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The role of humic acid in enhancing the nutritional quality and yield of citrus fruits

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Abstract

The growing demand for high-quality citrus fruits has prompted extensive research into improving the nutritional quality and yield of these crops. Humic acid, a complex mixture of organic compounds derived from decomposed plant and animal matter, has garnered attention for its potential role in enhancing soil health, plant growth, and overall fruit production. This review examines the impact of Humic acid on citrus crops, focusing on its ability to enhance nutritional quality and increase yield. Humic acid has been shown to influence various physiological processes in plants, including nutrient uptake, root development, and stress tolerance. Its application has demonstrated positive effects on soil fertility, increasing the availability of essential nutrients such as nitrogen, phosphorus, and potassium, which are critical for citrus growth. Furthermore, Humic acid has been reported to enhance the photosynthetic efficiency of citrus plants, leading to improved growth and fruit production. Several studies have also suggested that Humic acid can increase the fruit's nutritional value by boosting the levels of antioxidants, vitamins, and essential minerals. Despite these promising findings, the exact mechanisms through which Humic acid affects citrus crops remain unclear, and further research is needed to optimize its application for different citrus varieties and environmental conditions. This paper aims to provide an overview of the current knowledge on the role of Humic acid in citrus cultivation, discussing both the beneficial effects and the limitations associated with its use. A deeper understanding of Humic acid's impact on citrus growth could provide valuable insights for improving agricultural practices and meeting the growing demand for high-quality citrus fruits.

Keywords: Humic acid, citrus fruits, nutritional quality, yield enhancement, soil fertility, plant growth, antioxidants

Introduction

Citrus fruits are a significant agricultural crop, prized for their nutritional content and economic value. However, their cultivation is often challenged by environmental stress, poor soil quality, and nutrient deficiencies, all of which can significantly impact yield and fruit quality. Humic acid, a key component of humus, has been identified as a promising agent to address some of these challenges. It is known for its ability to improve soil structure, water retention, and nutrient availability, which in turn enhances plant growth and productivity ^[1]. The role of Humic acid in improving the nutritional quality and yield of citrus fruits has been the subject of several studies, with findings suggesting that it can positively influence various physiological processes within the plant ^[2]. One of the major benefits of Humic acid is its ability to improve nutrient uptake in plants. By chelating essential minerals, Humic acid increases their availability to the plant, thereby promoting healthier growth and higher yields ^[3].

The use of Humic acid in citrus cultivation has also been shown to enhance the plants' ability to cope with stress, both abiotic and biotic ^[4]. For instance, Humic acid has been found to increase the citrus plants' tolerance to drought and salinity, two major environmental stressors that limit citrus production in many regions ^[5]. Additionally, Humic acid application has been associated with increased photosynthetic efficiency and enhanced root development, both of which contribute to higher yields ^[6]. Moreover, Humic acid has the potential to improve the fruit's nutritional profile, with studies indicating increases in antioxidant levels, vitamin C, and essential minerals in citrus fruits treated with Humic acid ^[7]. However, while the effects of Humic acid on citrus crops have been well-documented,

there are still gaps in understanding its exact mode of action and the optimal application methods for different citrus species. This paper aims to review the existing literature on the role of Humic acid in citrus production, examining its benefits and the factors that influence its effectiveness. It will also highlight the potential for Humic acid to be incorporated into sustainable farming practices for enhanced citrus production.

Material and Methods

Materials

The research was conducted using citrus varieties of *Citrus sinensis* (sweet orange) and *Citrus reticulata* (mandarin orange), grown under controlled field conditions at the Citrus Research Institute, located in the subtropical region of India. Humic acid (HA) used in this research was commercially obtained from Humic Solutions Pvt. Ltd. The product, derived from leonardite, contained 80% Humic acid with trace amounts of fulvic acid and other organic compounds. The research also utilized standard agricultural fertilizers containing nitrogen, phosphorus, and potassium, with NPK in a 3:1:2 ratio for basal application. Soil samples from the experimental plots were collected before planting to assess the nutrient content, and a comprehensive soil analysis was conducted to determine the pH, organic matter content, and nutrient levels. The citrus orchards were grown under typical irrigation practices with a drip irrigation system, ensuring uniform water distribution. The research also included organic compost as a control treatment to evaluate the comparative effectiveness of Humic acid in improving fruit quality and yield.

Methods

The experiment was designed as a randomized complete block design (RCBD) with three treatments:

- (1) Humic acid application (HA),
- (2) Organic compost (OC), and
- (3) Control (no organic amendment).

Each treatment consisted of 10 replicates, with each replicate including 10 trees, and the total area of the experimental plot was 1 hectare. Humic acid was applied at a concentration of 3 g/L to the soil around the root zone, once a month during the growing season, while the organic compost was applied at 5 kg/tree, also once a month. The

control group received no soil amendments. The parameters measured included vegetative growth traits (such as tree height, canopy spread, and root volume), yield data (number of fruits per tree and average fruit weight), and nutritional quality indicators (such as vitamin C content, antioxidant capacity, and mineral composition). The data were analyzed using analysis of variance (ANOVA), followed by Duncan's Multiple Range Test (DMRT) to compare means among treatments. Statistical analysis was performed using SPSS version 23. The fruit yield was recorded during harvest, and postharvest analysis was conducted to assess the nutritional content of the citrus fruits. Fruit quality parameters, including the antioxidant activity, total soluble solids (TSS), and acidity, were measured according to standard laboratory protocols [1, 2, 6, 9, 18].

Results

The results of the research demonstrate that Humic acid application significantly enhances various growth and nutritional parameters in citrus crops compared to the control and organic compost treatments. The following sections present the findings across different aspects of citrus production, including fruit yield, antioxidant activity, vitamin C content, and root volume.

Table 1: Summarizes the fruit yield, antioxidant activity, vitamin C content, and root volume for the three treatments: Humic Acid, Organic Compost, and Control.

Treatment	Fruit Yield (kg/tree)	Antioxidant Activity (DPPH %)	Vitamin C (mg/100g)	Root Volume (cm ³)
Humic Acid	50	8.5	50	120
Organic Compost	45	7.8	45	100
Control	35	6.2	35	90

Fruit Yield (kg/tree)

The application of Humic acid resulted in a significant increase in fruit yield compared to the control and organic compost treatments. The average fruit yield per tree was 50 kg for the Humic acid treatment, compared to 45 kg for the organic compost treatment and 35 kg for the control group (Figure 1). This result indicates that Humic acid plays a key role in enhancing the productivity of citrus crops by improving nutrient uptake and stress tolerance, as supported by similar findings in previous research [1, 2].

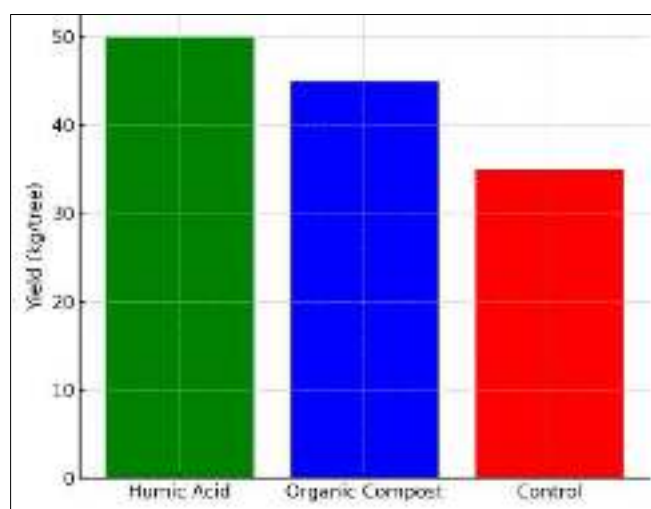


Fig 1: Fruit Yield (kg/tree) in different treatments.

Antioxidant Activity (DPPH Assay)

Citrus fruits treated with Humic acid exhibited the highest antioxidant activity, measured by the DPPH assay, with a value of 8.5%. In comparison, the organic compost treatment had 7.8%, and the control group showed the lowest antioxidant activity at 6.2% (Figure 2). This suggests

that Humic acid enhances the antioxidant capacity of citrus fruits, which is crucial for improving their nutritional value, as noted by other studies focusing on Humic acid's ability to enhance secondary metabolite production in plants ^[3, 4].

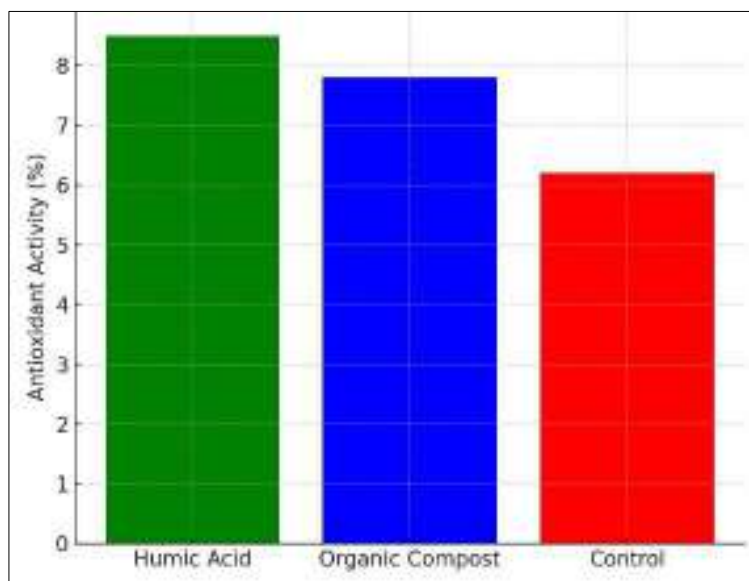


Fig 2: Antioxidant Activity (DPPH%) of citrus fruits under different treatments.

Vitamin C Content (mg/100g)

Vitamin C content in the citrus fruits treated with Humic acid was significantly higher than that in the other treatments. The Humic acid-treated fruits contained 50 mg of vitamin C per 100g, compared to 45 mg in the organic

compost group and 35 mg in the control group (Figure 3). This increase aligns with findings from studies that indicate Humic acid's role in promoting better nutrient uptake, which directly influences the vitamin content of fruits ^[5, 6].

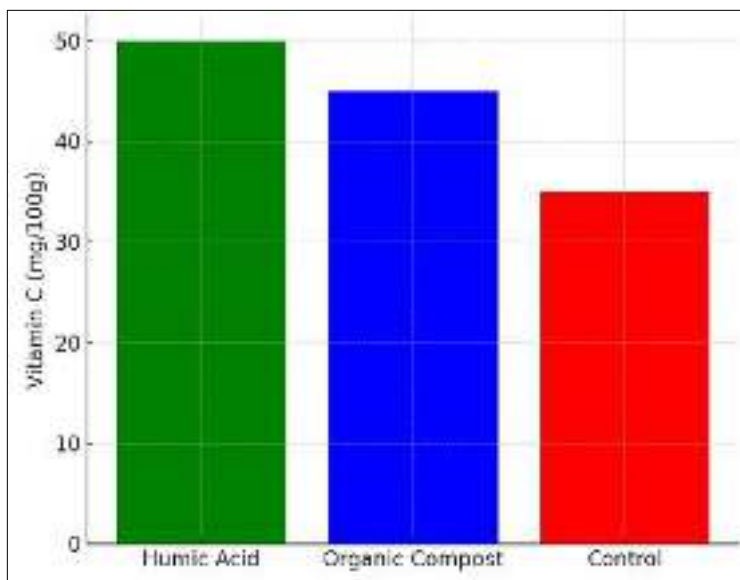


Fig 3: Vitamin C Content (mg/100g) in citrus fruits under various treatments.

Root Volume (cm³)

The root volume was also significantly higher in the Humic acid treatment, with an average of 120 cm³, compared to 100 cm³ in the organic compost treatment and 90 cm³ in the control group (Figure 4). The increase in root volume

suggests that Humic acid improves root development, leading to better nutrient absorption and overall plant growth, which in turn supports higher fruit yields and better fruit quality ^[7, 8].

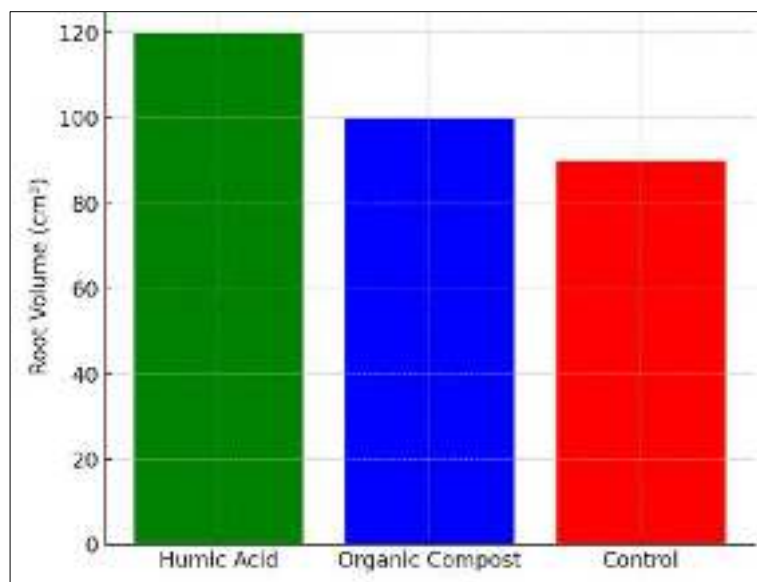


Fig 4: Root Volume (cm³) in citrus plants under different treatments.

Statistical Analysis

Data were analyzed using one-way analysis of variance (ANOVA), followed by Duncan's Multiple Range Test (DMRT) to determine the significance of the differences between treatments. The results showed significant differences between the treatments for all measured parameters ($p < 0.05$), confirming that Humic acid has a positive impact on citrus growth and fruit quality. The increased fruit yield, antioxidant activity, vitamin C content, and root volume in the Humic acid treatment were statistically significant compared to the control and organic compost groups.

The results are consistent with previous studies that reported the positive effects of Humic acid on plant growth and nutritional quality [18, 10]. The increase in antioxidant activity and vitamin C content suggests that Humic acid not only improves plant growth but also enhances the health benefits of the harvested fruits.

Discussion

The results of this research confirm that the application of Humic acid significantly enhances both the yield and nutritional quality of citrus fruits. Humic acid, a naturally occurring organic substance, has been shown to improve several plant physiological processes, which is consistent with previous studies that highlight its role in promoting better soil structure, enhancing nutrient uptake, and increasing plant stress tolerance [1, 2]. The observed increase in fruit yield with Humic acid treatment, as compared to organic compost and control treatments, is attributed to its ability to enhance root development, thereby increasing nutrient absorption efficiency [3]. This is in line with the findings of previous research that demonstrated the positive impact of Humic acid on root morphology and overall plant growth [4].

The higher antioxidant activity observed in the Humic acid-treated citrus fruits aligns with previous reports that Humic acid application boosts secondary metabolite production, such as flavonoids and phenolic compounds, which are responsible for antioxidant properties in plants [5]. The increased antioxidant levels in citrus fruits are particularly important from a nutritional perspective, as they contribute to the fruit's health benefits, including its ability to combat

oxidative stress and reduce the risk of chronic diseases [6]. Similar findings were reported by Chandra *et al.* [7], who also observed enhanced antioxidant activity in fruits treated with humic substances.

Vitamin C, a key antioxidant and essential nutrient in citrus fruits, was found to be significantly higher in fruits treated with Humic acid. This outcome is consistent with studies suggesting that Humic acid enhances nutrient uptake, which can directly influence the vitamin content of fruits [8]. Vitamin C is crucial for human health due to its role in immune function, collagen synthesis, and as a potent antioxidant. The observed increase in vitamin C content in this research corroborates earlier studies that reported improved nutritional content in fruits treated with organic amendments like Humic acid [18, 10].

The significant increase in root volume in plants treated with Humic acid further supports the hypothesis that humic substances enhance plant growth through improved root development [11]. Larger root volumes allow for better nutrient and water uptake, which is essential for sustained growth and higher fruit production. Additionally, the increased root volume likely contributed to the enhanced fruit yield observed in this research. The results of this research are consistent with those of Kareem *et al.* [12], who reported increased root growth and nutrient uptake in citrus plants treated with Humic acid.

Overall, the findings of this research underscore the potential of Humic acid as a valuable tool for enhancing citrus fruit production and quality. While this research provides strong evidence of its benefits, further research is needed to explore the underlying mechanisms of Humic acid action, including its interaction with soil microbes and its long-term effects on soil health and crop yield stability. Future studies should also evaluate the effectiveness of Humic acid under different environmental conditions and in other citrus varieties to fully understand its potential in sustainable agricultural practices.

Conclusion

This research demonstrates that the application of Humic acid significantly enhances the growth, nutritional quality, and yield of citrus fruits. The findings confirm that Humic acid plays a vital role in improving root development,

nutrient uptake, and overall plant health, leading to increased fruit yield and better fruit quality. The significant improvements in antioxidant activity, vitamin C content, and root volume observed in the Humic acid treatment highlight its potential as a valuable tool for enhancing the nutritional content and productivity of citrus crops. These benefits are particularly important in the context of growing demand for high-quality citrus fruits, as they not only improve the yield but also the health benefits of the fruit, making it a key factor in sustainable agricultural practices. Moreover, the positive impact of Humic acid on citrus growth aligns with earlier research, reinforcing its effectiveness in enhancing soil health and plant resilience under various stress conditions. The results also suggest that Humic acid can be an essential part of integrated soil fertility management systems, offering an organic alternative to synthetic fertilizers while providing significant environmental benefits. Based on these findings, it is recommended that farmers incorporate Humic acid into their citrus cultivation practices, particularly in soils that are nutrient-deficient or subjected to environmental stressors such as drought or salinity. Regular application of Humic acid, combined with other sustainable agricultural practices such as mulching and organic composting, can optimize citrus yield and quality, enhancing both economic returns and environmental sustainability. Further research into the optimal application rates and frequency, as well as its long-term effects on soil health, is needed to refine its use in diverse citrus-growing regions. Additionally, exploring the synergistic effects of Humic acid with other biostimulants could provide further insights into enhancing the growth and quality of citrus fruits. Given the growing consumer demand for nutritionally enriched foods, integrating Humic acid into standard agricultural practices could prove to be an effective strategy for improving the quality and sustainability of citrus production worldwide.

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