Institute (Deemed to be University), Agra 282005, India.

E-mail: akbarali@dei.ac.in

➤ **Received:** 08-05-2025 ➤ **Accepted:** 16-06-2025

displayed the maximum total carotenoids content increase (36.47%). Crucially, T-3 (4 ppm TRIA) significantly enhanced yield, increasing the number of rhizomes per plant by 52.94%, the weight of rhizome per plant by 112.28%, and essential oil (EO) content by 45.45%. The study concludes that 4 ppm TRIA (T-3) optimizes root growth, chlorophyll, rhizome yield, and EO content, while the combination of 4 ppm TRIA and 200 ppm SiO_2 (T-7) is most effective for shoot growth, fresh weight, and carotenoids accumulation in turmeric.

KEYWORDS

• Turmeric (*Curcuma longa* L.) • Triacontanol • Silicon dioxide • Rhizome and EO

INTRODUCTION

Curcuma longa L. (turmeric), a medicinally important plant widespread in the Ayurveda, Siddha, and Unani systems of Indian medicine, used as a common household remedy for the treatment of various diseases.[1–4] *Curcuma longa* L. is a short-stemmed perennial plant belonging to the ginger family (Zingiberaceae), which possesses large oblong-shaped leaves and produces ovate, pyriform, or oblong-shaped rhizomes that are usually dichotomously branched and brownish-yellow in colour.[2,5,6] It is used as a food additive (spice, preservative, and dye) in several Asian countries, such as China and Southeast Asia.[1] India has a long tradition of utilizing plants in medicine. It is also believed to be a good omen and runs as a tradition in religion. In ancient Hindu medicine, it is used predominantly for the treatment of sprains and swelling due to injury.[7] In Indian medicinal system, turmeric powder has been traditionally employed for the treatment of anorexia, biliary disorders, cough, diabetes, coryza, wounds, rheumatism, hepatic diseases, and sinusitis.[7,8] *Curcuma longa* is applied to treat diseases connected with abdominal cramps in China. The coloring principle of turmeric is the highest component of this plant, contributing to its anti-inflammatory effect.[1,3] The rhizomatous herbs forming the genus occur in the tropical belt, but it is cultivated as a spice mainly in India, Southeast Asia, and Indonesia.[6,9,10]

India holds a leading position in global turmeric production. It is grown across the country, but large-scale cultivation is mainly concentrated in the southern and eastern regions, including West Bengal, Andhra Pradesh, Karnataka, Orissa, and Tamil Nadu.[5,6,11] Curcuminoids are the main phytochemical ingredients in turmeric. In turmeric, curcuminoids concentration fluctuates between 2 and 9%, depending on cultivar, soil, and climatic conditions.[12,13] Turmeric contains carbohydrates (69.4%), moisture (13.1%), proteins (6.3%), fats (5.1%), and minerals (3.5%). The essential oil (EO) (5.8%) has sesquiterpenes (53), zingiberene (25%), cineol (1%), phellandrene (1%), and borneol (0.5%).[11,13,14]

Rhizomes or fingers provide the common mode of turmeric propagation. The most suitable time for planting is from April through June in India, depending on the local agroclimatic conditions. It is a plant adapted for warm and wet weather conditions.[11] Early planting with a soil temperature of 30–35 °C provides good and quick germination. Optimal growth is achieved in fertile and well-drained soils such as clayey, sandy, alluvial loam, black and red.[9]

TRIA is a 30-carbon primary alcohol, which has plant growth-regulating activity.[15,16] TRIA has been used as a plant growth regulator since 1977, and it promotes plant development and yield in a variety of crops, including sweet basil, canola, coffee, coriander, fennel, lemongrass, maize, mint, opium poppy, tomato, rice, soybean, and wheat.[15-20] Foliar spray of TRIA boosts plant biomass, photosynthetic pigment content, EO content, antioxidant enzyme activities, gas exchange parameters, carbonic anhydrase (CA) activity, nitrate reductase (NR) activity, mineral nutrient acquisition, osmolytes accumulation, yield, and quality aspects.[21,22,23]

TRIA has been identified as a substance that mitigates salinity stress, thereby enhancing crop productivity across a range of crops, including *Zea mays*, *Glycine max*, *Helianthus annuus*, *Raphanus sativus*, *Coriandrum sativum*, *Mentha piperita*, and *Erythrina variegata*.[24]

Silicon is the most plentiful element in the earth's crust, second only to oxygen. It occurs in various forms such as calcium silicate, potassium silicate, rock dust, and fine silica particles, and it is an important trace element for inducing resistance against diverse stresses, diseases, and pathogens of plants.[25] The application of silicon dioxide (SiO_2) helps in abiotic and biotic stress conditions in plants.[26,27] It provides defense[25] and resistance against herbivores and pests,[26] and also hinders the penetration of bacteria, fungi, and nematodes, and increases disease resistance.[27,28,29] Silicon can regulate plant growth development, plant water relation, leaf thickness, metabolism, elasticity and plasticity of the cell wall.[25]

Keeping the medicinal value and commercial properties of turmeric in mind, a hypothesis was developed to study the impact of TRIA and SiO_2 (alone or in combination) could promote plant development, physiological, biochemical, and yield characteristics of turmeric.

MATERIAL AND METHODS

Plant material and treatments

The Keshari variety of turmeric rhizome was obtained from the Council of Scientific and Industrial Research (CSIR), National Botanical Research Institute (NBRI) in Lucknow, Uttar Pradesh. The rhizomes were planted in August 2021. The field experiment was carried out using a Randomized Block Design. Three sprays were applied at 5-day intervals to ensure comprehensive coverage. Different doses are shown in Table 1.

Table 1: Different doses of TRIA and SiO_2

Treatments	Doses
T0	DDW (control)
T-1	1 ppm TRIA
T-2	2 ppm TRIA
T-3	4 ppm TRIA
T-4	200 ppm SiO_2
T-5	1 ppm+200 ppm (TRIA+ SiO_2)
T-6	2 ppm+200 ppm (TRIA+ SiO_2)
T-7	4 ppm+200 ppm (TRIA+ SiO_2)

Site location, agro-climatic conditions and soil properties

To study the effect of TRIA and SiO_2 on *Curcuma longa* L. To achieve this goal a field experiment was conducted at Botanical Garden (27°13′34.9″N 78°00′51.2″ E) DEI, Agra (U.P.) India, and situated at 163 m sea level height. The agroclimatic conditions of August to December at the experimental site are detailed in figure 1, while Table 2 presents the physiochemical properties of the soil before the plantation of *Curcuma longa* L. rhizomes.

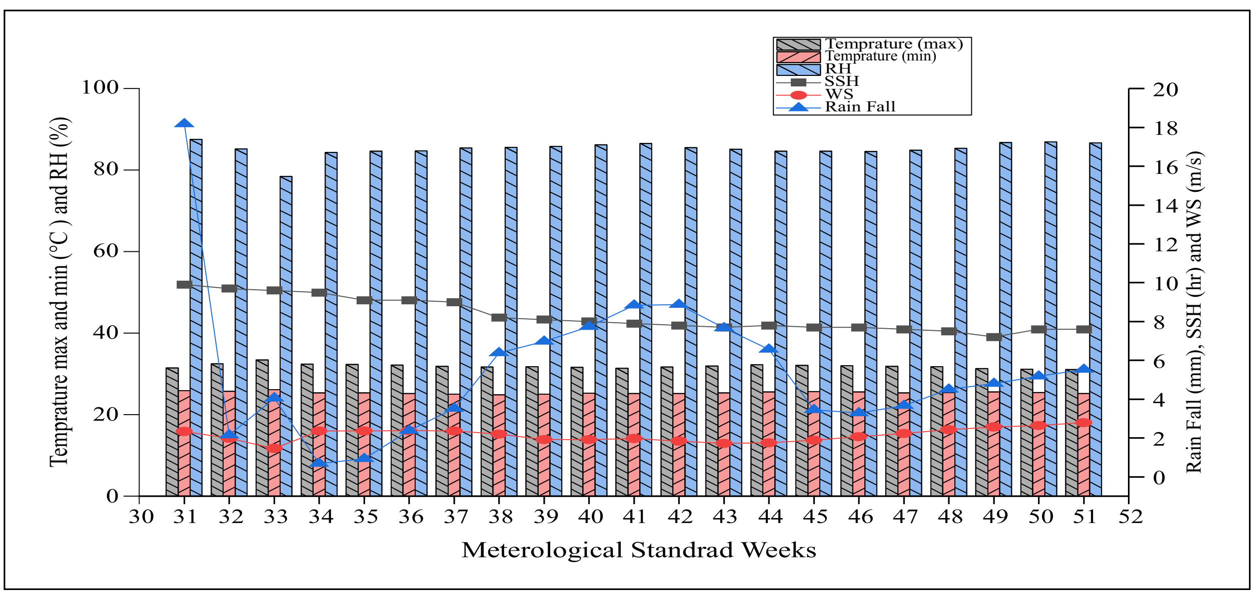

Figure 1: Climatic conditions during the growing metrological standard weeks

Estimation of pH, electrical conductivity (EC), and salinity of soil

Samples of the soil were collected randomly from the experimental site, at a depth of about 0-30 cm. Samples were air-dried and sieved via using 2 mm sieve to eliminate the granular fraction for determination of pH, EC, temperature, and salinity of soil (Table 2). Three replicants of each sample, measured 20 gm soil and mixed with 50 mL distilled water were made and each replicant was shaken for 5 min and kept for 30 min. pH, EC, and salinity were measured through the method given by Singh *et al.*[30] and all soil samples were analyzed through water analyser 371 (Systronics India).

Table 2: Physiochemical properties of the soil.

Property	Value
Soil depth (cm)	0-30
pH (1:2)	7.12
EC ($dS.m^{-1}$)	1.87
Salinity (ppt)	11.97
Moisture content (%)	20
OC (%)	5.98
N (%)	0.0028
Na (%)	0.0142
K (kg/ha)	26.760
P (kg/ha)	26.76
Sand (%)	30
Silt (%)	40
Clay (%)	30
Soil texture type	Loam soil

Determination of moisture content, soil texture, and organic carbon of soil

Soil moisture content was analyzed by Kadam and Shinde's gravimetric and international pipette method.[31] Organic carbon was analyzed by using Walkley and Black method.[30]

Estimation of nitrogen, sodium, phosphorus, and potassium in soil

Soil nitrogen content was determined through the alkaline permanganate method (Kjeldahl method) given by Page.[32] Sodium determination was done according to the protocol given by Knudsen *et al.*[33], and potassium was measured by flame photometer according to the protocol given by Ghosh *et al.*[34] Phosphorus was determined according to Olsen's method given by Olsen and Sommers,[35] and the absorbance of phosphorus colour intensity was measured by spectrophotometer at 882 nm.

Growth, biochemical and yield parameters

In these experiments the following growth parameters are measured during the study viz., shoot length per plant, root length per plant, fresh weight of shoot, number of leaves per plant, leaf area per plant, and length of rhizome. Biochemical parameters are total chlorophyll and carotenoids content, and yield parameters are number of rhizomes per plant, weight of rhizome and EO content in leaves.

Each plant from the respective treatment was carefully harvested, and both shoot and root lengths were measured using a meter scale. The fresh weight of each plant was determined using an electronic balance. The leaf area of the upper, middle, and lower leaves of each *Curcuma longa* L. plant sample was assessed by using graph paper. The count of rhizomes present in each plant was determined. The weight of rhizomes in each plant was measured using an electronic balance. In each treatment, plants were harvested carefully, and the length of rhizomes was measured with a meter scale.

Estimation of total chlorophyll and carotenoids content in leaves

The total chlorophyll and carotenoids content were estimated by the method of MacKinney[36] and MacLachlan and Zalik,[37] using a spectrophotometer at 645 and 663 nm (for chlorophyll estimation) and for carotenoids estimation at 480 and 510 nm.

Extraction of EO

The EO was extracted and quantified by gravimetrical method given by Guenther.[38] 100 g fresh leaves were used for extraction through hydrodistillation (3h) using Clevenger's apparatus.

Statistical analysis

All growth and yield parameters observed value were analyzed by SPSS software.

RESULTS

Effect of TRIA, SiO_2 and their combination on growth traits

The foliar application of TRIA, SiO_2, and their combined treatment exhibited a significant impact on both shoot and root length per plant, as depicted in Figure 2A and 2B. Notably, the application of 4 ppm TRIA led to a significant enhancement in shoot length per plant (16.66). Furthermore, the combined treatment, comprising 4 ppm TRIA and 200 ppm SiO_2, demonstrated an even more pronounced effect, elevating the shoot length by 18.93 in *Curcuma longa* L. when compared to the control.

Turning attention to root length, the application of TRIA at 4 ppm exhibited a substantial improvement, increasing root length by 45.45%. Similarly, the combined treatment of 4 ppm TRIA with 200 ppm SiO_2 showed a significant impact, elevating root length per plant by 38.18% as compared to the control.

The foliar application of TRIA, SiO_2, and their combination produced significant impacts on shoot fresh weight per plant. Notably, the 4 ppm TRIA resulted in a substantial improvement of 37.68%, while the combined treatment of 4 ppm TRIA with 200 ppm SiO_2 exhibited an even more remarkable enhancement of 68.53%, as illustrated in Figure 3A.

In terms of the number of leaves per plant, 4 ppm TRIA led to a noteworthy increase of 38.38. Moreover, the combined treatment of 4 ppm TRIA with 200 ppm SiO_2 demonstrated a considerable impact, elevating the number of leaves per plant by 27.77 in comparison to the control group, as depicted in Figure 3B.

The foliar application of TRIA, SiO_2, and their combination resulted in significant improvements in leaf area. Specifically, both the application of 4 ppm TRIA and the combined treatment (4 ppm TRIA + 200 SiO_2) demonstrated significant increases, registering at 48.54% and 36.47%, respectively, as compared to control.

Additionally, the length of rhizomes exhibited substantial growth under the influence of 4 ppm TRIA, showcasing a remarkable increase of 73.33. Similarly, the combined treatment (4 ppm TRIA + 200 ppm SiO_2) positively impacted rhizome length, demonstrating a notable growth of 47.61% over the control.

These results underscore the efficacy of both TRIA and the combined treatment in positively influencing the growth parameters of *Curcuma longa* L., providing valuable insights for optimizing plant development.

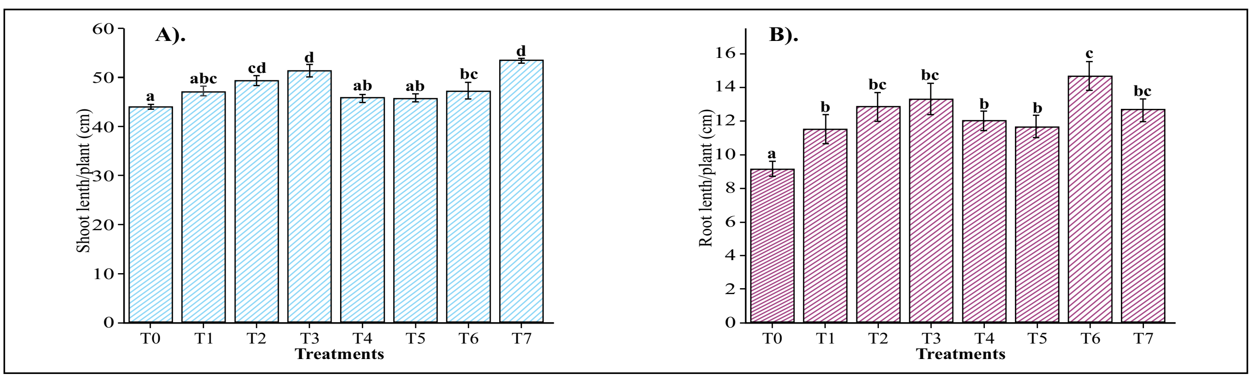

Figure 2: Effect of TRIA, SiO_2 and their combination on **(A)** Shoot length/plant, **(B)** Root length/plant. The data is statistically significant with a p-value ≤ 0.05, and the means were compared using DMRT

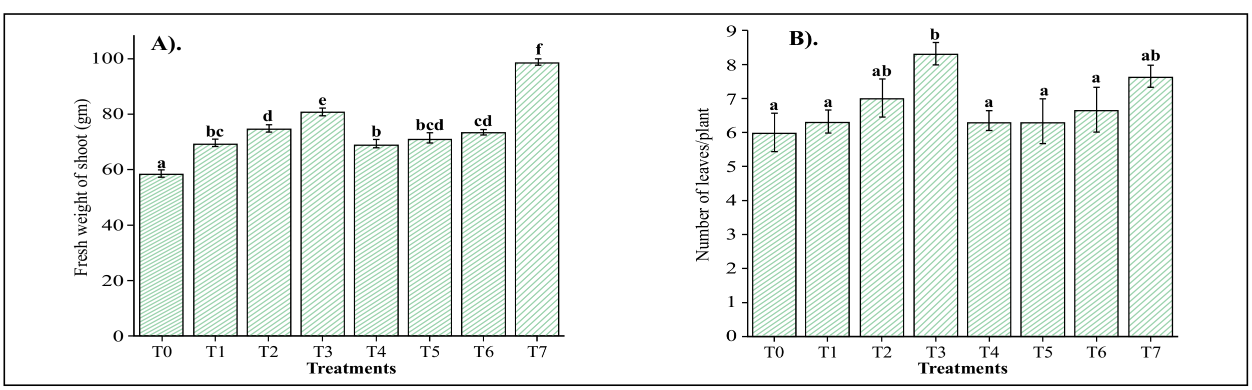

Figure 3: Effect of TRIA, SiO_2 and their combination on **(A)** Fresh weight of shoot, **(B)** Number of leaves /plant. The data is statistically significant with a p-value ≤ 0.05, and the means were compared using DMRT

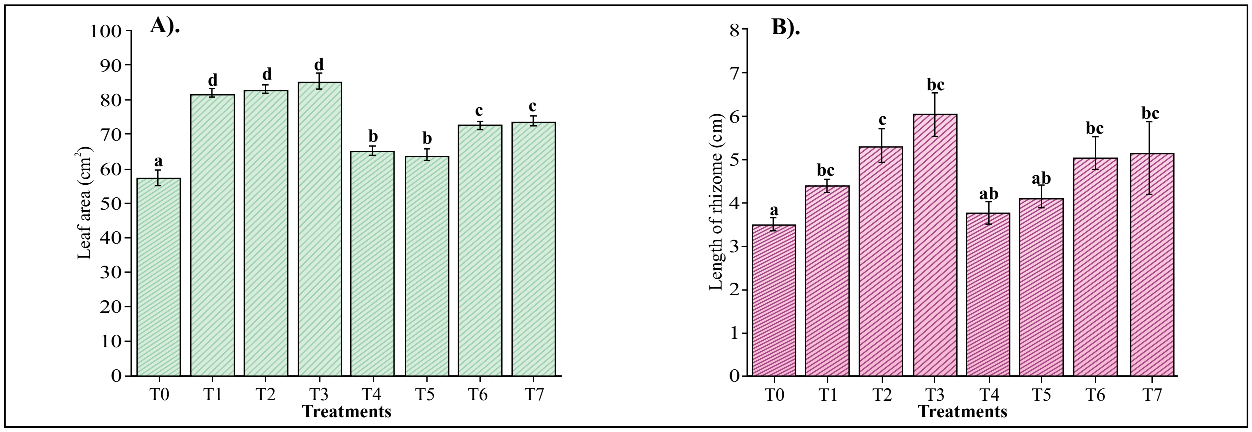

Figure 4: Effect of TRIA, SiO_2 and their combination on **(A)** Leaf area, **(B)** length of rhizome. The data is statistically significant with a p-value ≤ 0.05, and the means were compared using DMRT

Effect of TRIA, SiO_2 and their combination on physio-biochemical related traits Total chlorophyll and carotenoids content in leaf

The foliar application of TRIA, SiO_2, and their combination resulted in significantly improved leaves total chlorophyll and carotenoids content. Notably, the treatment with 4 ppm TRIA led to a significant increase total chlorophyll content (10.97) and the combined treatment (4 ppm TRIA + 200 ppm SiO_2) exhibited an 8.7 improvement as compared to control, as illustrated in Figure 5A.

Similarly, the total carotenoids content saw a positive impact, with the application of 4 ppm TRIA resulting in a notable increase of 19.42. The combined treatment (4 ppm TRIA + 200 ppm SiO_2) further enhanced carotenoids content, showing a significant growth of 36.47 compared to the control, as depicted in Figure 5B. These findings highlight the effectiveness of both 4 ppm TRIA and the combined treatment in enhancing the photosynthetic pigments, providing valuable insights for optimizing plant physiological processes.

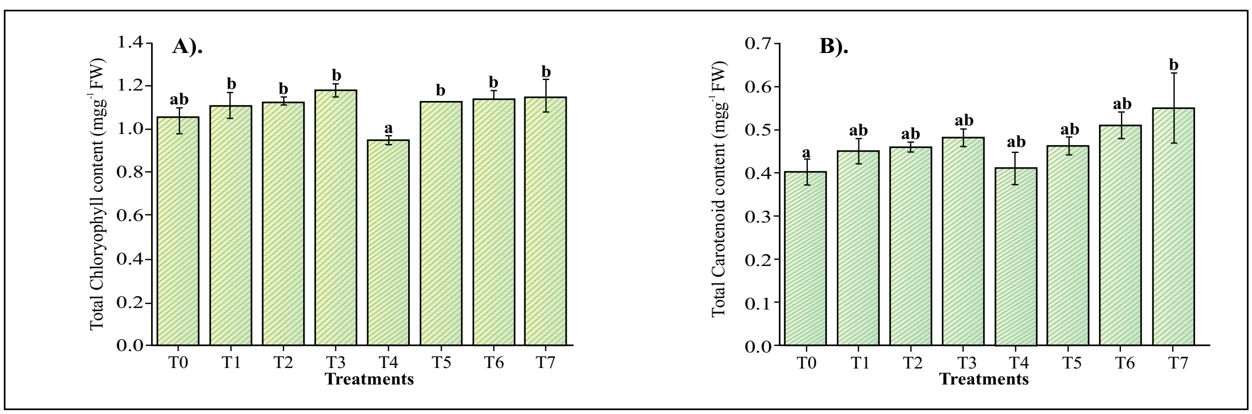

Figure 5: Effect of TRIA, SiO_2 and their combination on **(A)** Total chlorophyll content **(B)** Total carotenoids content. The data is statistically significant with a p-value ≤ 0.05, and the means were compared using DMRT

Effect of TRIA, SiO_2 and their combination on yield traits

The foliar application of TRIA, SiO_2, and their combination significantly enhanced the yield attributes. The maximum weight of rhizome increased by an impressive 112.28 with the combined treatment of 4 ppm TRIA and 200 ppm SiO_2. Additionally, the weight of rhizomes also saw a substantial increase of 54.95 with the application of 4 ppm TRIA alone compared to the control, as depicted in Figure 6A.

Furthermore, the number of rhizomes exhibited growth, increasing by 47.05 with both 4 ppm TRIA alone and the combined treatment of 4 ppm TRIA and 200 ppm SiO_2, in comparison to the control, as illustrated in Figure 6B.

The EO content of *Curcuma longa* L. reached its maximum with the combined treatment of 4 ppm TRIA and 200 ppm SiO_2, showing a substantial increase of 45.45. Spraying with 200 ppm SiO_2 alone also resulted in an important rise of 27.27. While the treatments with 1 ppm, 2 ppm, and 4 ppm TRIA exhibited a consistent and significant increase of 18.18 compared to the control, as depicted in Figure 6C. These findings underscore the significant positive impact of the treatments on the yield attributes and EO content, providing valuable insights for enhancing the overall productivity of *Curcuma longa* L.

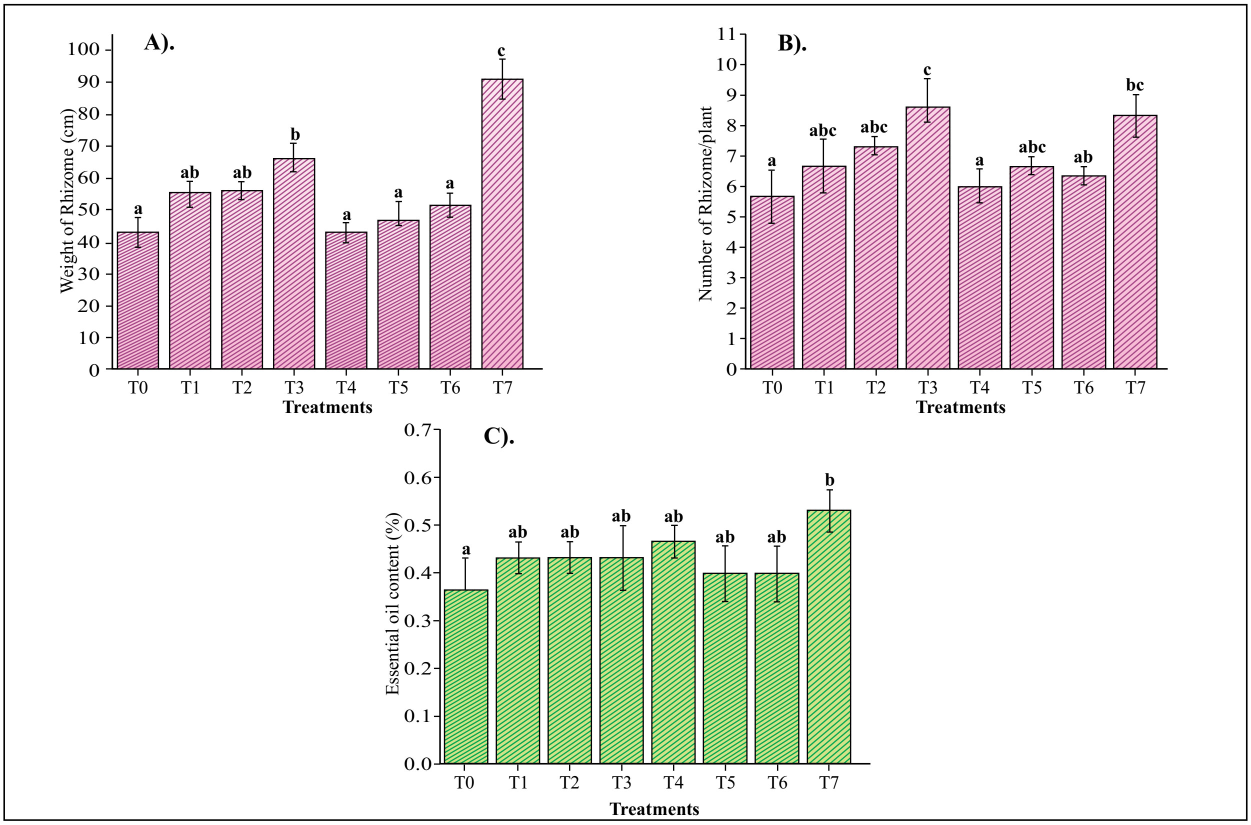

Figure 6: Effect of TRIA, SiO_2 and their combination on **(A)** Weight of rhizome **(B)** Number of Rhizome/plant **(C)** EO content of Curcuma plant. The data is statistically significant with a p-value ≤ 0.05, and the means were compared using DMRT

DISCUSSION

TRIA has been shown to enhance various aspects of plant growth and development, including photosynthesis, protein synthesis, yield, nitrogen fixation, water absorption, nutrient uptake, antioxidant enzyme activities, and the levels of secondary metabolites in various crops.[21,22] Silicon, another beneficial nutrient, also plays an important role in growth, development, and abiotic stress tolerance.[39,40]

The foliar application of plant growth regulators and nutrients can significantly improve crop yield and secondary metabolites in medicinal plants.[39,41] Furthermore, the use of TRIA in foliar spray applications at different concentrations has shown positive impact on the growth and physiological attributes of various crops.

Ali and Perveen[42] observed that, 1 μM TRIA (foliarly applied) significantly enhanced stomatal conductance, photosynthetic pigments, flavonoids, and anthocyanin contents in *Triticum aestivum* L. Similarly, Perveen *et al.*[43] reported that 5 μM TRIA improved growth, physiochemical attributes, and drought tolerance in Zea mays L. Additionally, Naeem *et al.*[44] observed that a concentration of 10^{-6} M TRIA enhanced growth, photosynthetic pigments, herbage yield, and EO content in *Mentha arvensis* L. The positive effects of TRIA have also been demonstrated in other crops, such as *Foeniculum vulgare*[19] and *Zingiber officinale*,[45] where foliar sprays of TRIA significantly increased yield, chlorophyll content, and EO yield.

In parallel, silicon nanoparticles (SiNPs) have shown similar benefits. Mukarram *et al.*[25] found that a foliar spray of 150 mg L^{-1} SiNPs enhanced the photosynthetic rate, chlorophyll content, and EO content in *Cymbopogon flexuosus.* Siddiqui *et al.*[46] applied nano-SiO_2 under salt stress, nano-SiO_2 (exogenously applied) increased growth attributes, chlorophyll pigments, proline content, and CA activity in *Cucurbita pepo* L.

Moreover, Othman *et al.*[47] demonstrated that foliar application of SiO_2 (333 mg L^{-1}) and 1-ethoxysilatrane (10^{-2} mlL^{-1}) significantly increased total chlorophyll and carotenoids content, fresh weight, height, and number of leaves in *Lactuca sativa.* Janmohammadi *et al.*[48] observed enhanced plant height, number of flowers, plant canopy, achene yield, and photosynthetic pigments in *Carthamus tinctorius* L. with a foliar spray of 20 mM SiO_2. Simko *et al.*[49] observed that foliar spray of SiO_2 at 3.66 mM on *Lactuca sativa* enhanced crop yield under abiotic stress.

In the case of *Solanum lycopersicum* L., Parveen and Siddiqui[50] found that foliar spray containing 0.20 g L^{-1} SiNPs led to higher levels of proline, antioxidant enzymes and photosynthetic pigments, against pathogens. Overall, the research suggests that both TRIA and silicon-based treatments can significantly enhance plant growth, development, and stress tolerance in various crops.

CONCLUSION

The foliar application of TRIA, SiO_2, and their combined treatment demonstrated significant impacts on various growth parameters in *Curcuma longa* L. Specifically, the application of 4 ppm TRIA resulted in a substantial enhancement in shoot length, root length, shoot fresh weight, and the number of leaves per plant. The combined treatment of 4 ppm TRIA with 200 ppm SiO_2 showed even more remarkable improvements in these parameters.

Moreover, both TRIA and the combined treatment positively influenced leaf area, with significant increases recorded. The height of rhizomes also exhibited substantial growth under the influence of 4 ppm TRIA and the combined treatment. These findings highlight the efficacy of both TRIA and the combined treatment in positively influencing the growth parameters of *Curcuma longa* L., providing valuable insights for optimizing plant development.

Furthermore, TRIA, SiO_2, and their combination as foliar application resulted in significant improvements in leaves total chlorophyll and carotenoids content, enhancing photosynthetic pigments and providing valuable insights for optimizing plant physiological processes.

Lastly, the yield attributes were significantly enhanced, with the combined treatment of 4 ppm TRIA and 200 ppm SiO_2 leading to an impressive increase in the maximum weight of rhizome, the number of rhizomes, and the EO content. These findings underscore the significant positive impact of the treatments on the yield attributes and EO content, providing valuable insights for enhancing the overall productivity of *Curcuma longa* L.

Conflict of Interest: The authors have no conflict of interest to report.

Funding: No funding

REFERENCES

1. Araujo CAC, Leon LL. Biological activities of *Curcuma longa* L. *Mem Inst Oswaldo Cruz*. 2001; 96:723–8.
2. Ansar S, Jilani S, Abbasi H, Hashimi A, Ahmed Y, Khatoon R, *et al. Curcuma longa*: A treasure of medicinal properties. *CellMed*. 2020; 10(2):9–1.
3. Sanghvi K, Chandrasheker KS, Pai V. Review on *Curcuma longa*: ethnomedicinal uses, pharmacological activity and phytochemical constituents. *Res J Pharm Technol*. 2020;13(8): 3983–6.
4. Praveen A, Mawale KS, Parvatam G, Chaudhari SR. Efficacy of silver nanoparticles (NPs) and fungal elicitors on the curcuminoid production in *Curcuma longa* L. *Plant Physiol Biochem*. 2025; 220:109501.
5. Chattopadhyay I, Biswas K, Bandyopadhyay U, Banerjee RK. Turmeric and curcumin: Biological actions and medicinal applications. *Curr Sci*. 2004; 87:44–53.
6. Fuloria S, Mehta J, Chandel A, Sekar M, Rani NNIM, Begum MY, *et al.* A comprehensive review on the therapeutic potential of *Curcuma longa* Linn. in relation to its major active constituent curcumin. *Front Pharmacol*. 2022; 13:820806.
7. Vaughn AR, Branum A, Sivamani RK. Effects of turmeric (*Curcuma longa*) on skin health: a systematic review of the clinical evidence. *Phytother Res*. 2016;30(8):1243–64.

8. Sarı E, Sarıışık M. Use of turmeric, the golden spice in kitchen in different discipline areas. *Toros Univ J Food Nutr Gastronomy*. 2025;4(1):97–108.

9. Omosa LK, Midiwo JO, Kuete V. *Curcuma longa*. In: Kuete V, editor. *Medicinal Spices and Vegetables from Africa*. London: Academic Press; 2017. p. 425–35.

10. Amante G, Wedajo M, Temteme S. Growth and yield response of turmeric (*Curcuma longa* L.) to NPSB and urea fertilizer in Yeki district, southwest Ethiopia. *Int J Food Agric Nat Resour*. 2025;6(1):100–5.

11. Soleimani V, Sahebkar A, Hosseinzadeh H. Turmeric (*Curcuma longa*) and its major constituent (curcumin) as nontoxic and safe substances. *Phytother Res*. 2018;32(6):985–95.

12. Kotra VSR, Satyabanta L, Goswami TK. A critical review of analytical methods for determination of curcuminoids in turmeric. *J Food Sci Technol*. 2019;56(12):5153–66.

13. Albaqami JJ, Hamdi H, Narayanankutty A, Visakh NU, Sasidharan A, Kuttithodi AM, *et al.* Chemical composition and biological activities of the leaf EOs of *Curcuma longa*, *Curcuma aromatica* and *Curcuma angustifolia*. *Antibiotics*. 2022;11(11):1547.

14. Parthasarathy M, Anand AK, Rakesh Rao KR, Ramakrishnan R, Sudheer WN, Nagella P. Plant breeding advances in turmeric (*Curcuma longa* L.). In: Nagella P, editor. *Biodiversity and Genetic Improvement of Herbs and Spices*. 2025. p. 435–69.

15. Naeem M, Khan M. Triacontanol: A potent plant growth regulator in agriculture. *J Plant Interact*. 2012; 7:129–42.

16. Khan MMA, Hashmi N, Moinuddin, Dar TA. Changes in growth, yield, photosynthetic characteristics, enzyme activities and EO production of fennel (*Foeniculum vulgare* Mill.) under growth regulator treatments. *J Essent Oil Res*. 2014;26(2):105–13.

17. Krishnan RR, Kumari BD. Effect of N-triacontanol on the growth of salt stressed soybean plants. *J Biosci*. 2008;19(2):53–62.

18. Borowski E, Blamowski ZK. The effects of triacontanol 'TRIA' and Asahi SL on the development and metabolic activity of sweet basil (*Ocimum basilicum L.*) plants treated with chilling. *Folia Hortic*. 2009;21(1):39–48.

19. Khan MMA, Hashmi N, Moinuddin, Dar TA. Changes in growth, yield, photosynthetic characteristics, enzyme activities and EO production of fennel (*Foeniculum vulgare* Mill.) under growth regulator treatments. *J Essent Oil Res*. 2014;26(2):105–13.

20. Karam EA, Keramat B. Foliar spray of triacontanol improves growth by alleviating oxidative damage in coriander under salinity. *Indian J Plant Physiol*. 2017;22(1):120–4.

21. Naeem M, Ansari AA, Aftab T, Shabbir A, Alam MM, Khan MMA, *et al.* Application of triacontanol modulates plant growth and physiological activities of *Catharanthus roseus* (L.). *Int J Bot Stud*. 2019; 4:131–5.

22. Islam S, Mohammad F. Triacontanol as a dynamic growth regulator for plants under diverse environmental conditions. *Physiol Mol Biol Plants*. 2020;26(5):871–83.

23. Zaid A, Mohammad F, Fariduddin Q. Plant growth regulators improve growth, photosynthesis, mineral nutrient and antioxidant system under cadmium stress in menthol mint (*Mentha arvensis* L.). *Physiol Mol Biol Plants*. 2020;26(1):25–39.

24. Islam S, Zaid A, Mohammad F. Role of triacontanol in counteracting the ill effects of salinity in plants: a review. *J Plant Growth Regul*. 2021; 40:1–10.

25. Mukarram M, Khan MMA, Corpas FJ. Silicon nanoparticles elicit an increase in lemongrass (*Cymbopogon flexuosus* (Steud.) Wats) agronomic parameters with a higher EO yield. *J Hazard Mater*. 2021; 412:125254.

26. Assis FA, Moraes JC, Auad AM, Coelho M. The effects of foliar spray application of silicon on plant damage levels and components of larval biology of the pest butterfly *Chlosyne lacinia saundersii* (Nymphalidae). *Int J Pest Manag*. 2013;59(2):128–34.

27. Avestan S, Ghasemnezhad M, Esfahani M, Byrt CS. Application of nano-silicon dioxide improves salt stress tolerance in strawberry plants. *Agronomy*. 2019;9(5):246.

28. Hedayati A, Hosseini B, Palazon J, Maleki R. Improved tropane alkaloid production and changes in gene expression in hairy root cultures of two Hyoscyamus species elicited by silicon dioxide nanoparticles. *Plant Physiol Biochem*. 2020; 155:416–28.

29. Khan MR, Siddiqui ZA. Use of silicon dioxide nanoparticles for the management of *Meloidogyne incognita*, *Pectobacterium betavasculorum* and *Rhizoctonia solani* disease complex of beetroot (*Beta vulgaris* L.). *Sci Hortic*. 2020; 265:109211.

30. Singh D, Chhonkar PK, Pandey RN. *Soil plant water analysis: a methods manual*. New Delhi: IARI; 1999. p. 80–2.

31. Kadam JR, Shinde PB. Practical manual on soil physics—A method manual. Rahuri: Dept. of Agricultural Chemistry and Soil Science, PGI; 2005. p. 24.

32. Page AL, editor. The Methods of Soil Analysis, Part-2. Madison: ASA, SSSA; 1983.

33. Knudsen DL, Peterson GA, Pratt PF. Lithium, sodium, and potassium. In: Page AL, editor. *Methods of soil analysis: Part 2. Chemical and microbiological properties*. 2nd ed. Madison: ASA, SSSA; 1982. p. 225–46.

34. Ghosh AB, Bajaj JC, Hasan R, Singh D. Soil and water testing methods: A laboratory manual. New Delhi: IARI; 1983. p. 31–6.

35. Olsen SR, Sommers LE. Phosphorous. In: Page AL, editor. *Methods of soil analysis: Part 2, Chemical and microbiological properties*. 2nd ed. Madison: ASA, SSSA; 1982. p. 403–30.

36. Mackinney G. Absorption of light by chlorophyll solutions. *J Biol Chem*. 1941;140(2):315–22.

37. Maclachlan S, Zalik S. Plastid structure, chlorophyll concentration, and free amino acid composition of a chlorophyll mutant of barley. *Can J Bot*. 1963;41(7):1053–62.

38. Guenther E. *The EOs*. Vol. 1. New York: D. Van Nostrand Company; 1972.

39. Kant K, Gupta S, Kaur N, Jindal P, Ali A. Novel foliar approaches enhancing active constituents, flower yield and EO content in Damask rose (*Rosa damascena* Mill.): A review. *J Plant Nutr*. 2023;46(18):4532–58.

40. El-Beltagi HS, Gad M, Abdel-Haleem M, Shalaby TA, Rezk AA, Khedr EH. Triacontanol: A multifunctional growth regulator for enhancing stress tolerance. *J Crop Health*. 2025;77(2):1–20.

41. Kaur K, Gupta M, Rattanpal HS, Kaur A, Anand S, Singh M. Influence of exogenously applied growth regulators on mitigating fruit splitting and enhancing yield and quality in 'Daisy' mandarin in an arid irrigated region of the Punjab. *Appl Fruit Sci*. 2025;67(3):94.

42. Ali HMM, Perveen S. Effect of foliar applied triacontanol on wheat (*Triticum aestivum* L.) under arsenic stress: A study of changes in growth, yield and photosynthetic characteristics. *Physiol Mol Biol Plants*. 2020; 26:1215–24.

43. Perveen S, Iqbal M, Nawaz A, Parveen A, Mahmood S. Induction of drought tolerance in *Zea mays* L. by foliar application of triacontanol. *Pak J Bot*. 2016;48(3):907–15.

44. Naeem M, Khan MMA, Moinuddin, Idrees M, Aftab T. Triacontanol-mediated regulation of growth and other physiological attributes, active constituents and yield of *Mentha arvensis* L. *Plant Growth Regul*. 2011; 65:195–206.

45. Singh M, Khan MMA, Moinuddin, Naeem M. Augmentation of nutraceuticals, productivity and quality of ginger (*Zingiber officinale* Rosc.) through triacontanol application. *Plant Biosyst*. 2012;146(1):106–13.

46. Siddiqui MH, Al-Whaibi MH, Faisal M, Al Sahli AA. Nano-silicon dioxide mitigates the adverse effects of salt stress on *Cucurbita pepo* L. *Environ Toxicol Chem*. 2014;33(11):2429–37.

47. Othman AJ, Eliseeva LG, Ibragimova NA, Zelenkov VN, Latushkin VV, Nicheva DV. Dataset on the effect of foliar application of different concentrations of silicon dioxide and organosilicon compounds on the growth and biochemical contents of oak leaf lettuce (*Lactuca sativa* var. *crispa*) grown in phytotron conditions. *Data Brief*. 2021; 38:107328.

48. Janmohammadi M, Amanzadeh T, Sabaghnia N, Ion V. Effect of nano-silicon foliar application on safflower growth under organic and inorganic fertilizer regimes. *Bot Lith*. 2016;22(1):53–64.

49. Simko I, Zhao R, Peng H. Differential impact of SiO_2 foliar application on lettuce response to temperature, salinity, and drought stress. *Plants*. 2025;14(12):1845.

50. Parveen A, Siddiqui ZA. Impact of silicon dioxide nanoparticles on growth, photosynthetic pigments, proline, activities of defense enzymes and some bacterial and fungal pathogens of tomato. *Vegetos*. 2022;1–11.