# Synergistic Effects of Rice Husk Pre-Treatment Forms and NPK Fertilizer Rates on Nutrient Uptake, Bioactive Compounds, and Physicochemical Quality of Tomato (*Solanum lycopersicum* L.)

*Nurhidayati* Nurhidayati[1,3], *Masyhuri* Masyhuri[2], *Sunawan* Sunawan[1], *Muchamad Haris* Abdillah[1], and *Puji Rahayu* Lestari[1]

[1] Department of Agrotechnology, Faculty of Agriculture, Universitas Islam Malang, Malang 65144, Indonesia
[2] Department of Agribusiness, Faculty of Agriculture, Universitas Islam Malang, Malang 65144, Indonesia
[3] Center for Food Security Studies, Universitas Islam Malang

**Abstract.** This study aimed to evaluate the effects of rice husk pre-treatment forms combined with different NPK fertilizer rates on nutrient uptake and fruit quality parameters of tomato (*Solanum lycopersicum* L.) under pot conditions in a greenhouse. The experiment was arranged in a factorial randomized block design with two factors: (T) rice husk pre-treatment forms (powder and compost), and (D) NPK fertilizer rates (0%, 25%, 50%, 75%, and 100% of the recommended dose). Each treatment combination was replicated three times, with three plants per replication. Data collected included N, P, and K uptake, vitamin C content, total flavonoids, β-carotene, antioxidant Activity (IC-50), total soluble solids, firmness and fruit dry weight. Results indicated significant interaction effects between rice husk pre-treatment forms and NPK rates on nutrient uptake and fruit quality parameters. The combination of rice husk compost with 75% NPK showed the highest nutrient uptake. The combination of rice husk powder with 75% NPK improved bioactive compound levels and antioxidant activity. The combination of rice husk powder with 50% NPK improved the dry weight and firmness of the fruit. These findings highlight the potential for integrating organic pre-treatments with optimized fertilizer use to enhance tomato quality while reducing chemical inputs.

**Keywords**: rice husk powder, rice husk compost, NPK uptake, tomato quality, bioactive

[1] Corresponding author: nurhidayati@unisma.ac.id

# 1 Introduction

The tomato (Solanum lycopersicum L.), which is consumed both fresh and processed, is one of the most significant horticultural crops in the world and a high-value commodity with the highest cultivated area of any vegetable. Recent estimates indicated that approximately 4.85 million hectares are used to raise over 182.3 million tons of tomato fruits annually [1]. It is valued not only for its economic significance but also for its high content of nutritional and bioactive compounds, including vitamin C, flavonoids, and β-carotene, which contribute to its antioxidant capacity [2].

To support the growth and yield of tomato plants, high nutrient inputs are required; therefore, tomato plants are considered a fertiliser-intensive crop [3]. However, the long-term application of chemical fertilizers in high doses has a negative impact on soil and plant fertility and health [4]. Research has shown that incorporating organic fertilizer into vegetable cultivation enhances plant quality compared to using only inorganic fertilizer [5].

Various types of organic waste can be utilized as soil amendments to enhance soil fertility and promote plant growth. One type of organic waste often used as a soil amendment in greenhouse potting systems is rice husk. Rice husk is a nutrient-rich but underutilized byproduct of rice milling, which is sometimes pyrolyzed as biochar or incinerated to produce rice husk ash [6]. Generally, unprocessed rice husk is used as a growing medium for soilless culture for vegetables and ornamental plants [7]. Little is known about processing rice husks into powder and compost. Therefore, this research has developed an additional pretreatment method for rice husks.

Rice husks contain high levels of $SiO_2$ by 93.4% wt. Although Si is not an essential nutrient, it plays a crucial role in plant metabolism. Therefore, Si is known as a functional nutrient. Silicon application has been known to enhance the plant tolerance against several biotic and abiotic stresses [8]. The application of silicon (Si) to plants can overcome the problem of potassium (K) deficiency in plants, increase the K content in plant roots, and enhance the efficiency of carbon (C) and phosphorus (P) use in shoots [9].

Maintaining high yield and superior fruit quality in tomato production requires adequate and balanced nutrient management, particularly nitrogen (N), phosphorus (P), and potassium (K), which are essential for plant growth, fruit development, and metabolite synthesis. Nutrient deficiencies have a direct impact on tomato yield and quality [10]. The integration of organic amendments and inorganic fertilizers is a sustainable approach to enhance soil fertility, nutrient uptake, and fruit quality. Organic fertilizers enhance the soil's chemistry, structure, and biological activity. They increase the amount of organic matter in the soil and are renowned for their slow-release of nutrients [7]. The interaction between rice husk pre-treatment forms and NPK fertilizer rates on tomato nutrient uptake and quality has not been extensively studied. This research aimed to determine the synergistic effects of rice husk powder and compost, combined with varying NPK fertilizer rates, on nutrient uptake and fruit quality parameters of tomato grown under controlled conditions.

# 2 Materials and Methods

## 2.1 Experimental Site and Design

This research was a pot experiment conducted in a plastic house in Sidomulyo Village, Jabung, Malang Regency, from December 2024 to May 2025 with a geographical location of 7°95'68" South Latitude and 112°75'49" East Longitude with an altitude of 550 meters above sea level and an average temperature ranging between 22-26°C, with air humidity between 70-90%. Composting was conducted in a field laboratory at the exact location, while leaves and tomato fruits analysis were conducted in the Integrated Laboratory of Universitas Islam Malang.

A factorial randomized block design (RBD) was used with two factors: Factor I, rice husk pre-treatment forms (T1 = powder, T2 = compost). Factor II: NPK fertilizer rates (D0 = 0%, D1 = 25%, D2 = 50%, D3 = 75%, D4 = 100% of the recommended dose). This resulted in 10 treatment combinations, replicated three times, with three plants per replicate. There were 90 pots in total.

## 2.2 Crop Management

The growing medium used in this experiment consisted of a mixture of 10 kg of sandy soil and 400 g of conventional compost per pot. Rice husk compost was made from a mixture of rice husks, cow dung, and *Tithonia diversifolia* leaves in a ratio of 10:4:1. These materials were composted using a decomposer for two weeks. Rice husk powder was produced by grinding dry rice husks using a grinding machine and a blade mill until it was reduced to a fine powder. The results of the laboratory analysis of the C-Organic, N, P and K content of the rice husk pre-treatment are presented in Table 1.

**Table 1**. The results of laboratory analysis for parameters pH, C-organic content, N, P, and K of rice husk pre-treatment.

| Pre-treatment of Rice Husk | pH H2O | % C-Organic | % N | C/N | % organic matter | $P_2O_5$ % | $K_2O$ % |
|---|---|---|---|---|---|---|---|
| Rice husk powder | 7.90 | 22.72 | 2.23 | 10.19 | 39.08 | 2.64 | 2.43 |
| Rice husk compost | 8.19 | 27.92 | 2.39 | 11.68 | 48.02 | 3.38 | 2.24 |

A total of 125 g of husk powder for T1 treatments and 375 g of rice husk compost for T2 treatments were weighed and mixed with growing media according to the first factor treatments. The application of this soil amendment was carried out two days before planting. Tomato seedlings (variety Servo F1) were transplanted into the pots. NPK fertilizers were applied according to the treatment dose. The recommended dose (100%) for tomato cultivation in pots is 25 g per pot, divided into four applications, namely at 7, 21, 35, and 49 days after transplanting (DAT). Plants were watered regularly and managed for pests and diseases as needed. Harvesting of tomato fruits was started at 62 until 80 DAT.

## 2.3 Data Collection

Parameters measured included nutrient uptake, namely N, P, and K concentrations in plant tissue (mg plant$^{-1}$). The nitrogen (N) content in the leaves of these crops was measured using a modified Kjeldahl's method. The P and K were determined by the wet combustion method using a HNO3+HClO4 solvent, with K content measured by a Flame photometer and P content measured by a UV spectrophotometer [11]. All measurements of nutrient content in leaves were carried out 55 days after transplanting (DAT). The parameters of Bioactive compounds concentration included vitamin C (mg 100 g$^{-1}$ FW), total flavonoids (mg EQ 100 g$^{-1}$ FW), β-carotene (µg g$^{-1}$ FW), and antioxidant activity IC-50 (mg L$^{-1}$). Vitamin C content was measured using the Iodometric titration method. Total flavonoid content was measured using a Shimadzu UV-1900i spectrophotometer, while beta carotene content was measured using a Shimadzu SPD-40 HPLC. Antioxidant activity was measured using the DPPH (2,2-diphenyl-1-picrylhydrazyl) method [12]. The parameters of physicochemical quality included Firmness (kg $cm^{-1}$), measured using a fruit penetrometer; total soluble solids (°Brix), measured using a refractometer; and fruit dry weight (g), determined by oven-drying at 70 °C for 2 × 24 hours until a constant weight was achieved.

### 2.4 Data Analysis

The data collected was statistically analyzed for variance (F-test) at the 5% level. If the analysis results have a significant effect, proceed with the 5% Tukey test to determine the differences between treatments using Minitab Version 14.12. Microsoft Excel was employed to present the charts.

## 3 Results and Discussion

### 3.1 Overview and ANOVA summary

Two-way ANOVA on the collected dataset indicated that both rice husk pre-treatment form (Powder vs Compost) and NPK fertilizer rate (0, 25, 50, 75, 100% recommended) had significant interaction effects ($p < 0.05$) on most measured variables (N, P, K uptake; vitamin C; flavonoids; β-carotene; antioxidant activity; Total Soluble Solid). It indicated synergistic responses for particular treatment combinations (Table 2).

**Table 2.** Summary of analysis of variance (ANOVA) for nutrient uptake and fruit quality parameters of tomato.

| Variable | Rice Husk Form (T) | NPK Dose (D) | T x D Interaction |
|---|---|---|---|
| N uptake | **p < 0.01** | **p < 0.01** | **p < 0.01** |
| P uptake | **p < 0.01** | **p < 0.01** | **p < 0.01** |
| K uptake | **p < 0.01** | **p < 0.01** | **p < 0.01** |
| Vitamin C | **ns** | **p < 0.01** | **p < 0.01** |
| Flavonoid | **p < 0.05** | **p < 0.01** | **p < 0.01** |
| β-carotene | **p < 0.01** | **p < 0.01** | **p < 0.01** |
| Antioxidant activity (IC-50) | **p < 0.01** | **p < 0.01** | **p < 0.01** |
| TSS (°Brix) | **p < 0.01** | **p < 0.01** | **p < 0.01** |
| Dry weight | **p < 0.05** | **p < 0.01** | **P<0.01** |

Remark : ns = not significant; **p < 0.05** = significant; **p < 0.01** = highly significant.

### 3.2 Nutrient uptake (N, P, K)

Based on the results of the Tukey test ($P < 0.05$) of the mean values from the collected data, significant differences were found among treatments. Compost treatments had higher N uptake than the powder at both the 0% and 25% NPK rates. At NPK rates of 50%, 75% and 100%, N uptake in powder and compost treatments was not significantly different. The highest simulated mean N uptake was observed in Compost + 75% NPK rates (9.74 g $plant^{-1}$), followed closely by powder + 100% NPK and Compost + 100% NPK rates (8.92–9.02 g $plant^{-1}$). Powder treatments showed lower uptake values at 0% and 25% NPK rates, with powder + 0% NPK rates being the lowest (3.16 g $plant^{-1}$) (Fig. 1A).

P uptake increased with increasing NPK rate until 75% of the NPK dose was applied. Compost increased P uptake modestly relative to powder at 0-75% of NPK rate. Peak P uptake occurred at 75% NPK rates with compost. However, at a 100% NPK rate, P uptake decreased in the compost pre-treatment (Fig. 1B). K uptake followed the trends of N and P uptake. The highest K uptake occurred under Compost + 75% NPK (8.56 g $plant^{-1}$). Powder treatments yielded peak K uptake at 50% NPK rates (7.20 g $plant^{-1}$). A significantly lower K uptake occurred at 75% of the NPK rates. The nutrient uptake (NPK) was maximized in compost treatments at 75% NPK rates, with diminishing incremental gain at 100% compared to 75% NPK rates. Meanwhile, in powder treatments, total nutrient uptake (NPK) was maximized at 50% NPK rates, decreased at 75% of NPK rates and increased again at 100% NPK rates (Fig. 1C). These results indicate that the addition of soil amendments, either rice husk powder or rice husk compost, increases nutrient uptake efficiency, reducing NPK fertilizer use by 25-50%. These findings align with those reported by [13], which indicate that the addition of organic soil amendments can increase nutrient use efficiency in tomato cultivation.

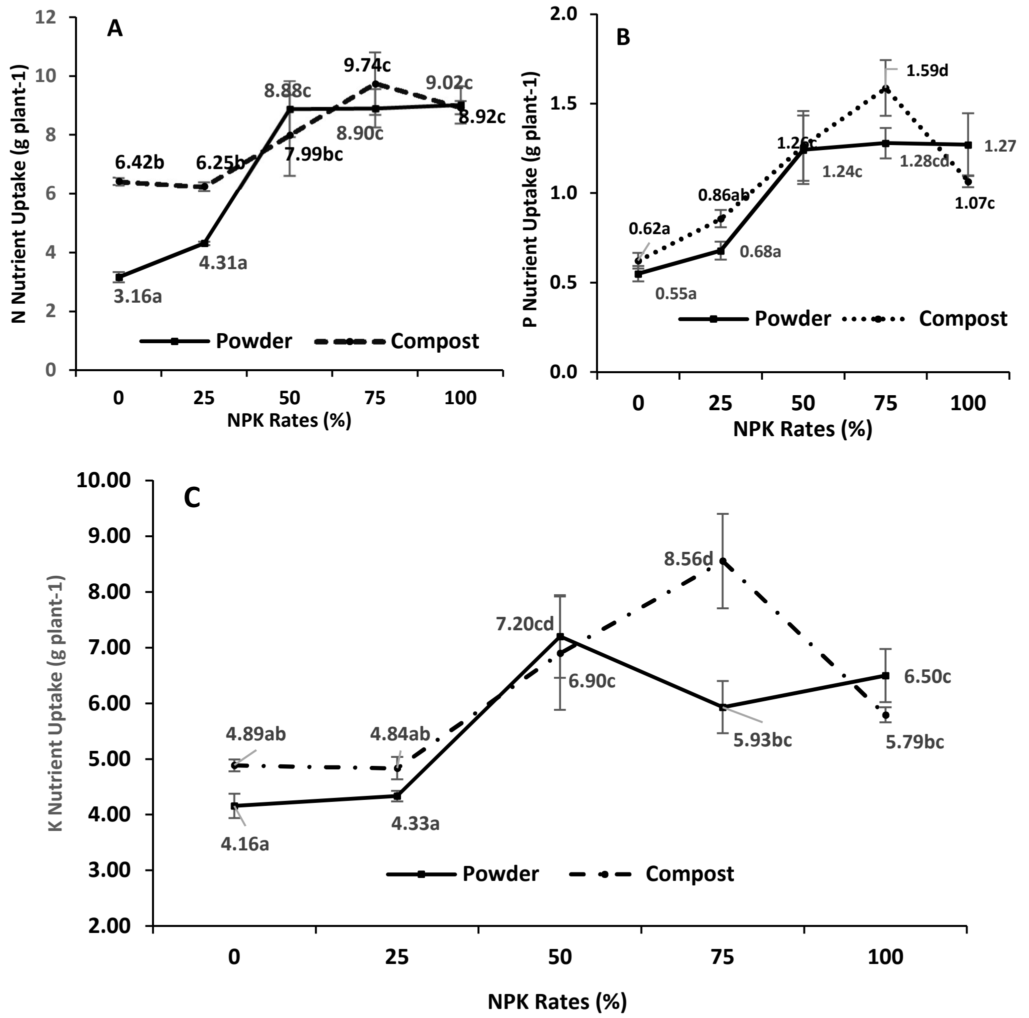


**Fig. 1**. NPK Nutrient Uptake due to the interaction effect between powder and compost treatments and NPK dose.

### 3.3 Fruit quality: bioactive compounds and physicochemical attributes

Based on the results of the Tukey test ($P < 0.05$), it was found that the vitamin C content of tomato fruits peaked at moderate NPK rates, specifically 50% under compost treatment and 75% under powder treatment. Compost treatment tended to yield slightly lower vitamin C levels than powder under more than 50% of NPK rates, but the combination of powder and 75% NPK rates also showed relatively high vitamin C levels, indicating parameter-specific responses (Table 1).

Flavonoid content of tomato fruits increased with NPK rates from 0-75% for powder treatment and 0-100% for compost treatment. The powder treatments had higher flavonoid levels by mean flavonoid concentration by 26.27–27.54 mg QE/100 g compared to 24.82-25.57 µg/100 g FW for compost treatment (Table 3).

**Table 3.** Mean Vitamin C, Flavonoids, and β-carotene content of tomato fruits due to the interaction effect between powder and compost treatments and NPK dose.

| Pre-treatment | NPK rate (%) | Vitamin C (mg/100g FW) | Flavonoids (mg QE/100g FW) | β-carotene (µg/100g FW) |
|---|---|---|---|---|
| Powder | 0 | 31.68 ab | 22.09 a | 0.27 ab |
| | 25 | 28.39 a | 22.42 a | 0.29 b |
| | 50 | 28.09 a | 23.41 b | 0.35 c |
| | 75 | 36.30 bc | 27.54 e | 0.43 d |
| | 100 | 32.33 ab | 26.27 de | 0.39 cd |
| Compost | 0 | 33.65 abc | 21.06 a | 0.23 a |
| | 25 | 28.93 a | 24.20 bc | 0.25 ab |
| | 50 | 40.03 c | 24.04 b | 0.29 b |
| | 75 | 27.99 a | 24.82 bcd | 0.37 c |
| | 100 | 27.57 a | 25.57 cd | 0.43 d |
| HSD 5% | | 6.85 | 1.52 | 0.04 |

Remark: Means followed by different letters in the same column are statistically significantly different at HSD test, p = 0.05.

β-carotene content followed a similar pattern to vitamin C and flavonoid for powder treatment, where the highest is at a rate of 75% NPK by 0.43 (µg/100g FW). For compost treatment, β-carotene content followed a similar pattern to flavonoids, with the highest value at a rate of 100% NPK, at 0.43 µg/100g FW (Table 1). The results showed the highest accumulation in treatments receiving powdered rice husk under each NPK rate. This suggests that nutrient availability and an improved root environment promote the synthesis of secondary metabolites.

In this study, antioxidant activity was measured using the IC-50, which represents the half-maximal inhibitory concentration, a measure of the potency of a substance in inhibiting a specific biological or biochemical function. Specifically, it represents the concentration of a substance that is required to inhibit a specific biological process by 50%. This means that the lower the IC-50 value, the higher the antioxidant activity. Based on the average IC-50 value and the Tukey test ($P < 0.05$) results, the powder and 0% NPK and 75% NPK treatments exhibited the highest antioxidant activity. Antioxidant capacity increased with the application of rice husk pre-treatments, regardless of NPK rates (0%) or low NPK rates (25%), indicating a negative correlation with NPK rates (Table 4).

Total Soluble Solids increased with NPK up to 50% on the powder treatments, but on the compost treatments, the highest total soluble solids were found in the 25% NPK dose. The TSS was higher in powder than compost. This means that the NPK fertilizer dosage plays a significant role in determining the TSS of tomatoes. Too high a dosage of NPK fertilizer will reduce the TSS of tomatoes (Table 4).

**Table 4**. Mean antioxidant activity (IC-50), Total Soluble Solid, and Firmness of tomato fruits due to interaction effect between powder and compost treatments and NPK dose.

| Pre-treatment | NPK Dose (%) | IC-50 (mg $L^{-1}$) | | Total Soluble Solid (°Brix) | | Firmness (kg $cm^{-2}$) | |
|---|---|---|---|---|---|---|---|
| Powder | 0 | 6.30 | a | 1.93 | b | 12.57 | b |
| | 25 | 14.77 | b | 2.17 | bc | 14.63 | cd |
| | 50 | 21.34 | bc | 2.37 | bcd | 16.37 | d |
| | 75 | 9.63 | ab | 4.10 | e | 14.53 | c |
| | 100 | 41.35 | d | 3.80 | e | 14.13 | bc |
| Compost | 0 | 19.21 | bc | 1.07 | a | 10.67 | a |
| | 25 | 25.20 | c | 2.83 | d | 15.07 | cd |
| | 50 | 37.03 | d | 2.43 | cd | 13.80 | bc |
| | 75 | 38.88 | d | 2.27 | bc | 13.70 | bc |
| | 100 | 51.35 | e | 2.33 | bc | 13.90 | bc |
| HSD 5% | | 8.30 | | 0.50 | | 1.87 | |

Remark: Means followed by different letters in the same column are statistically significantly different at HSD test, p = 0.05.

Firmness of tomato fruits increased with NPK up to 75%-100% on the powder treatments, but on the compost treatments, the highest firmness was found in the 25% of NPK dose. The TSS was higher in the powder than in the compost. The addition of NPK fertilizer, resulting in a more than 50% reduction in the NPK rate, decreased the firmness of tomato fruit (Table 4).

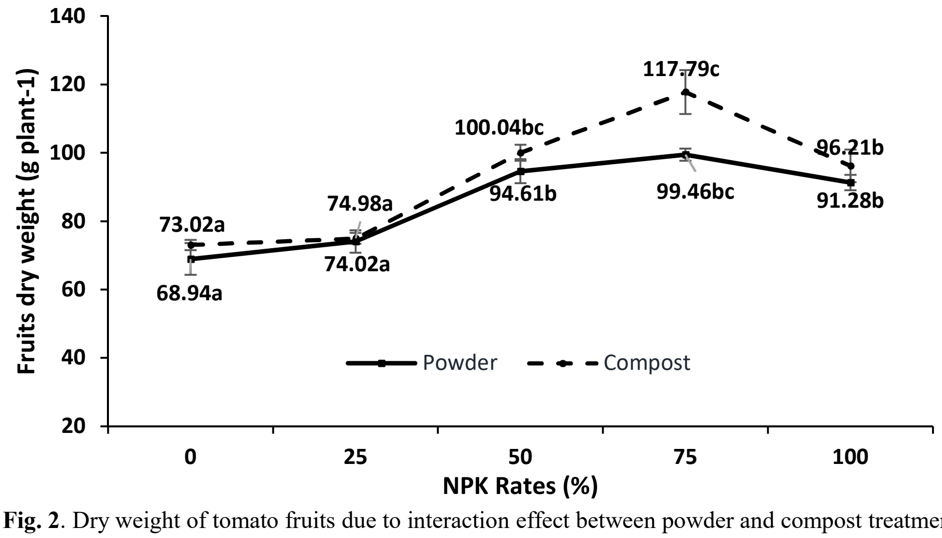


**Fig. 2**. Dry weight of tomato fruits due to interaction effect between powder and compost treatments and NPK dose.

The dry weight of tomato fruit in the compost treatment was higher than the powder treatment, and the 75% of NPK dose gave a high dry weight of tomato fruits, but it was not significantly different from the compost and 50% NPK fertilizer dose and powder and 75% of NPK dose (Fig.2).

The research results are consistent with the general expectation that the addition of organic amendments can improve the soil fertility of the planting medium, particularly in terms of increasing the soil organic C content, soil pH, soil CEC, and microbial activity [14]. Soil ameliorant from composted rice husk improves the properties of growing media substrates, such as organic matter content, cation exchange capacity, and microbial activity, relative to rice husk powder. Compost enhanced N, P, and K uptake likely occurs by (i) supplying mineralized nutrients during decomposition, (ii) improving root growth and root-zone moisture retention, and (iii) stimulating beneficial microbial processes that mobilize nutrients. Enhanced nutrient uptake translated into greater dry weight [15].

In terms of tomato fruit quality, the application of rice husk powder yielded better fruit quality compared to compost, as indicated by beta-carotene, flavonoid, IC-50, TSS, and firmness. This is likely due to the silicon content in rice husk, which can stimulate the formation of secondary metabolites in plants. Silicon (Si) possesses multiple strategies to adjust morpho-anatomical and physio-biochemical processes in plants to counteract stressful factors [8]. Thus, the addition of organic soil amendments enhances the efficiency of fertilizer use and improves the quality of crop yields.

## 4. Conclusion

This study demonstrated that the interaction between rice husk pre-treatment forms and NPK fertilizer rates significantly influenced the nutrient uptake and fruit quality of tomatoes (*Solanum lycopersicum* L.). Rice husk powder and compost both improved plant nutrient uptake; however, the powder form generally showed slightly higher efficiency in enhancing N, P, and K uptake. Moderate to high NPK applications (50–75% of the recommended dose) combined with rice husk amendments maximized nutrient uptake and improved fruit bioactive compounds, including vitamin C, flavonoids, and β-carotene. Physicochemical quality attributes, such as firmness, antioxidant activity, total soluble solids, and fruit dry weight, also responded positively to the integration of rice husk pre-treatment and NPK fertilization. Notably, antioxidant activity and total soluble solids peaked at high NPK levels, whereas firmness peaked at low NPK levels under both powder and compost treatments. Overall, the findings suggest that combining rice husk pre-treatments with reduced rates of NPK fertilizer can enhance tomato fruit quality while reducing chemical input requirements. This integrated strategy offers a sustainable approach to tomato cultivation, balancing crop productivity, fruit nutritional quality, and resource efficiency.

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