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Effect of Rice Husk Biochar and Potassium Humate on the Change of Soil Chemical Properties, Yield and Quality of Cherry Tomato (*Lycopersicon esculentum* Mill.)

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ABSTRACT

Background: This study aimed to evaluate the effects of potassium humate and rice husk biochar on cherry tomatoes' key soil chemical properties, yield and quality parameters.

Methods: The experiment was conducted in the Can Tho University Department of Soil Science's greenhouse. Experimental soil is alluvial soil collected in Tra On, Vinh Long. Two seasons (Summer-Autumn 2020 and Autumn-Winter 2020) were used for the experiment. The experiment design was completely randomized (CRD), with two factors: 9 treatments (corresponding to 9 fertilizer formulas), 4 replications and 4 plants each. Factor A (F_A) is 3 levels of biochar rice husk application: 0 tons/ha (B0), 2.5 tons/ha (B_1) and 5 tons/ha (B_2). Factor B (F_B) is 3 levels of potassium humate: 0 kg/ha (K_0), 50 kg/ha (K_1) and 100 kg/ha (K_2). The experiment was conducted in a greenhouse at the Department of Soil Science, Can Tho University, using alluvial soil collected from Tra On, Vinh Long. The study spanned two growing seasons (Summer-Autumn 2020 and Autumn-Winter 2020). A completely randomized design (CRD) was employed with two factors and four replications. Factor A comprised three levels of rice husk biochar application: 0 tons/ha (B_0), 2.5 tons/ha (B_1) and 5 tons/ha (B_2). Factor B consisted of three levels of potassium humate: 0 kg/ha (K_0), 50 kg/ha (K_1) and 100 kg/ha (K_2), resulting in nine treatment combinations. Each replication contained four plants.

Result: The experimental results showed that adding rice husk biochar and potassium humate improved soil P. Compared to the control (no biochar, no potassium humate), they significantly and statistically enhanced the amount of accessible nutrients (N, P and K) in the soil. The number of fruits/plants, fruit diameter, fruit yield and percentage of Brix all significantly increased when cherry tomatoes were continuously monitored for growth, yield and quality during both growing seasons while being treated with biochar husk and potassium humate. These results were statistically different from those of the control. The analysis of nitrate in tomato fruit showed that the nitrate of fruit was 23.45-24.94 (mg NO_3^-/kg fresh fruit), not exceeding the allowable threshold of 150 (mg NO_3^-/kg fresh fruit) and applying rice husk biochar and potassium humate significantly improved soil chemical properties compared to the control treatment. Notably, the soil's availability of essential nutrients (N, P and K) was enhanced. Treatments with biochar and potassium humate throughout both growing seasons resulted in statistically significant improvements in various plant parameters, including fruit number per plant, diameter, total yield and Brix content compared to the control. Fruit nitrate content ranged from 23.45 to 24.94 mg NO_3^-/kg fresh weight, remaining well below the regulatory threshold of 150 mg NO_3^-/kg fresh weight.

Key words: Cherry tomato, Potassium humate, Rice husk biochar.

INTRODUCTION

Fertilizers are essential inputs for enhancing yield, product quality and cultivation efficiency in vegetable production, particularly for tomato plants. Biochar, resulting from the thermochemical conversion of organic matter in oxygen-limited conditions (Adekiya *et al.,* 2020; Lehmann and Joseph, 2009), along with potassium humate and appropriate fertilizer selection, can significantly improve soil fertility and plant productivity. According to Adekiya *et al*. (2020) and Rillig (2009), biochar incorporation enhances various soil properties, including pH, water retention, organic matter content, cation exchange capacity and microbial populations. Furthermore, biochar significantly can adsorb various nutrients, including NH_4^+, NH_3, nitrate and phosphorus, effectively reducing nutrient leaching from soil (Adekiya *et al.,* 2020; Yin and Xu, 2009).

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Potassium humate, a biological substance utilized as a fertilizer, has been shown to enhance soil biological, chemical and physical properties while improving nutrient retention (Izhar Shafi *et al.,* 2020). In rice cultivation, Kumar et al. (2013) reported that applying 100% recommended NPK combined with 10 mg/kg potassium humate significantly increased growth, development and yield compared to treatments without potassium humate supplementation, findings later corroborated by Nassar *et al.* (2021).

Biochar has recently been proposed as a management strategy to improve crop productivity and mitigate global warming. Biochar may be added to soils with the goal to improve the soil properties (Ramamoorthy *et al.,* 2022). Besides, Adusu *et al.* (2020) concluded that biochar can improve the nutrient status of both stockpiled topsoil and degraded mined soil. Its use also enhances plant diversity and improves stockpiled and degraded soils. However, limited information is available regarding the combined use of rice husk biochar and potassium humate in tomato cultivation. Therefore, this study investigated the effects of various potassium humate and biochar application rates on soil chemical properties, cherry tomato development and yield.

MATERIALS AND METHODS

Materials varieties

The tomato variety used in the experiment is the F_1 Rado 27 hybrid red cherry tomato produced by Rang Dong Seed One Member Company Limited.

Experimental pot

Experiment using cylindrical terracotta pots (20 cm × 40 cm × 20 cm).

Fertilizers

The experiment utilized three primary fertilizers: Urea (46% N), diammonium phosphate (DAP; 18% N, 46% P_2O_5) and potassium chloride (60% K_2O). The potassium humate used in the study contained 80% humate, 16% K_2O and 10% moisture. Rice husk biochar was characterized by 24% total carbon content and contained various nutrients, including 0.86% N, 1.358% P_2O_5, 1.5% K_2O, 0.021% Mg, 0.019% Cu and 0.018% Zn.

Experimental soil

The experimental soil, classified as Gleyic Fluvisols (Alluvial soil group), was collected from vegetable cultivation fields in Thien My commune, Tra On district, Vinh Long province (9°57′12.9″N 105°55′57.6″E). Soil samples were obtained from the cultivation layer at 0-20 cm depth (Fig 1). According to the USDA texture triangle, the soil exhibited a clay-silty texture, comprising 1.36% sand, 53.54% silt and 45.10% clay. Chemical analysis revealed slightly acidic conditions (pH_{H2O} = 5.63), low organic carbon content (2.67% C), low total nitrogen (0.17% N)and high total phosphorus (0.15% P_2O_5).

Research location and time

The experiment was conducted at Can Tho University's net house, Vietnam, over two seasons in 2020-2021. Season 1 (Summer-Autumn 2020) ran from March 15 to July 20, 2020, while Season 2 (Autumn-Winter 2020) extended from September 15, 2020, to January 25, 2021. In both seasons, 14-day-old seedlings were transplanted two weeks after sowing.

Soil preparation

After the soil is collected, it is returned to the laboratory and dried in the air. After the soil is dry, pound it into small pieces and mix well. A small amount of soil sample (about 5 kg) was collected and pulverized through 0.5 mm and 2 mm sieves to determine pre-experiment soil parameters such as pH_{H20}, % C, total N, total P and soil texture. The remaining was used for the experimental setup. Each pot of experimental soil contains 10 kg (mass of dry soil).

Experimental layout

The experiment had two factors

Four replicates with four plants each, 9 treatments (9 fertilizer formulas) and a completely randomized design (CRD).

+ Factor A (F_A) is 3 levels of biochar rice husk application: 0 tons/ha (B_0), 2.5 tons/ha (B_1) and 5 tons/ha (B_2).

+ Factor B (F_B) is 3 levels of potassium humate: 0 kg/ha (K_0), 50 kg/ha (K_1) and 100 kg/ha (K_2). The fertilizer combinations applied to NPK fertilizers, as recommended by Ddamulira *et al.* (2019) is 200 N-150 P_2O_5-200 K_2O kg/ha. Rice husk biochar is entirely applied before sowing and the fertilizer used depends on each treatment. Potassium humate was applied twice at 20 DAS and 40 DAS, each at 50%.

Method of crop sowing and care

Tomato seeds were sown in nursery pots made from banana leaves, using rice husk ash as the substrate. After 30 days, seedlings with 2-3 leaves and a height of 12-15 height were transplanted at a density of 25,000 plants per hectare, with 100 cm between rows and 40 cm between plants (from the center of the pot), one plant per pot (Fig 1).

Plant care was conducted in accordance with Vietnamese Standards (QCVN 01-63: MARD, 2011). Selected plants were healthy and non-malformed, exhibiting white roots, well-developed tops and no signs of infection.

Collection and monitoring indicators

Soil sampling

When the tomato crop was harvested at the end of the season, soil samples were taken. Soils were collected by hand drill (0-20 cm), 4 points on each pot at each treatment and each replicate. Samples were collected, dried at room temperature and then powdered through a 0.5 mm filter to determine the soil's pH, EC, exchangeable K, available N and P.

Collecting agronomic indicators

Crop growing criteria

Plant height and stem diameter were recorded 30 days after snowing, 60 DAS and 90 DAS.

Yield and factors affecting yield

At each sampling period, fruit yield (kg/plant), fruit number per plant and diameter (cm) were recorded.

Indicators related to fruit quality

% Brix and nitrate content in fruit were measured at the time of complete harvest.

Methods of soil sample analysis and evaluation of criteria related to growth, yield and quality of cherry tomato plants
Methods of evaluating agronomic and yield parameters

Crop growth criteria

A graduated ruler and an electronic caliper measure crop height and stem diameter.

Criteria for evaluating fruit quality

% Brix measured by a hand refractometer, measures 10 fruits/plant of equivalent ripeness. The nitrate content in the fruit was analyzed by colorimetric method at 410 nm with phenolsulfonic acid reagent in the alkaline environment according to TCVN 8742:2011.

Indicators related to yield and yield components

Fruit diameter (cm), fruit number/plant, average fruit weight (g/fruit) and yield/plant (kg/plant) are recorded and received in batches by counting, measuring and weighing methods.

Soil analysis

Soil sample analysis followed standard procedures (Houba *et al.,* 1995). Soil pH (pHH_2O) and electrical conductivity (EC) were measured at a 1:2.5. Organic the Walkley-Black method determined matter content (%C), while available phosphorus (P) was assessed using the Bray II method. Available nitrogen (N), including ammonium and nitrate, was extracted with a 1:10 (w/v) solution of 2M KCl and quantified colorimetrically at 650 nm for ammonium and 540 nm for nitrate. Exchangeable potassium was extracted with 1M $BaCl_2$ and measured using atomic absorption spectroscopy at 766 nm.

Data processing

The data were synthesized, calculated using Excel 2013 software and tested for ANOVA using Minitab 16.0 statistical software, Duncan's test at 1% and 5% significance levels.

RESULTS AND DISCUSSION

Rice husk biochar and potassium humate affect soil chemistry over two cherry tomato crops (1st and 2nd season)

pHH_2O

Table 1 shows that biochar can improve soil pH levels. 5 tons/ha of biochar yielded the highest soil pH value, followed by 2.5 tons/ha combined with 50-100 kg/ha of potassium humate and 2.5-5.0 tons/ha of biochar significantly improved soil pH in the second season. It is a sustainable and effective way to enhance soil health.

Nutrient availability (available N, P and K)

Table 2 shows that applying potassium humate or biochar alone significantly increases soil nutrient availability, particularly N, P and K. Fertilizing the soil with 5 tons/ha of biochar and 50-100 kg/ha of potassium humate significantly enhances nutrient bioavailability throughout the growth of cherry tomatoes in both cropping seasons.

Effects of biochar rice husk and potassium humate on the growth of cherry tomatoes through two cropping seasons (1st and 2nd season)

Plant height

Plant height is crucial for growth and development. Biochar rice husk showed no effect on plant height, but potassium humate made tomato plants significantly taller ($p< 0.05$),

Table 1: Effect of rice husk biochar and potassium humate application rates on soil pH changes over two cherry tomato cropping seasons.

Season	Biochar (FA) (ton/ha)	Potassium humate (kg/ha) (FB)			Average(A)
		0	50	100	
1st season	0	5.39	5.86	5.96	5.53^{b}
Summer-	2.5	5.59	6.03	5.99	6.00^{a}
Autumn 2020	5.0	5.63	6.10	6.10	6.02^{a}
	Average (B)	5.74	5.87	5.94	
	CV (%) =4.36	F_A = *	F_B = ns	F_Ax_B = ns	
2nd season	0	5.37^{f}	5.77^{d}	5.95^{c}	5.55^{c}
Autumn-	2.5	5.64^{e}	6.04^{abc}	6.07^{ab}	5.94^{b}
Winter 2020	5.0	5.64^{e}	6.00^{bc}	6.12^{a}	6.05^{a}
	Average (B)	5.70^{b}	5.92^{a}	5.92^{a}	
	CV (%) =4.18	F_A = *	F_B = *	F_Ax_B = *	

Note: Numbers followed by the same letter are not statistically significant in the same column or row. ns: The difference is not statistically significant ($p>0.05$), *: The difference is significant ($p<0.05$).

Table 2: Impact of rice husk biochar and potassium humate application rates on available soil nutrient content across two cherry tomato cropping seasons.

Treatments	Available N (mg/kg)		Available P (mg P/kg)		K+ (Cmol/kg)	
	1st	2nd	1st	2nd	1st	2nd
Biochar (F_A)						
0	27.9^{b}	27.4^{b}	43.0^{b}	42.9^{b}	0.47^{b}	0.51^{c}
2.5	29.5^{ab}	29.9^{ab}	45.5^{ab}	45.8^{ab}	0.50^{ab}	0.61^{b}
5.0	32.4^{a}	32.3^{a}	50.0^{a}	50.2^{a}	0.55^{a}	0.66^{a}
Potassium humate (F_B)						
0	26.4^{b}	25.6^{b}	40.8^{b}	41.0^{b}	0.44^{b}	0.49^{b}
50	30.9^{a}	25.6^{b}	47.5^{a}	47.8^{a}	0.52^{a}	0.64^{a}
100	32.6^{a}	32.4^{a}	50.1^{a}	50.2^{a}	0.55^{a}	0.65^{a}
F_A	*	*	*	*	*	*
F_B	*	*	*	*	*	*
$F_A \times F_B$	*	*	*	*	*	*
CV (%)	24.00	13.87	23.70	13.43	13.80	20.90

Note: Numbers followed by the same letter are not statistically significant in the same column or row. ns: The difference is not statistically significant ($p>0.05$), *: The difference is significant ($p<0.05$).

Table 3: Effects of rice husk biochar and potassium humate application rates on cherry tomato plant height over two cropping seasons.

Treatments	Plant height (cm)					
	1st season (Summer-autumn 2020)			2nd season (Autumn-winter 2020)		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Rice husk biochar (F_A)						
0 tons/ha	50.9	96.3	180.9	61.8	136.4	179.3
2.5 tons/ha	53.8	97.1	181.8	67.7	140.3	182.0
5.0 tons/ha	55.9	100.1	185.7	63.8	145.2	182.0
K - Humate (F_B)						
0 kg/ha	50.7^{b}	95.9^{b}	176.0^{b}	56.1^{b}	124.9^{b}	176.6^{b}
50 kg/ha	52.2^{b}	97.4^{a}	183.8^{a}	65.9^{a}	145.4^{a}	183.4^{a}
100 kg/ha	57.7^{a}	100.1^{a}	188.6^{a}	71.3^{a}	151.5^{a}	183.3^{a}
F_A	ns	ns	ns	ns	ns	ns
F_B	*	*	*	*	*	*
$F_A \times F_B$	ns	ns	ns	*	ns	ns
CV (%)	13.90	16.10	19.60	12.60	10.00	2 . 95

Note : DAS: The day after planting. Numbers followed by the same letter are not statistically significant in the same column or row. ns: The difference is not statistically significant ($p>0.05$), *: The difference is significant ($p<0.05$).

regardless of the amount applied (50 kg or 100 kg of potassium humate/ha). The interaction analysis also revealed that biochar made from rice husk and potassium humate did not significantly affect plant height during both tomato growing seasons (Table 3).

Stem diameter

According to experimental findings, potassium humate and biochar dosage did not affect tomato stem diameter during either growing season (Table 4). According to the interaction analysis, the amount of biochar and potassium humate applied to cherry tomato plants did not impact how much their stems grew in diameter.

Effect of rice husk biochar and potassium humate on yield and yield components of cherry tomatoes grown in pots under greenhouse conditions over two growing seasons

Tomato yield comprises the following factors: Fruit diameter, fruit number/plants and fruit weight. The results presented in Table 5 show that:

Table 4: Effect of rice husk biochar and potassium humate application rates on cherry tomato plant stem diameter over two cropping seasons.

Treatments	Stem diameter (cm)					
	1st season (Summer-autumn 2020)			2nd season (Autumn-winter 2020)		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Rice husk biochar (F_A)						
0 tons/ha		0.49	0.99	1.48	0.49	0.99
1.40						
2.5 tons/ha	0.48	0.98	1.49	0.49	1.00	1.51
5.0 tons/ha	0.52	1.02	1.51	0.53	1.00	1.51
K - Humate (F_B)						
0 kg/ha	0.46^{b}	1.02	1.49	0.48	1.01	1.52
50 kg/ha	0.53^{a}	0.99	1.49	0.50	0.99	1.50
100 kg/ha	0.49^{ab}	0.98	1.50	0.53	1.00	1.49
F_A	ns	ns	ns	ns	ns	ns
F_B	*	ns	ns	ns	ns	ns
$F_A \times F_B$	ns	ns	ns	ns	ns	ns
CV (%)	13.06	6.07	1.69	12.27	6.04	1.81

Note: Numbers followed by the same letter are not statistically significant in the same column or row. ns: The difference is not statistically significant ($p>0.05$), *: The difference is significant ($p<0.05$).

Table 5: Effects of rice husk biochar and potassium humate application rates on yield parameters of cherry tomatoes over two cropping seasons.

Treatments	Fruit diameter (cm)		Total fruits number (fruit/plant)	
	1st Season	2nd Season	1st Season	2nd Season
Rice husk biochar (F_A)				
0 tons/ha	3.26	2.24	73.5	147.5^{b}
2.5 tons/ha	3.27	2.30	76.9	154.5^{a}
5.0 tons/ha	3.32	2.30	89.3	177.6^{a}
K - Humate (F_B)				
0 kg/ha	3.24	2.23^{b}	61.8^{c}	122.4^{c}
50 kg/ha	3.32	2.31^{a}	81.9^{b}	171.3^{b}
100 kg/ha	3.29	2.30^{ab}	96.3^{a}	185.9^{a}
F_A	ns	ns	ns	*
F_B	ns	*	*	*
$F_A \times F_B$	ns	ns	ns	ns
CV (%)	3.29	3.62	22.70	22.11

Note: Numbers followed by the same letter are not statistically significant in the same column or row. ns: The difference is not statistically significant ($p>0.05$), *: The difference is significant ($p<0.05$).

Fruit diameter

Adding biochar did not increase tomato fruit diameter in both cultivation seasons. However, potassium humate helped increase the fruit diameter in the second season. The analysis revealed no interaction between biochar husk dose and potassium humate on cherry tomato fruit diameter.

Total fruit/plant

Using Biochar for two seasons increased fruit yield/plant significantly compared to control. There is no difference in fruits/plants between 2.5 and 5 tons of biochar/ha. Treatments with potassium humate had higher fruit/plant, with a dose-dependent effect-no interaction between potassium humate and biochar on fruit/plant increase.

Yield

Crop yield is essential for farmer profitability and is influenced by genetic makeup, environmental factors, nutrition and cultivation techniques. Effective management of these variables is crucial for maximizing profits. Fig 2 illustrates that applying 5 tons of biochar and 100 kg of potassium humate per hectare significantly enhances tomato yield, yielding the highest results. Interaction analysis, however, indicated no significant interaction between the biochar and potassium humate doses.



Fig 1 : (A) Tomato seedling stage and (B) Tomato 15 days after sowing (DAS).

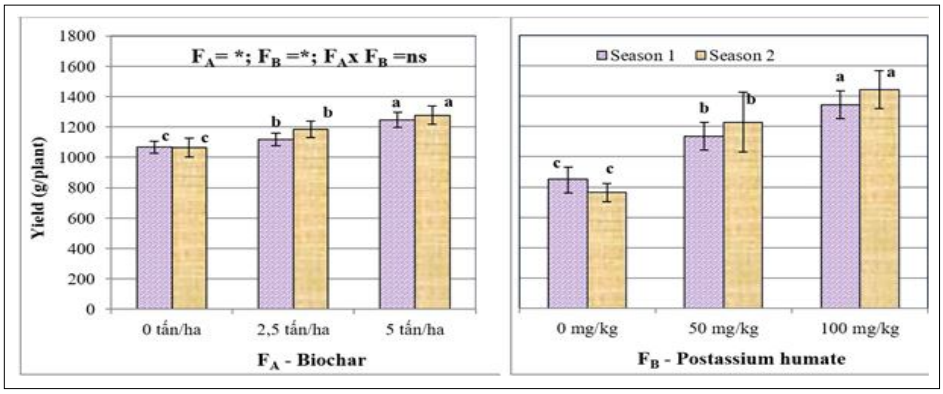


Fig 2: Effect of rice husk biochar and potassium humate application rates on cherry tomato fruit yield over two cropping seasons.

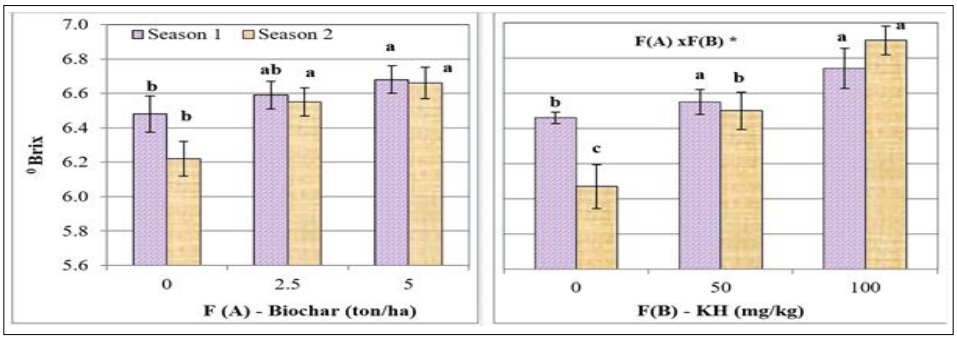


Fig 3: Brix content in cherry tomato fruit as influenced by rice husk biochar and potassium humate application rates over two cropping seasons.

Effects of rice husk biochar and potassium humate on cheery tomato quality at two cropping seasons in net house conditions

The study found that the recommended NPK application, biochar and potassium humate can increase tomato yield without nitrate accumulation (Fig 3). Nitrate content was lower than the VietGap standard (<150 mg/kg). The doses of biochar and potassium humate did not affect the nitrate content of fresh tomatoes.

Biochar and potassium humate significantly increased tomato fruit's sugar content (brix level). The optimal treatment was 5 tons of biochar per hectare and 100 kg of potassium humate per hectare, resulting in the highest brix content (Fig 4). It suggests that these additives can be a powerful tool in boosting the nutritional value of tomato fruit.

Fertilizing rice husk biochar can significantly improve soil pH and nutrient availability (N, P, K) in soil compared tobiochar. Due to the alkaline nature of biochar, soil pH is

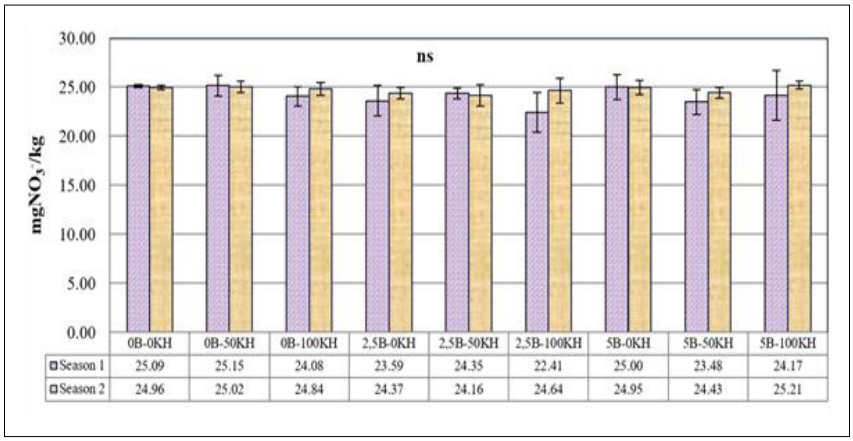


Fig 4: Impact of rice husk biochar and potassium humate application rates on nitrate content in cherry tomato fruit over two cropping seasons.

raised and a better environment for plant growth is created. According to Tan Huiyi *et al.* (2021), pH plays a crucial role in plant growth and nutrient availability. Biochar contains organic functional groups like C C, C=C, OH, COOH and alkaline elements like Ca^{2}+, Mg^{2}+, Na+ and K+. It is why biochar has a high pH (Mandal *et al.,* 2019). Therefore, adding biochar to the soil can change its physicochemical properties, add more nutrients and significantly increase the content of K+ (Hassan *et al.,* 2020; Adekiya *et al.,* 2022). At the same time, adding biochar to the soil improves soil quality and reduces nutrients' leaching, thereby increasing crop yields (Diatta *et al.,* 2020).

Potassium humate is the salt of humic acid, derived from lignite brown coal and rich in hydroxyl (-OH), carboxylic (-COOH) and phenolic (-COH) groups (El-Beltagi *et al.,* 2023). Potassium humate is a natural fertilizer that resembles humus in soil. It enhances soil properties and nutrient accessibility for plants, improving growth by enhancing nutrient uptake and cellular activities. Recent studies have shown that it is a highly concentrated form of humus with strong cation adsorption capacity. Potassium humate increases tomato plant yield, biomass and harvest index and improves plant biochemicals.

Potassium humate has been shown to significantly enhance crop performance and physiological parameters in various studies. Research results of Rahi *et al.* (2021) demonstrated that tomato crop yield, total plant Biomass and harvest index increased proportionally with potassium humate application rates. Similarly, El-Bassiouny *et al.* (2014) reported dramatic increases in proline content, total soluble sugars, total amino acids and photosynthetic pigments in response to potassium humate treatments.

The positive effects of potassium humate on plant growth and crop yield can be attributed to several mechanisms. According to Abdeen (2020), potassium humate enhances water retention, nutrient availability, hormonal activity and microbial growth and promotes organic chemical minerals' transformation during plant growth. Furthermore, Baldotto *et al.* (2009) observed that potassium humate application led to increased soil N, P and K levels, enhanced root development, improved plant nutrient uptake and consequently, higher crop yields.

The combined application of biochar and potassium humate significantly increased the °Brix content of tomato fruit flesh compared to the non-fertilized control. This improvement in fruit quality parameters can be attributed to enhanced nutrient uptake and utilization efficiency. The synergistic effect of biochar and potassium humate increases the availability of both macro (N, P and K) and micronutrients and improves the plant's nutrient absorption capacity. This enhanced nutrient uptake leads to better accumulation of metabolites in leaves and fruits, ultimately resulting in improved fruit quality characteristics. These findings align with the results reported by Spehia *et al.* (2020).

CONCLUSION

Applying rice husk biochar and potassium humate positively affected soil properties and cherry tomato production. This treatment improved soil pH and enhanced the availability of essential nutrients (N, P and K) in the soil. Consequently, significant improvements were observed in plant growth parameters, fruit yield and the number of fruits per plant. The combined application also resulted in increased °Brix content of fruits without causing excessive nitrate accumulation. Notably, the nitrate levels in fruits remained within acceptable limits, ranging from 23.45 to 24.94 mg NO_3^-/ kg fresh weight, below the regulatory threshold.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the study design, data collection, analysis, decision to publish, or manuscript preparation.

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