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Article

Biostimulation Effects of Seaweed Extract (*Ascophyllum nodosum*) on Phytomorpho-Physiological, Yield, and Quality Traits of Tomato (*Solanum lycopersicum* L.)

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Abstract: Biostimulants are innovative organic tools, which promote the growth, plant development, production, and quality of various crops without harming the environment; however, the effects of biostimulants on the production of tomato needed to be explored further under open field conditions. Based on this view, this study's objective was to assess the impact of Kendal Root, a biostimulant-containing seaweed, *Ascophyllum nodosum*, and plant extracts on the phytomorpho-physiological, yield, and quality of tomato. Three doses of Kendal Root (2.5, 5.0, and 10 L ha^{-1}) were given as soil drenching, and the results were compared with control. Generally, the Kendal Root treatments positively improved the growth, physiological, yield, and quality attributes of tomato. However, among the three different concentrations, Kendal Root 5.0 L ha^{-1} significantly improved the plant growth and physiological aspects of tomato, such as plant height, leaf area, shoot and root dry weight, SPAD value, and gas exchange parameters. Considering the yield traits, the Kendal Root 5.0 L ha^{-1} application significantly improved the tomato fruit number, yield per plant, and yield per hectare. Conversely, flower number per plant and average fruit weight was not remarkably improved by Kendal Root 5.0 L ha^{-1}. Moreover, Kendal Root 5.0 L ha^{-1} positively improved the quality traits of tomato, including total soluble solids, ascorbic acid content, lycopene, and total sugars than the titratable acidity content of tomato fruits. Hence, the integration of Kendal Root biostimulant in tomato production could be an effective way to boost plant growth, production, and quality of tomato.

Keywords: Kendal Root; soil drenching; tomato crop growth; fruit yield; fruit quality; tomato production

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1. Introduction

Globally, tomato (*Solanum lycopersicum* L.), being the more consumable, popular, and nutrient rich vegetable, comes under the Solanaceous family. It ranks second in vegetable production in the world with 189.13 million metric tonnes during 2021. Tomato is essential for supplying the human diet with a considerable quantity of vitamins C, A, and lycopene [1]. By 2050, the world's population is expected to exceed 10 billion [2]; thus, a higher crop productivity is required to feed the expanding population. As consumer demand increases with excellent organoleptic, nutritional, and functional qualities of products are contemporarily important problems for farmers and they need to strengthen the crop quality [3]. Here, the quality of tomato fruit is determined by various factors, including color, size, shape, flavor, storage capabilities, and bioactive compounds, viz., organic acid, sugar content, soluble solids, vitamin C, minerals, and lycopene [4].

Conversely, producers apply excessive levels of fertilizers and pesticides to attain respectable yields, and good grade tomato fruits, endanger the ecology of agricultural systems and water supplies and degrade the health of soil and fertility [5]. Therefore, enhancing agricultural produce with maximum output without harming the environment is still a difficult task. In this way, biostimulators may be the best option to advance the production of vegetables, such as tomato, in sustainable way. Biostimulants are innovative agronomic tools, and nowadays, they have gained more attention in the global market. Contrary to fertilizers, plant biostimulants have different mechanisms. They do not directly address pests and diseases; instead, they increase plant vigor, nutrient uptake, and crop protection [6].

Plant biostimulants are formulations that contain either a single or a combination of microbes, vitamins, amino acids, algal, seaweed extracts, and hydrolyzed proteins, which are applied either as foliar or to the rhizosphere of the plant and amplify the processes to increase crop quality and production, by augmenting nutrient uptake and nutrient usage efficiency, as well as improving the crop resistance to environmental stress [7–11]. In recent years, seaweeds are more and more being utilized as a biostimulant, which has phytohormones, polysaccharides, minerals, proteins, fatty acids, and polyphenols that enhance plant performance even under stress conditions [12–15].

Many commercial biostimulants contain the extracts of *A. nodosum*, which has been shown to considerably increase crop production, biometric traits, and quality, and it also imparts tolerance against various abiotic stresses [16–19]. A plethora of studies explained that *A. nodosum* has biostimulation effects on various agricultural and horticultural crops, such as watermelon [20,21], tomato [22–24], wheat [25], soybean [26], sweet pepper [27], pea [28], maize [29], and okra [30]. Clearly, the application of *A. nodosum* extract as soil drenching increased the tomato fruit yield under drought conditions [22]. Likewise, plant growth traits of tomato, such as plant height, root and shoot length, chlorophyll content, phytohormones (auxin, cytokinin, gibberelins), and antioxidant enzymes are enhanced by the application of *A. nodosum extract*, resulting in improved plant growth and defense [23]. In okra, *A. nodosum* extract significantly improved the plant photosynthetic pigments, proline, and antioxidant enzymes under water deficit conditions thereby improving the biochemical and physiological functions of plants [30].

Moreover, various reports are suggest that the application of *A. nodosum*-containing biostimulant positively influences tomato plant growth, yield, and quality. However, the effects of *A. nodosum* extract on tomato production under open field condition needs to be explored further. Kendal Root is a biostimulant product containing *A. nodosum* has the ability to improve the nutrient uptake and plant physiological process with the result of increasing root growth. Therefore, we formulated the hypothesis that Kendal Root might improve the plant growth, yield, and fruit quality of tomato. In this context, the current study was carried out to understand the impact of different doses of the biostimulant Kendal Root on plant growth attributes, physiological traits, yield, and quality of tomato.

2. Materials and Methods

2.1. Plant Material

Tomato seeds, (*Shivam*, a semi-determinate hybrid) were sown in 96 well protrays filled with the media of vermicompost and coir peat in the ratio of 1:3. After seed germination, seedlings were watered frequently by sprinkling.

Water-soluble nutrients (19:19:19 NPK) were given as foliar spray for two times in a week. Then, the seedlings with 4 to 5 leaves were transplanted in the main field at a spacing of 60 × 45 cm.

2.2. Experimental Design

The field trial was carried out at Eastern Block Farm, Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore from December 2021 to April 2022 to evaluate the performance of Kendal Root biostimulant on growth, physiology, yield, production, and quality of tomato. The field is located at 110° N latitude and 770° E longitude with an altitude of 426.7 m above mean sea level. The field trial was performed in randomized block design (RBD) with four treatments and six replications. Nearly 50 plants were maintained in each replication with a plot size of 15 m^2. The experimental field was irrigated at weekly intervals depending on the requirement. The soil sample from the experimental plot was collected before transplanting and physiochemical characteristics were analyzed (Table 1). The field was first fertilized with NPK @ 50:250:100 kg ha^{-1} and zinc sulphate 50 kg ha^{-1} as basal. Then, top dressing with 150 kg ha^{-1} of each N and K was given in 3 equal splits at 30, 45, and 60 days after transplanting (DAT). Two days after transplanting, the pre-emergence herbicide pendimethalin was sprayed @ 25 mL 10^{-1} L of water for weed control.

Table 1. Physiochemical properties of soil.

Soil Properties	Range
Texture	Clay loam
pH	7.57
Electrical conductivity (dS m^{-1})	0.66
Soil organic carbon (%)	0.69
Available nitrogen (kg ha^{-1})	275
Available phosphorous (kg ha^{-1})	38
Available potassium (kg ha^{-1})	975

2.3. Biostimulant Treatment

The biostimulant Kendal Root was obtained from the leading plant biostimulant company, M/s. Valagro Biosciences Pvt. Ltd., Hyderabad, India. The Kendal Root biostimulant contains seaweed (*A. nodosum*) and plant extracts. The treatments include control (CT), Kendal Root 2.5 L ha^{-1} (KR1), Kendal Root 5.0 L ha^{-1} (KR2), and Kendal Root 10.0 L ha^{-1} (KR3). The solution required per plot was prepared by adding 3.75 (KR1), 7.50 (KR2), 15.00 (KR3) mL of Kendal Root in 5 L of water and applied as soil drenching by pouring 100 mL of prepared biostimulant solution per plant on the root zone by digging the soil around the plants (Figure 1). The biostimulant treatments were given at two stages i.e., 15 and 60 days after transplanting (DAT). The plant growth and physiological attributes were measured at 30, 45, and 60 DAT (15, 30, and 45 after first application of biostimulants). Three plants per replication were selected for measuring the growth and physiological parameters of tomato (3 leaves from each plant). The plant yield and quality traits were analyzed at the harvest stage after the second application of biostimulants. The yield parameters were taken from three plants in each replication at 8 harvests and cumulative data were presented here.

Figure 1. Soil drenching of Kendal Root biostimulant at 15 days after planting.

2.4. Growth Parameters

The following growth traits were recorded at 15-day intervals after first application of Kendal Root. Plant height was measured from ground level to the tip of the topmost leaf of plant using the scale, and it was expressed in centimeters (cm). Leaf area was recorded by using a leaf area meter (LICOR, Model LI 3000, Lincoln, NE, USA). Briefly, the plant leaf samples were obtained from each replication of all the treatments and inserted into the leaf area meter, to measure leaf area per plant, and it was expressed as cm^2 $plant^{-1}$. To measure the shoot and root dry weight of the plant, the plant samples from each replication in all the treatments were collected from the field, and roots were washed with running tap water to clean the soil that adhered to the root surface. The collected plant samples were shade dried for 2 days, then dried in a hot air oven for 48 h at 80 °C, and measured the dry weight by using an electronic weighing balance. Shoot and root dry weight was expressed as g $plant^{-1}$.

2.5. Physiological Parameters

2.5.1. Chlorophyll Index (SPAD Value)

The chlorophyll index was recorded by using a portable chlorophyll meter (soil plant analytical development) SPAD Model 502′ Minolta (Konica Minolta, INC, Tokyo, Japan) at field conditions. The physiologically active leaf was selected, five SPAD readings were collected from every replication, and the average was computed [31].

2.5.2. Leaf Gas Exchange Parameters

The gas exchange attributes were detected at 15-day intervals after first treatment. Photosynthetic rate, stomatal conductance, and transpiration rate were found by using a portable photosynthesis system (PPS; LI-6400 XT, Licor Inc., Lincoln, NE, USA). For each replication, three observations were recorded. Briefly, physiologically active leaf was selected, cleaned, and placed in situ in a cuvette (6.0 cm^2), and the values were recorded using PPS between 10:00 a.m. to 12:00 noon on a bright sunny day. The photosynthetic rate was denoted as µmol CO_2 $m^{-2}s^{-1}$, stomatal conductance was denoted as mol H_2O $m^{-2}s^{-1}$, and the transpiration rate was expressed as mmol H_2O m^{-2} s^{-1}.

2.6. Yield Parameters

The yield of the tomato crop was recorded by manual handpicking of physiologically matured fruits. Fruit harvesting started from 65 DAT, and the fruits were harvested weekly, thrice from the first week of March to the last week of April. The yield parameters, viz., number of flowers per plant, number of fruits per plant, average fruit weight (g), and yield per plant (kg), were recorded at every harvest, and cumulative yield data were used to calculate the mean and yield per hectare (t ha^{-1}).

2.7. Quality Parameters

Three uniformly ripened, unblemished, same-size fruits from each replication were selected for fruit quality analysis.

2.7.1. Total Soluble Solids (TSS)

TSS of fruits were observed by using an ERMA hand refractometer (0–32 °C) by following the procedure of Tigist et al. [32]. The juice was squeezed from uniformly ripened tomatoes, and a few drops of juice were placed on the prism of the digital hand refractometer; it was expressed in °Brix. The prism of the instrument was cleaned by using distilled water after each sample.

2.7.2. Ascorbic Acid Content

The analysis was performed by following the procedure of Ikewuchi et al. [33]. Briefly, about 5 mL of 0.1% ascorbic acid as a working standard and 10 mL of 4% oxalic acid were taken and titrated against the 2,6-dichlorophenol indophenol dye solution, and we noted the volume of the consumed dye solution (V_1) at the appearance of the endpoint (pink color). Similarly, about 0.5 g of a fruit sample was extracted with 4% oxalic acid, and then volume was made up of 100 mL using distilled water. The above mixture was centrifuged at 6000 rpm for 10 min. Then, 5 mL of supernatant was mixed with 10 mL of 4% oxalic acid and titrated against the dye solution. The volume of the consumed dye solution was noted (V_2), and the values were used for calculation. Ascorbic acid content was expressed as mg 100 g^{-1} fruit.

The amount of dye consumed was equivalent to the amount of ascorbic acid.

$$\text{Amount of ascorbic acid in the sample} = 0.5/V_1 \times V_2/5 \times 100/0.5 \times 100 \quad (1)$$

2.7.3. Titratable Acidity

The titratable acidity of tomato fruits was analyzed based on the procedure of Tigist et al. [32]. First, about 2 g of a fruit sample was weighed and macerated in a glass mortar to extract the juice, and the volume was made up of 100 mL using distilled water in a volumetric flask. Then, the sample was filtered, and 20 mL of filtrate was transferred to a conical flask. Next, 2 drops of a phenolphthalein indicator were added to the sample, and the solution was titrated against 0.1 N NaOH till the appearance of a pink color (endpoint). The acidity was calculated by using the following formula and expressed as percent of citric acid.

$$\text{Titratable acidity (\%)} = (\text{Titratable value} \times \text{Normality of NaOH} \times \text{m.eq.wt. of acid})/(\text{Volume of sample}) \times 100 \quad (2)$$

Milli-equivalent weight of citric acid = 0.06404.

2.7.4. Lycopene Content

Lycopene in the fruit was estimated by using the method of Ranganna [34]. In detail, about 1 g of pulp was macerated with 5 mL of acetone and transferred into a separating funnel. Then, 20 mL of petroleum ether and 20 mL of 5% sodium sulphate were added to the sample and mixed well. After incubation, the petroleum ether layer was separated, and collected the lower aqueous phase. Then again, 20 mL of petroleum ether was added to extract the lycopene and pool the ether layer. About 10 g of anhydrous sodium sulphate was added into petroleum ether and left for 20 min. Then, petroleum ether extract was collected in a 25 mL volumetric flask, and we made the volume 25 mL using petroleum ether. The absorbance of the sample was red at 503 nm using a spectrophotometer, and it expressed as mg 100 g^{-1}.

$$\text{Lycopene content} = (3.12 \times \text{Absorbance value} \times \text{Total volume} \times 100)/(\text{Weight of sample (g)} \times 1000) \quad (3)$$

Unit absorbance of lycopene = 3.12.

2.7.5. Total Sugars

Total sugars in the fruit sample were estimated by the anthrone method suggested by Hedge and Hofreiter [35]. Briefly, about 250 mg of pulp was macerated with 10 mL of 80% warm ethanol. Then, the solution was centrifuged at 3000 rpm for 10 min, and 0.5 mL of supernatant was collected and kept in a water bath for 30 min. Then, 1 mL of distilled water and 4 mL of anthrone reagent were added to a test tube and again kept in a water bath for 8 min. The solution was cooled and red at 630 nm using a spectrophotometer. The total sugar content was expressed as mg 100 g^{-1} of sample.

$$\text{Total sugars present in sample} = X/0.5 \times 10/0.25 \times 1$$

$$X = \text{Absorbance at 630 nm} \quad (4)$$

2.8. Statistical Analysis

The experimental data were analyzed by SPSS software (version 16.0) and XLSTAT version 2022.5.1 (XLSTAT, 2022). One-way analysis of variance (one-way ANOVA) was performed separately for the data collected from each time intervals (15, 30 and 45 days after first application) after the biostimulant application concerned with growth, physiological, yield, and quality traits of tomato, and the results were stated as mean with standard error (mean ± SE). The mean value of the treatments was compared by using Duncan's multiple range test (DMRT) at $p = 0.05$. Pearson correlation analysis was performed by using SPSS to examine the liner relationship between the biostimulant and the growth, physiological, yield, and quality traits of tomato. Likewise, principal component analysis was performed using XLSTAT to understand the treatment effects on tomato with observed variables. Data visualization of the observed variables was carried out by using GraphPad Prism (version 8.2.0).

3. Results

3.1. Growth Parameters

The effect of soil drenching of Kendal Root biostimulant on growth parameters of tomato is presented in Figure 2. The measurement of growth parameters was performed at 30, 45, and 60 DAT on tomato plants treated with three doses of Kendal Root biostimulant.

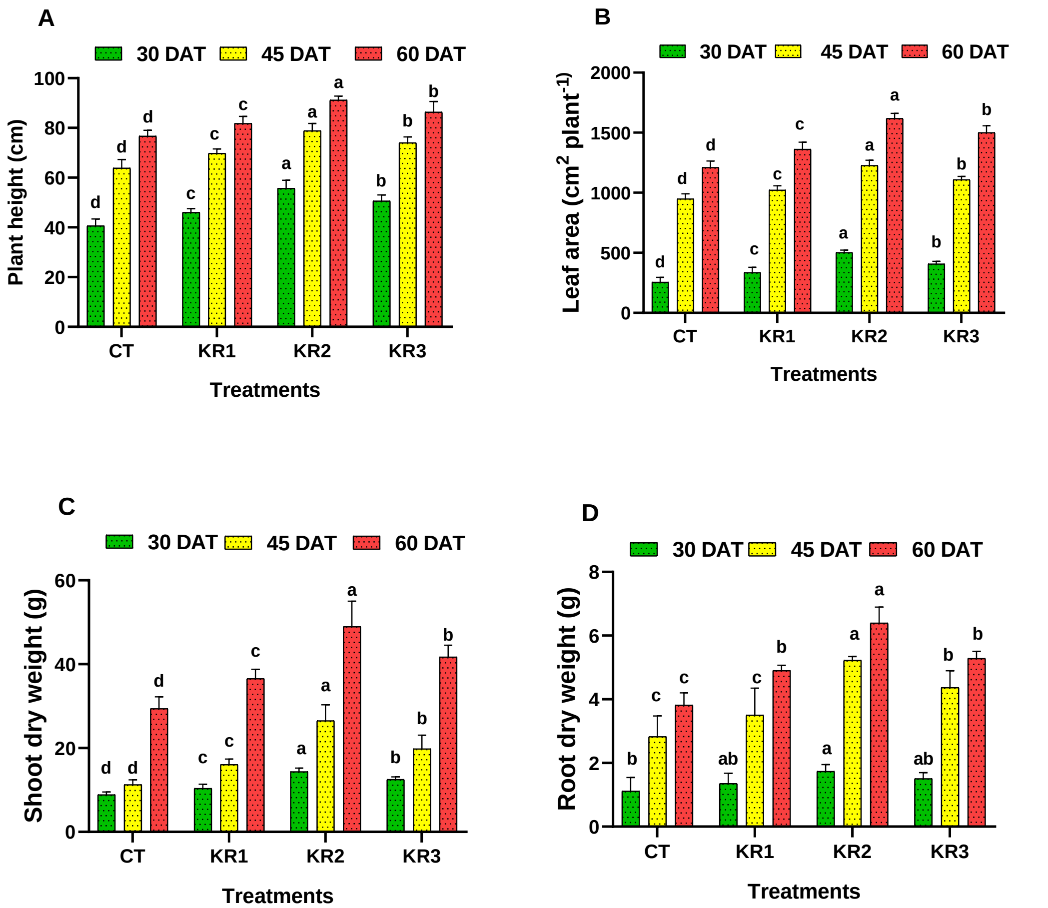

Figure 2. Growth parameters of tomato plants treated with Kendal Root biostimulant: (**A**) Plant height; (**B**) leaf area; (**C**) shoot dry weight; and (**D**) root dry weight. Data in the figure are expressed as mean ± SE. Mean values followed by the same letter do not differ significantly at $p \leq 0.05$ by DMRT.

Plant height was significantly improved by the Kendal Root treatment irrespective of the doses, in contrast, to control (CT); Kendal Root 5.0 L ha^{-1} (KR2) recorded a higher plant height of 55.67, 78.90, and 91.18 cm at 30, 45, and 60 DAT, respectively. Similarly, the leaf area of tomato plants was also significantly increased in Kendal Root treated plant over an untreated control plant (CT). Among the biostimulant treatments, Kendal Root 5.0 L ha^{-1} (KR2) had the highest leaf area of 502.05, 1226.97, and 1618.62 cm^2 $plant^{-1}$ at 30, 45, and 60 DAT, respectively.

Shoot and root dry weight of tomato plants were significantly increased by soil drenching of Kendal Root biostimulant, and overall, Kendal Root 5.0 L ha^{-1} (KR2) recorded higher shoot dry weight of 14.35, 26.53, and 48.98 g $plant^{-1}$ and root dry weight of 1.74, 5.22, and 6.40 g $plant^{-1}$ at 30, 45, and 60 DAT, respectively.

3.2. Physiological Parameters

3.2.1. SPAD Value (Chlorophyll Index)

The SPAD value was increased significantly with the root application of Kendal Root biostimulant compared to the control (Figure 3A). Though, the greater SPAD value was observed in plants treated with Kendal Root 5.0 L ha^{-1} (KR2) to 39.63, 45.93, and 47.27 at 30, 45, and 60 DAT, respectively.

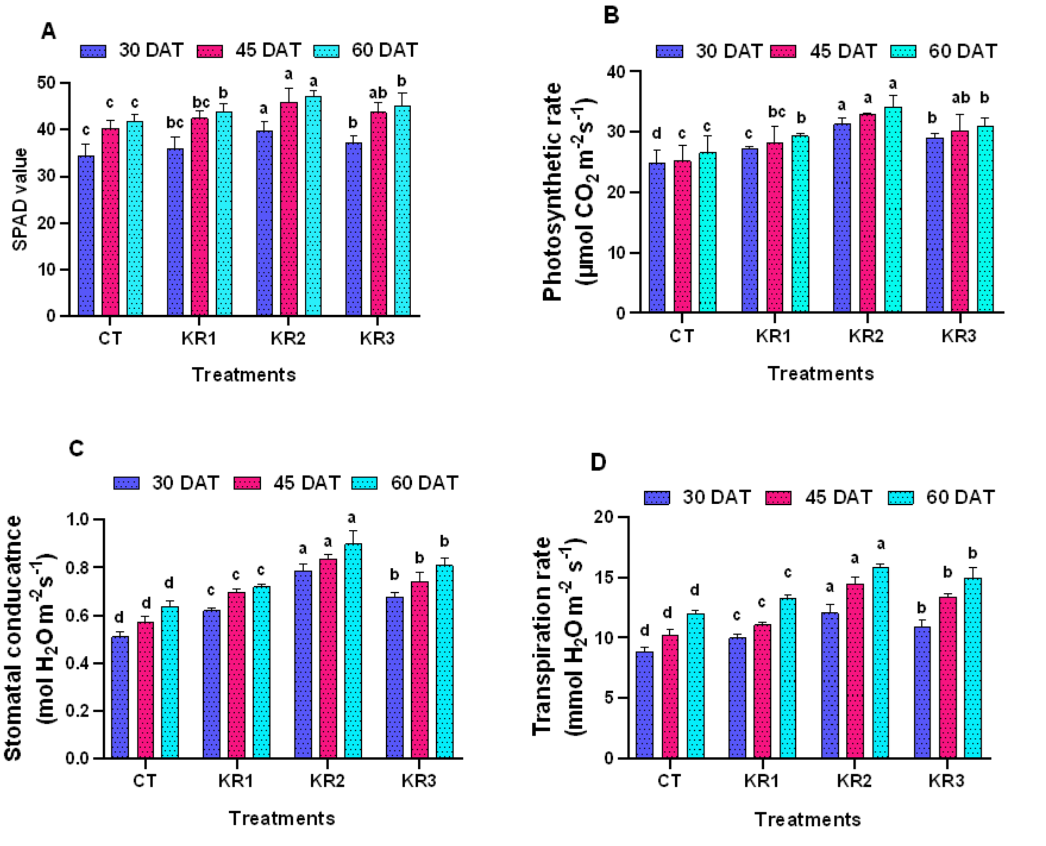

Figure 3. Physiological parameters of tomato plants treated with Kendal Root biostimulant: (**A**) SPAD value; (**B**) photosynthetic rate; (**C**) stomatal conductance; and (**D**) transpiration rate. Data in the figure are expressed as mean ± SE. Mean values followed by the same letter do not differ significantly at $p \leq 0.05$ by DMRT.

3.2.2. Gas Exchange Parameters

The results of three Kendal Root biostimulant treatments on gas exchange parameters of tomato plants at various stages are represented in Figure 3. Soil drenching of Kendal Root biostimulant significantly enhanced the photosynthetic rate, stomatal conductance, and transpiration rate of tomato plants compared to control plants. Among the different doses, Kendal Root 5.0 L ha^{-1} (KR2) recorded the highest photosynthetic rate (31.32, 32.84, and 34.18 μmol CO_2 m^{-2} s^{-1}, respectively), stomatal conductance (0.79, 0.84, and 0.90 mol

H_2O m^{-2} s^{-1}, respectively) and transpiration rate (12.07, 14.50, and 15.86 mmol H_2O m^{-2} s^{-1}, respectively) at 30, 45, and 60 DAT.

3.3. Yield Parameters

The influence of soil drenching of Kendal Root biostimulant on yield traits of tomato is given in Figure 4. The number of flowers per plant was not significantly improved by the Kendal Root treatments in either of the concentrations over a control. As expected, the number of fruits per plant was significantly increased in Kendal Root biostimulant-treated plants than the control plants and recorded a greater number of fruits 31.33 in Kendal Root 5.0 L ha^{-1}. The average fruit weight of tomato plants was slightly improved by Kendal Root biostimulant treatments, but it was not statistically significant. The soil drenching of Kendal Root biostimulant significantly affected the yield per plant and yield per hectare of tomato. The higher yield per plant (4.64 kg) and yield per hectare (35.16 tonnes) was recorded in tomato plants treated with Kendal Root 5.0 L ha^{-1}.

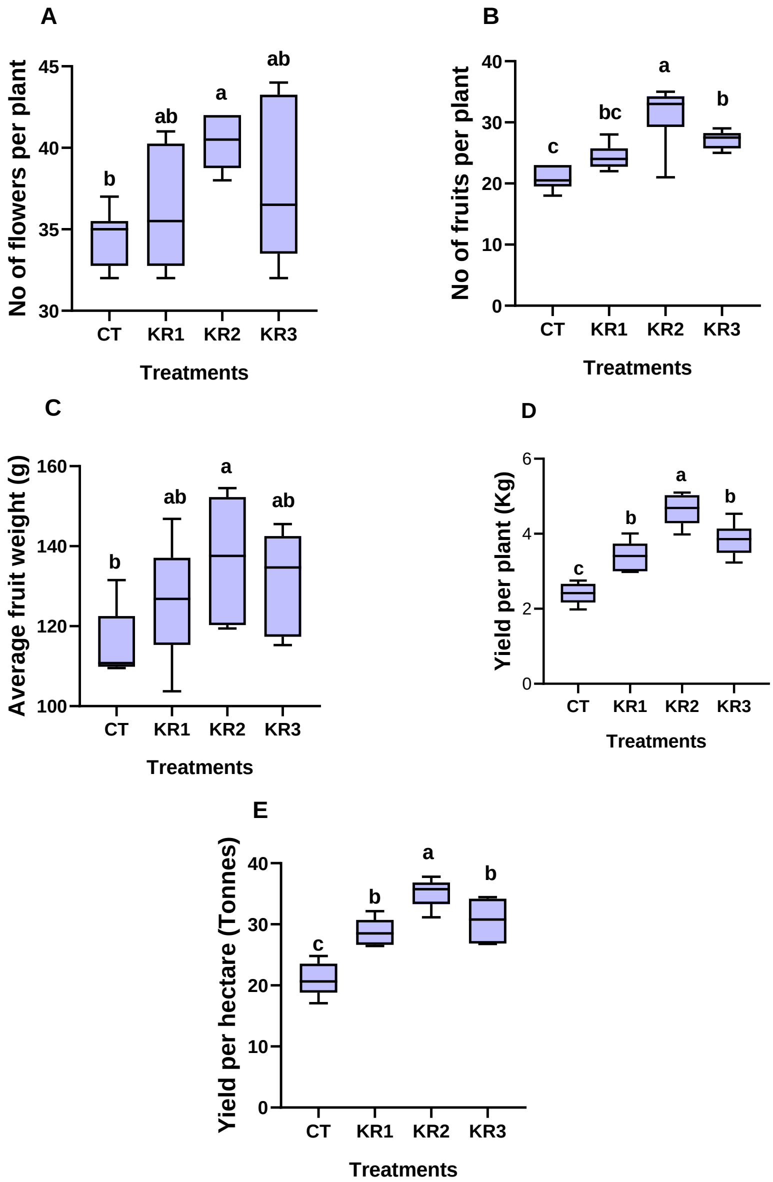

Figure 4. Yield parameters of tomato plants treated with Kendal Root biostimulant: (**A**) Number of flowers per plant; (**B**) number of fruits per plant; (**C**) average fruit weight; (**D**) yield per plant; and (**E**) yield per hectare. Data in the figure are expressed as mean ± SE. Mean values followed by the same letter do not differ significantly at $p \leq 0.05$ by DMRT.

3.4. Fruit Quality Parameters

The obtained results presented that the Kendal Root biostimulant significantly changes the fruit quality parameters of tomato irrespective of the doses (Figure 5). Total soluble solids (TSS), ascorbic acid content, lycopene content, and total sugars were statistically improved in Kendal Root biostimulant-treated plants as compared to the control, but it reduced the titratable acidity of tomato fruits. The greater TSS (5.31 °Brix), ascorbic acid (35.46 mg 100 g^{-1}), lycopene content (3.65 mg g^{-1}), and total sugars (5.17 mg 100 g^{-1}) were found in Kendal Root 5.0 L ha^{-1} treatment.

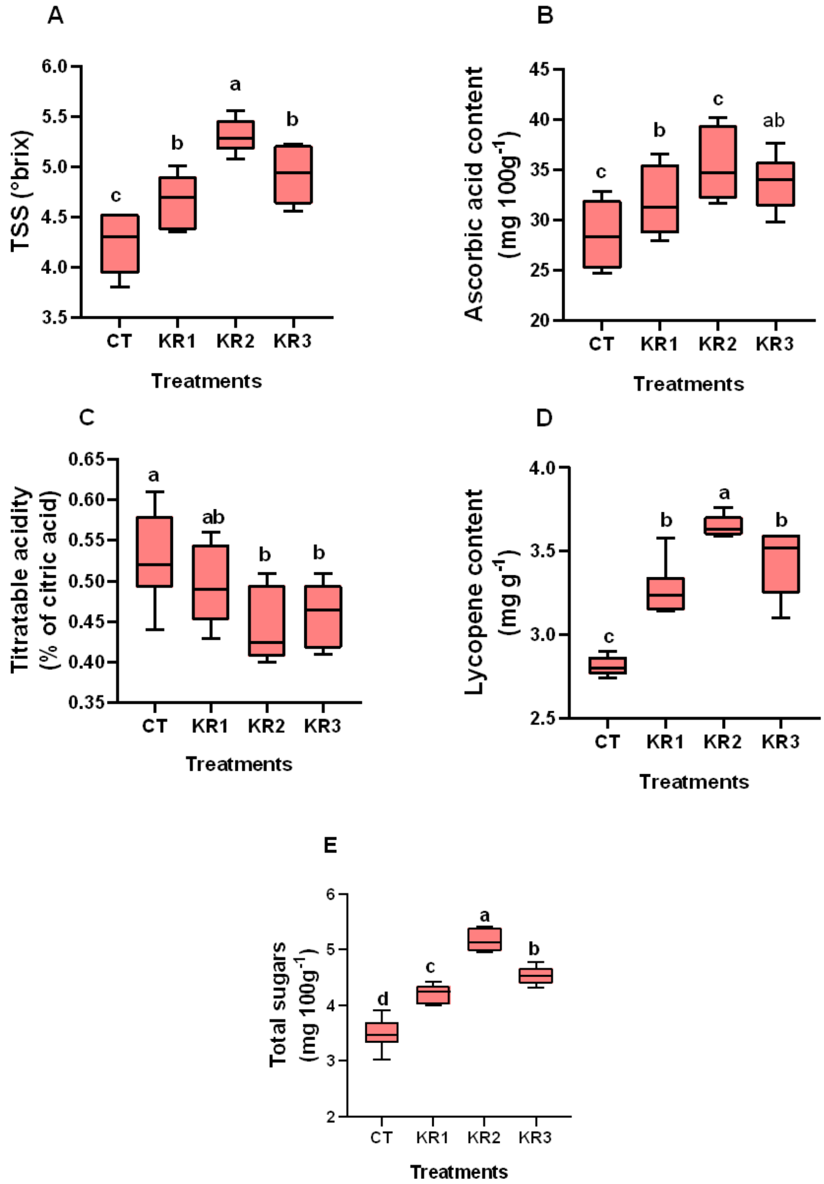

Figure 5. Quality parameters of tomato plants treated with Kendal Root biostimulant: (**A**) Total soluble solids; (**B**) ascorbic acid content; (**C**) titratable acidity; (**D**) lycopene; and (**E**) total sugars. Data in the figure are expressed as mean ± SE. Mean values followed by the same letter do not differ significantly at $p \leq 0.05$ by DMRT.

3.5. Correlation

Pearson correlation analysis confirmed that (Table 2) Kendal Root treatments positively influenced the growth, yield, and quality traits of tomato, such as plant height (PH; r^2 = 0.608), leaf area (LA; r^2 = 0.678), shoot and root dry weight (r^2 = 0.579 and 0.542, respectively), SPAD value (r^2 = 0.474), photosynthetic rate (Pn; r^2 = 0.519), stomatal conductance (gs; r^2 = 0.640), transpiration rate (Trn; r^2 = 0.717), number of fruits per plant (NFrPP; r^2 = 0.508), yield per plant (YieldPP; r^2 = 0.584), yield per hectare (YieldPH; r^2 = 0.576), total soluble solids (TSS; r^2 = 0.545), ascorbic acid content (AA; r^2 = 0.469), lycopene (r^2 = 0.650), and total sugars (TS; r^2 = 0.593), except the number of flowers per plant (NFPP; r^2 = 0.338) and average fruit weight (AFW; r^2 = 0.389). However, the titratable acidity (TA) of tomato was negatively correlated with Kendal Root biostimulant treatments (r^2 = −0.461). Moreover, the number of flowers per plant (NFPP) positively correlated with the yield traits of tomato, such as the number of fruits per plant (NFrPP; r^2 = 0.424), yield per plant (YieldPP; r^2 = 0.452), and yield per hectare (YieldPH; r^2 = 0.526).

3.6. Principal Component Analysis

Principal component analysis (PCA) was performed with the data of growth, physiological, yield, and quality traits of tomato influenced by Kendal Root biostimulant with three different concentrations (Figure 6). Principal components one and two (PC1 & PC2) of the PCA of treatments and variables shared the value of 98.76% and 0.74%, respectively. The observations KR2 and KR3 were located on the right side of the scoring plot, which denotes the positive correlation between the components of observation and variables, whereas CT and KR1 are located on the left side of the scoring plot. Among the assessed variables, all growth, yield, and quality related variables, expect titratable acidity (TA) located on the right side of the loading plot had the positive impact by Kendal Root treatment. Hence, PCA suggested that the application of the biostimulant Kendal Root (KR2) positively influenced the growth, yield, and quality traits of tomato.

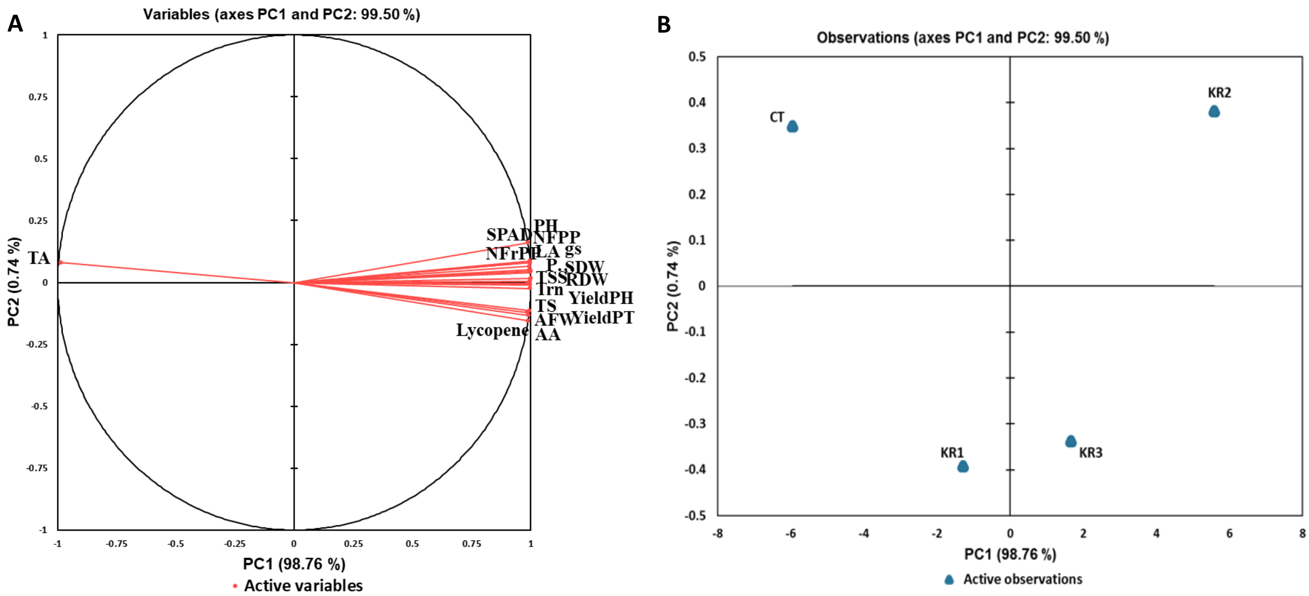

Figure 6. Principal component analysis of tomato plants treated with biostimulants: (**A**) Loading plot of variables; (**B**) scoring plot of treatments. Treatments include CT, control; KR1, Kendal Root 2.5 L ha^{-1}; KR2, Kendal Root 5.0 L ha^{-1}; KR3, Kendal Root 10.0 L ha^{-1}. The variables are plant height (PH), leaf area (LA), shoot dry weight (SDW), root dry weight (RDW), SPAD value, photosynthetic rate (Pn), stomatal conductance (gs), transpiration rate (Trn), number of fruits per plant (NFrPP), yield per plant (YieldPP), yield per hectare (YieldPH), total soluble solids (TSS), ascorbic acid content (AA), lycopene, total sugars (TS), and titratable acidity (TA).

Table 2. Correlation coefficient (Pearson) between biostimulant and assessed variables of tomato.

Variables	BS	PH	LA	SDW	RDW	SPAD	Pn	gs	Trn	NFPP	NFrPP	AFW	YieldPP	YieldPH	TSS	AA	TA	Lycopene	TS
BS	1																		
PH	0.608 **	1																	
LA	0.678 **	0.864 **	1																
SDW	0.579 **	0.782 **	0.870 **	1															
RDW	0.542 **	0.839 **	0.898 **	0.881 **	1														
SPAD	0.474 *	0.732 **	0.661 **	0.649 **	0.741 **	1													
Pn	0.519 **	0.817 **	0.839 **	0.790 **	0.822 **	0.648 **	1												
Gs	0.640 **	0.822 **	0.900 **	0.894 **	0.890 **	0.682 **	0.852 **	1											
Trn	0.717 **	0.852 **	0.910 **	0.853 **	0.887 **	0.701 **	0.787 **	0.915 **	1										
NFPP	0.338	0.550 **	0.549 **	0.452 *	0.581 **	0.745 **	0.462 *	0.491 *	0.463 *	1									
NFrPP	0.508 *	0.824 **	0.731 **	0.673 **	0.721 **	0.538 **	0.809 **	0.785 **	0.749 **	0.424 *	1								
AFW	0.389	0.554 **	0.537 **	0.398	0.614 **	0.314	0.426 *	0.439 *	0.576 **	0.379	0.588 **	1							
YieldPP	0.584 **	0.830 **	0.881 **	0.785 **	0.894 **	0.613 **	0.797 **	0.857 **	0.880 **	0.452 *	0.799 **	0.752 **	1						
YieldPH	0.576 **	0.824 **	0.853 **	0.839 **	0.906 **	0.752 **	0.813 **	0.838 **	0.849 **	0.526 **	0.657 **	0.475 *	0.757 **	1					
TSS	0.545 **	0.808 **	0.786 **	0.809 **	0.848 **	0.707 **	0.763 **	0.783 **	0.760 **	0.607 **	0.725 **	0.449 *	0.778 **	0.753 **	1				
AA	0.469 *	0.539 **	0.532 **	0.553 **	0.658 **	0.686 **	0.605 **	0.574 **	0.653 **	0.378	0.562 **	0.438 *	0.616 **	0.652 **	0.586 **	1			
TA	−0.461 *	−0.602 **	−0.621 **	−0.387	−0.480 *	−0.380	−0.436 *	−0.480 *	−0.591 **	−0.376	−0.521 **	−0.241	−0.437 *	−0.531 **	−0.451 *	−0.253	1		
Lycopene	0.650 **	0.779 **	0.864 **	0.816 **	0.826 **	0.746 **	0.741 **	0.851 **	0.876 **	0.569 **	0.692 **	0.477 *	0.811 **	0.830 **	0.689 **	0.574 **	−0.544 **	1	
TS	0.593 **	0.860 **	0.892 **	0.820 **	0.910 **	0.782 **	0.751 **	0.879 **	0.899 **	0.587 **	0.768 **	0.534 **	0.848 **	0.859 **	0.751 **	0.707 **	−0.604 **	0.886 **	1

**. Correlation is significant at the 0.01 level (2-tailed); *. Correlation is significant at the 0.05 level (2-tailed); biostimulant (BS), plant height (PH), leaf area (LA), shoot dry weight (SDW), root dry weight (RDW), SPAD value (SPAD), photosynthetic rate (Pn), stomatal conductance (gs), transpiration rate (Trn), number of fruits per plant (NFrPP), average fruit weight (AFW), yield per plant (YieldPP), yield per hectare (YieldPH), total soluble solids (TSS), ascorbic acid content (AA), titratable acidity (TA), lycopene, total sugars (TS).

4. Discussion

4.1. Growth Parameters of Tomato Influenced by Kendal Root

Plant height is a critical morphological attribute that is highly correlated with plant dry matter and the yield of the crop. The Kendal Root biostimulant increased the plant height significantly irrespective of concentration; however, the middle concentration recorded higher plant height, which is due to the presence of growth promoting stuff in the biostimulant that enhances the plant growth processes, viz., cell division and cell elongation; thereby, it improves the vegetative growth of the tomato plant. Similarly, the increased plant height of tomato by using biostimulants was also reported by Gedeon et al. [36] and Ikuyinminu et al. [24]. The application of a novel biostimulant extracted from eucalyptus and rosemary remarkably increased the tomato plant's height [37]. Moreover, polysaccharide-enriched extracts (PEEs) from Moroccan seaweeds also enhanced the plant height of tomato at different day intervals [38]. This enhanced plant growth, i.e., plant height, suggests that polysaccharides and alginates in the seaweed algae contain the functional molecules that stimulate the various plant signaling mechanisms, which improve the nutrient use efficiency, and it also enhances the nitrogen metabolism, thereby increasing the growth of tomato plants [15,39–41].

Leaf area is the major factor that determines the net photosynthetic rate and total dry matter production, thereby improving the overall crop yield. From our results, soil drenching of the Kendal Root biostimulant effectively improved the leaf area of the tomato plant, through which it enhanced photosynthesis. Similarly, the brown seaweed *Padina gymnospor* on tomato statistically enhanced the leaf area [42], and *A. nodosum* extract also had a higher leaf area under drought [43]. The hormones present in plant extracts as well as polysaccharides and polyphenols in the seaweed contain functional hydroxyl groups, which can chelate the micronutrient from soil, which leads to improved plant growth [44].

The most important criteria of plants are to produce higher dry matter by making use of available resources and obtain rises with elevation in the duration of the crop. In the present study, the biostimulant Kendal Root significantly improved the shoot and dry weight of tomato plants compared to the control. The increasing percentage of root dry weight over control is around 55.52%, 84.73%, and 67.76% in Kendal Root 5.0 L ha^{-1} at 30, 45, and 60 DAT, respectively. The increased shoot and root dry weight in *A. nodosum* plants was also observed by Campobenedetto et al. [45]. This increased root dry weight is due to more water and nutrient uptake from soil; thereby, it improves the shoot growth and productivity of the crop. Seaweed extract enhanced the plant biomass due to its variety of bioactive substances, such as polysaccharides, fatty acids, vitamins, phytohormones, and mineral nutrients, and they may cause various favorable physiological reactions that are reflected in increased dry weight of the plants [15,17,46].

4.2. Kendal Root Application on Physiological Parameters of Tomato

The SPAD value represents the accumulation of chlorophyll in the plants, an important pigment involved in photosynthesis. In our current study, the biostimulant Kendal Root (5.0 L ha^{-1}) significantly increased the SPAD value by 15.55%, 14.17%, and 13.8% compared to the control at 30, 45, and 60 DAT, respectively. These results are in line with the findings of Souri and Bakhtiarizade [47] that both foliar and soil application of biostimulant derived from rosemary enhanced the chlorophyll content (SPAD) of tomato seedlings. This increased SPAD value under biostimulant treatments is due to lesser chlorophyll degradation, reduced leaf senescence, more nitrogen uptake, and altered plant hormone function [48].

The leaf gas exchange parameters are potential indicators of the plant's ability to produce a good yield. Photosynthetic rate is the base of plant growth, and it depends on light interception and concentration of CO_2. The photosynthetic rate ascertains the rate of assimilate production, thereby regulating the crop yield. From our findings, the Kendal Root biostimulant (5.0 L ha^{-1})-treated plants increased the photosynthetic rate by 26.40%, 32.84%, and 28.43% at 30, 45, and 60 DAT, respectively. Similarly, the commercial biostimulant Radifarm contains multiple plant extracts, including *Pelargonium hortorum*, that upregulate the net photosynthetic rate of tomato plants at 15 DAT [49]. This higher photosynthetic rate is due to the changes in photosynthetic machinery and an increase in leaf area, chlorophyll content, and plant water relations [48]. According to Kaluzewicz et al. [50], the increased photosynthetic rate under biostimulant treatment is due to reduced stomatal closure, enhanced growth of above ground parts, maintenance of leaf water relations, and cell turgor pressure.

Stomatal conductance is the speed of opening and closing of stomata at which the water molecules transpire from the stomatal pore of the plant, and it depends on the size of the stomal aperture. The present study suggests that the application of plant- and seaweed-extract-based biostimulants improved the stomatal conductance of tomato crops at different day intervals; these increased the stomatal conductance under biostimulant treatments and were also observed by Rashid et al. [51]. The novel biostimulant extracted from eucalyptus and rosemary enhanced the stomatal conductance of tomato [37]. Stomatal conductance is connected to photosynthesis and plant water relations [52]; soil drenching of biostimulants increases the plant water uptake by enhancing the root growth in tomato plants. Transpiration rate is the amount of evaporation of water molecules from the surface openings of the leaves or stomata. In our study, biostimulant treatment slightly increased the transpiration rate, and significant differences were found between all Kendal Root biostimulant treatments and the control. The growth promoting substances in the biostimulant raises the chlorophyll content, nitrogen, and phosphorous uptake that significantly enhances the gas exchange parameters [51].

4.3. Yield Traits of Tomato Influenced by Kendal Root

Tomato fruit yield is a polygenic factor, which is controlled by many internal and external factors throughout the crop growth period, and it is the manifestation of growth, morphological, biochemical, and physiological characteristics. In our study, a significant increase was observed in Kendal Root biostimulant treated plants; among the different treatments, Kendal Root 5.0 L ha^{-1} registered a higher yield compared to the control. The yield per hectare (tonnes) was statistically increased by 37.27%, 67.8%, and 46.1% in Kendal Root 2.5 L ha^{-1}, Kendal Root 5.0 L ha^{-1}, and Kendal Root 10.0 L ha^{-1}, respectively. These enhanced yield parameters are due to an increased nitrogen metabolism by biostimulant treatments [53,54]. Similarly, Mzibra et al. [38] suggested that polysaccharide-enriched extracts (PEEs) derived from six Moroccan seaweeds improved the number of fruits per plant, the average fruit weight (g), and the yield per plant (g) of a tomato crop, and they decided that this increased yield is due to the combination of many factors, including raises in vegetative and reproductive growth of the plant.

The tropical plant-derived biostimulant significantly increased the yield of tomato landraces [55], and *A. nodosum* extracts also increased the yield of tomato plants under water limited conditions [43]. In our results, the average fruit weight was not significantly increased by biostimulant treatments; their findings are in line with Di Stasio et al. [56]. Biostimulant products produced from seaweed extracts enhanced the colonization and growth of beneficial microbes in the rhizosphere of the plant, which increases the nutrient solubilization and mineral nutrient uptake in plants, thereby enhancing the growth, photosynthetic rate, and plant yield [57]. Foliar spraying of plant extract, seaweed extract, and legume-derived protein hydrolysate significantly improved the tomato fruit yield. This better performance is due to the presence of polysaccharides in *A. nodosum*, which enhance the productivity of plants by stimulating the auxin and cytokinin phytohormones activity [16,53].

4.4. Kendal Root Application on Quality Parameters of Tomato

The influence of soil drenching of the Kendal Root biostimulant on tomato fruit quality parameters showed a significant variation in total soluble solids (TSS), ascorbic acid content, titratable acidity, lycopene, and total sugars. Among the treatments, Kendal Root 5.0 L ha^{-1}

had a more positive impact on fruit quality parameters. Total soluble solids (TSS) represent the fruit organic acids, minerals, fats, proteins, and carbohydrate content, and ascorbic acid content shows the vitamin C content of the fruit. The Kendal Root biostimulant significantly improved the TSS content by 10.01%, 25.06%, and 16.03% in Kendal Root 2.5 L ha^{-1}, 5.0 L ha^{-1}, and 10.0 L ha^{-1}, respectively. These results are in line with Mannino et al. [58]. Similarly, Mzibra et al. [38] found that polysaccharide-enriched extracts (PEEs) from six Moroccan seaweeds positively affected the fruit quality parameters, such as total soluble solids (TSS) and lycopene content, and they said that higher TSS is due to improved metabolic activities of fruit, which lead to the synthesis of more quantity of metabolites, glucose, and acids through biostimulant treatments.

The *A. nodosum*-based algal extracts significantly enhanced the ascorbic acid content of fruits even under the salt stress conditions. It is due to the growth promoting substances present in the algal extract that improved the nutrient and vitamin content of the fruit [46,58]. Titratable acidity is the quantity of organic acid present in tomato fruit. From our results, the titratable acidity is reduced under biostimulants treatments. It is due the conversion of acids into sugars at ripening, which gives extra taste in treated plants. The organic acids and soluble sugars and their interactions are important for fruit quality, which determines the taste and flavor of the fruit [38].

Lycopene is the important antioxidant present in tomato that is responsible for the deep red color of the fruit. The soil drenching of Kendal Root biostimulant significantly improved the lycopene content by 16.17%, 29.8%, and 22.27% in Kendal Root 2.5 L ha^{-1}, 5.0 L ha^{-1}, and 10.0 L ha^{-1}, respectively, compared to the control. This increased lycopene content in the biostimulant-treated tomato plants was also observed by Mannino et al. [58], Mzibra et al. [38], and Rouphael et al. [55]. The plant-derived and legume-derived protein hydrolysate biostimulant enhanced the lycopene content. This increased lycopene content is due to a higher potassium (K) concentration in fruit; the K activates the enzymes, such as pyruvate and phosphofructokinase, which regulate carbohydrate metabolism, and thereby K regulates carotenoid biosynthesis [53]. Total sugars contain glucose, fructose, sucrose, etc., which determine the taste of the tomato fruit. In our study, the biostimulant treatments increased the total sugar content. The Kendal Root 5.0 L ha^{-1} recorded the highest total sugar content, and these results are in line with Sani et al. [57]. The increased sugar content is due to increased CO_2 uptake and photosynthetic efficiency, which results in more accumulation of sugars in fruits.

5. Conclusions

In this study, we evaluated the effect of different doses of the biostimulant Kendal Root on plant growth, physiological, gas exchange parameters, yield, and quality parameters of tomato. Our data suggest that soil drenching of different doses of the Kendal Root biostimulant significantly improved the growth parameters, such as plant height, leaf area, and shoot and root dry weight, and it also enhanced the SPAD value and gas exchange parameters of tomato plants. Different concentrations of the Kendal Root biostimulant significantly enhanced the fruit yield characteristics, such as the number of fruits per plant, yield per plant, and yield per hectare, and it also significantly improved the fruit quality parameters analyzed from tomato juice, such as total soluble solids (TSS), ascorbic acid content, lycopene, and total sugars, but the biostimulant treatments reduced the titratable acidity content. Among the three doses of the Kendal Root biostimulant used, Kendal Root 5.0 L ha^{-1} (KR2) showed a significant rise in all growth, physiological, yield, and quality parameters of tomato. Moreover, the effects of Kendal Root on improving root growth and nutrient uptake by tomato will need to be confirmed further through molecular approaches. In conclusion, the biostimulant enhanced the tomato growth and yield attributes, but the Kendal Root 5.0 L ha^{-1} (KR2) significantly improved the tomato plant growth, physiology, yield, and quality parameters.

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