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MORALITY BEFORE KNOWLEDGE

Growth responses of cherry tomato plants (Solanum lycopersicum L.) under elevated temperature and different nitrogen doses

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ABSTRACT
Background: Cherry tomatoes are one of the horticultural crops that can potentially be cultivated with household farming systems to fulfil the food supply. The increasing global temperature caused by climate change makes growing cherry tomato plants challenging. Besides that, nitrogen efficiency in the cultivating process of cherry tomato plants is crucial. This study aims to know the growth responses of cherry tomato plants in temperature and nitrogen doses. **Methods**: A completely randomized design with two factors was used for this study. The first factor was the temperature (normal and high-temperature treatment). The second factor was the nitrogen doses (55 ppm, 110 ppm, and 165 ppm). Observations of growth characteristics included plant height, leaf number, stem diameter, root length, root fresh weight, root dry weight, root-shoot ratio, shoot fresh weight, shoot dry weight, plant canopy diameter, and growth index. **Findings:** On day 8, normal temperature was the best result for enhancing the number of leaves. Besides that, nitrogen 55 ppm was the most effective for increasing the number of leaves. Next, at day 20, normal temperature was the best result for increasing leaf number, stem diameter, root length, root fresh weight, root dry weight, shoot fresh weight, shoot dry weight, and growth index. Then, nitrogen 110 ppm + normal temperature was the most significant response of root-shoot ratio. **Conclusion**: Normal temperature and minimal nitrogen doses were the most effective conditions for enhancing the growth of cherry tomato plants. **Novelty/Originality of this article:** This study examines cherry tomato plants' remarkable ability to grow at normal temperature and minimum nitrogen level.

KEYWORDS: global warming; horticulture; morphology; nitrogen.

1. Introduction

Tomato is a global commodity because of its flavour, high-nutrient contents, and health-improving properties, and it is mainly processed to be industrial products such as juice, puree, paste, ketchup, and diced tomatoes (Kumar et al., 2022; Wu et al., 2022). Tomato fruit is plentiful in micronutrients and phytocompounds such as carotenoids, minerals, and vitamins, and it is known for improving human health (Vats et al., 2022). Lycopene content in tomato fruits has pharmacological benefits, such as antioxidant, cardioprotective, anticancer, and antihypertensive effects (Khan et al., 2021). Green tomatoes can promote human health because of their glycoalkaloids and chlorophyll content (Patel et al., 2024). The cherry tomato is one of the commodities that provide nutritional content, bioactive components, and antioxidant function. The nutrients

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consisted of sugar, proteins, fats, and minerals, whilst the bioactive elements include β-carotene, vitamin C, lycopene, glutathione, and nucleoside A. The antioxidant function can be measured by preventing lipid peroxidation in mice liver and scavenging hydroxyl free radicals via in-vitro analysis (Yang et al., 2023). The fruit quality of cherry tomatoes depends on the plant variety and its colour (Chang et al., 2024; Joung et al., 2024).

The growth of tomato plants is divided into five stages involving early growth, vegetative, flowering, fruit formation, and mature fruiting. At the fruit stage, tomato plants is separated into several phases which is respectively known as green, breaker, turning, pink, light red, and red. Determining optimum temperature is one of the crucial factors that enhance vegetative growth, fruit quality, fruit yield. The results of the study can be used to build mathematical model for standardizing microclimate management and tomato growth. Energy conservation and energy efficient of green-house systems can be resulted by creating the best economic model based on the study (Shamshiri et al., 2018). The other studies uncovered a correlation between microclimate conditions and the progression of inflorescence development, as well as their growth. The optimal temperature conditions between 18 °C and 22 °C, a light intensity in the range of 360.87 to 384.45 W m^{-2}, and a carbon dioxide level ranging from 450.85 to 480.74 ppm. The duration of each stage among the inflorescences is varied due to the impact of microclimate conditions (Jerca et al., 2024).

Plant growth evaluation is crucial to know how it responds towards the environment (Hilty et al., 2021). Nowadays, some researchers try to assess plant growth by integrating plant, soil, and air systems into a mathematical model (Maksimov et al., 2021). Advances in integrated models are an open way for in-silico treatment and scenario experimentation to improve crop production and sustainability (Benes et al., 2020). Transdisciplinary merging and joined research approaches are required to get a multiple modelling patterns that will let for more powerful and practical use in predicting the crop production under climate change through its environmental impacts. Wide integration among modellers across different multidisciplines, encouragement of science exchange, data sharing, open-sources coding and community-based development, standardization and intercomparison are rewarding ways that drive to success (Peng et al., 2020). Relative growth approaches are important for measuring growth performance and its efficiency. Nowadays those approaches are important for determining and modelling of mortality and reproduction processes which is essential for rebuilding growth processes in dendrochronology, climate change, and another implemented research. From the technical aspects, relative growth approaches are more simple to model than absolute growth approaches and more attention should be focused on model development (Pommerening & Muszta, 2016).

In China, combining agricultural system model, machine learning, and life cycle assessment in spatiotemporally fertilizer application, irrigation, and residue management are important to achieve maximum yield of maize and wheat and reduce greenhouse gases. By optimizing-farm practices, the projected fertilizer use, water irrigation, and residue inputs are reduced at the range of 14-21%, 7-32%, 16-26%, respectively (Xiao et al., 2024). Integrating growth and genomic prediction models helps forecast paddy biomass with intermediate characteristics (Toda et al., 2020). Furthermore, the partitioning of assimilations can be predicted as the property of many physiological processes in the root and the shoot without complicated partitioning functions. Because of its estimating power, in the future, the model will be developed as a tool to analyze partitioning in shoot and root of crops (Feller et al., 2015).

Practicing an urban farming system can raise food production and create food resilience in the city (Lal, 2020). Tomato plants are potentially used as a crop in urban farming systems (Efendi et al., 2021). The cherry tomato is one of the types potentially cultivated in urban agriculture (Richardson & Arlotta, 2022). Enhancing cherry tomato productivity in urban areas is well developed using organic matter on farm (Duffaut et al., 2023). For instance, vermicompost is effectively used for improving soil structure, water retention, and supply of important minerals, and nitrogen metabolism that help plants are more adaptable to heat stress (Ahanger et al., 2021; Banjade et al., 2024). A high delivery rate of Ca, Mg, P, and K in lettuce plants is recorded as an effect of vermicompost and fecal compost, but N supply is still required to support the growth process in the high accuracy of doses (Schroder et al., 2021).

Another challenge of high-temperature affects was begun as a problem in the urban farming area (Maheshwari, 2021). Between 2011 and 2020, global land surface temperature was increased by 1.34-1.83 °C (IPCC, 2023). Agriculture and food security will be heavily at risk because elevating global temperature negatively impacts plant morphology, physiology, biochemistry, and fruit nutrient contents (Dasgan et al., 2021; Taratima et al., 2022; Anderson et al., 2023). In South Florida, the decrease in tomato yield is correlated with the increase of temperature, but the accumulation of plant biomass and leaf index were increased to the contrary (Ayankojo & Morgan, 2020). Therefore, study of morphology, physiology, and molecular is necessary to evaluate the tolerance level of plants against heat stress (Hoshikawa et al., 2021). Nitrogen, a key component of amino acids and proteins, is essential for crops (Mu & Chen, 2021). Nitrogen deficiency will cause a chlorosis symptom on leaves, low chlorophyll content, impaired biomass accumulation, and nitrogen assimilation (Lin et al., 2021). Meanwhile, nitrogen fertilizer in excessive doses leads to morphological changes and nutritional imbalances (Bonomelli et al., 2021). Nitrogen is used to optimize growth and increase the photosynthesis rate to improve plant resistance in high-temperature conditions (Shaukat et al., 2024). Furthermore, sufficient nitrogen can increase tomato plant adaptation in producing fruits under high temperature by improving sugar metabolism (Zheng et al., 2023). Recently, the huge amount of studies carried out on this topic, but more focusing during the flowering and fruiting stages (Li et al., 2023; Luo et al., 2023) or selecting traits of heat tolerance (Lee et al., 2022). Thus, evaluating the optimum level of nitrogen doses to boost vegetative growth of tomato plants in climate change condition such as an increasing temperature is essential of this study, same as the work by Cammarano et al., (2020). This study aims to provide information about the great response of cherry tomato plant growth by determining the optimum level of temperature and nitrogen supply.

2. Methods

2.1 Plant materials and experimental setup

This study was conducted in the Leuwikopo Screenhouse at the Department of Agronomy and Horticulture, IPB University (-6.564441 N, 106.724762 E, 250 masl) from March to April 2023. A seedling tray, polybag, elite data logger, ruler, calliper, hand counter, analytical balance, and oven were the tools used in this study. Cherry tomato seeds var. Chung IPB, planting media, water, urea, and UV plastic were the materials used in this research. Seeds, 14 days after planting, were used as the treatment plants.

Fig. 1. The setting of plant growth chamber. High-temperature chamber was covered by UV plastic. Normal-temperature chamber was free open space

This study used a completely randomized design (CRD) with two factors and three replications of plants. The first factor was that there were two levels of temperature condition: normal and high-temperature. UV plastic was used to cover the growth chamber and maintain high-temperature conditions (Fig. 1). High-temperature chamber was conceptualized by keeping heat still inside. The second factor was the nitrogen doses, separated into three levels: 55 ppm, 110 ppm, and 165 ppm (Papadopoulos, 1998). A pour watering system was used by applying nitrogen fertilizer once a week with a volume of 15 ml plant^{-1}. The volume was calculated by actual measurement to get the field capacity of conditon.

2.2 Temperatures of growth chamber

Elitech RC-5 USB Temperature Data Logger was used to record all temperature data. This temperature data logger has broad measuring range at -30°C to +70°C. Data was automatically collected by Elitech every 5 minutes and then copied into the database. Two Elitech were put in each type of growth chamber (normal and high-temperature chamber).

2.3 Plant growth and morphology aspects

Plant morphology measurement was conducted on day 8 and 20. The morphology parameters were plant height, leaf number, stem diameter, root length, root fresh weight, root dry weight, shoot fresh weight, shoot dry weight, and plant canopy diameter. Root length, root fresh weight, root dry weight, shoot fresh weight, shoot dry weight, and plant canopy diameter were measured on day 20. Thus, measuring on day 20 was conducted for obtaining peak of the vegetative phase. Meanwhile, other parameters were measured into two phases for distinguishing plant between early (day 8) and late vegetative growth (day 20). All parameters were surely measured for each of replicated plants. Plant height was measured from the ground level to the growing point. The leaf number was counted on all the opening leaves. The stem diameter was measured at a 2 cm high from the ground level. Root length was measured from the end of the shoots to the tip of the roots. Shoot fresh weight and root fresh weight were measured by an analytical balance. Shoot and root dry weights were prepared using an oven at 60 °C for two days and then measured using an analytical balance. The canopy diameter was observed by taking the plant photo from the top side and then analysed with *image-j* software. To use image-j, the scale of photos was adjusted by the actual measure, and then ROI manager was used to measuring line from the furthest points on the edges of the plant's body.

The root-shoot ratio and growth index were calculated using a formula described in Kusumiyati et al. (2023). The formula is (Equation 1):

$$Root - shoot\ ratio = \frac{Root\ dry\ weight\ (g)}{Shoot\ dry\ weight\ (g)} \quad \text{(Eq. 1)}$$

The growth index was measured with % as a unit. The formula was calculated by applying some morphology variables as data sources. The formula is (Equation 2):

$$Growth\ index = \left[\frac{Stem\ diameter}{Plant\ height} + \frac{Root\ dry\ weight}{Shoot\ dry\ weight}\right] \times Total\ dry\ weight \quad \text{(Eq. 2)}$$

2.4 Data analysis

Data analysis was processed by operating Microsoft Excel Office® 2019 and R Studio version 4.3.1. The data were calculated using variance analysis (ANOVA) at the α value = 0.05. If the analysis of variance was significant (α < 0.05), then the Duncan multiple range test (DMRT) was performed at the α value = 0.05.

3. Results and Discussion

3.1 Temperature of growth chamber

In general, high-temperature fluctuations occurred in the elevated-temperature treatment compared to the normal-temperature (Fig. 2). The difference of both treatments fluctuated between 0.1°C and 22°C. The highest difference of those two treatments was usually happened at midday.

Temperature is the main factor affecting plant growth and development, seasonal behaviour, and distribution of plants. The plant life cycle is influenced by ambient temperatures (Ding et al., 2020). The optimum temperature for growing cherry tomato plants is 27.6 °C (He et al., 2022). The high-temperature treatment impacted the stress effect and potentially suppressed cherry tomato growth and development. The growth of root, mineral absorption content, protein assimilation, and mineral absorption pace of root was potentially decreased by increasing ambient temperature (Giri et al., 2017). Study from Sherzod et al., (2020) showed that the high temperature increases plant height and stem diameter, but leaf expansion is not significantly affected by it. For generative traits, high temperature has a great impact on the increasing of flower numbers, but number of fruits, fruit set, fruit weight and yield, pollen germination, and tube length were not highly affected by it.

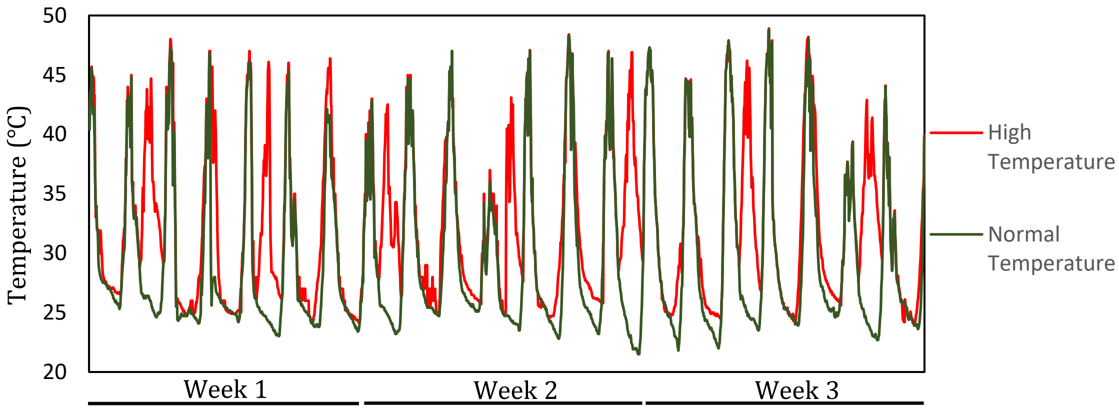

Fig. 2. The graph of temperature conditions throughout the period of treatments

3.2 Plant growth and morphology aspects

Based on the plant height data on days 8 and 20 (Table 1), there was no interaction between temperature and nitrogen doses. There was also no significant difference among those two treatments. Between days 8 and 20, the same pattern of insignificant value occurred in the plant height trait.

Plant height is an important measurement of plant architecture, apical dominance, lodging, cultivation, harvesting, and yield (Miao et al., 2024). Reducing plant height is typically impacted by high-temperature conditions (Li et al., 2023). Another report have shown that an increased temperature at 26 °C can boost plant height as the chlorophyll content in leaves is noted in the high level. So the optimum level of temperature is crucial for growing cherry tomato plants (Kong et al., 2021). Besides that, excessive levels of nitrogen negatively result in nitrate leaching, which can release sulphate and other elements, such as arsenic, copper, cobalt, lead, manganese, nickel, and zinc (Pahalvi et al., 2021). In other studies, the increasing of nitrogen at an optimal level can improve plant height structure affected to reduce the salinity effect in cherry tomato plants after transplantating (Vieira et al., 2016). From the data, all values were insignificant which can be happened because the number of samples was too low to visualize into plant height organ.

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Table 1. Plant height of cherry tomato plants on days 8 and 20

	Day 8	Day 20
Treatment	Plant height (Cm)	Plant height (Cm)
Temperature		
Normal	5.31 a	15.67 a
High	5.20 a	15.51 a
Significance	ns	ns
Nitrogen doses (ppm)		
55	5.33 a	16.23 a
110	5.43 a	15.67 a
165	5.00 a	14.88 a
Response	ns	ns
Interaction	ns	ns

Details: Data are presented as a mean from 3 replications. Day= Day after treatment. *= Significant effect on statistical test ($\alpha<0.05$), ns= no significant effect on statistical test ($\alpha>0.05$)

No interaction between the two factors has been shown in the leaf number (Table 2). On days 8 and 20, the best response leaf number response occurred on normal-temperature treatment. On day 8, nitrogen 55 ppm was selected as the effective dose to increase leaf numbers. Leaves counting is aimed at estimating the specific number of plant leaves. There are two ways to determine leaf numbers: calculating the leaf number as a by-product of leaf separation (Tassis et al., 2021) and concerning the task as a comprehensive regression (Ubbens et al., 2018). The plant work function was decreased by high-temperature stress, which negatively affects the photosynthetic efficiency, photosynthetic pigments, rubisco number, and lipid accumulation (Parrotta et al., 2020). High-temperature conditions ultimately decrease leaf number, correlated with a decline in CO_2 index, transpiration rate, and photosynthetic rate (Ali et al., 2021). The role of elevated CO_2 levels in high temperature is key to increase leaf numbers and plant heights. Further, the interaction of those two climatic conditions results the increasing number of flowers, fruits per plant, quality of tomato fruit (Rangaswamy et al., 2021). From another treatment represented on day 8, the lowest nitrogen dose showed the highest leaf number. Nitrogen toxicity conditions impact a mineral imbalance, for instance, the antagonistic effect of NH_4^+ and NO_3^-, a decrease of Mg_2^+ absorption that roles in forming ATP in the chloroplast and SO_4^{2-} on the *ferredoxin photosynthesis* apparatus (Ramos, 2020). Silicon can be used for reducing stress of ammonium toxicity by less content of H_2O_2 and malondialdehyde. The positive response of growth characteristics such as root, leaf area, root dry weight, shoot dry weight is impacted by adding silicon in the ammonium treatment. The presice doses of silicon and ammonium is still interesting to observe further (Barreto et al., 2016).

Table 2. Leaf number of cherry tomato plants on days 8 and 20

	Day 8	Day 20
Treatment	Leaf number (Strands)	Leaf number (Strands)
Temperature		
Normal	18.56 a	46.44 a
High	14.33 b	37.56 b
Significance	*	*
Nitrogen doses (ppm)		
55	19.00 a	46.50 a
110	15.83 a	39.50 a
165	14.50 b	40.00 a
Response	L*	ns
Interaction	ns	ns

Details: Data are presented as a mean from 3 replications. Day= Day after treatment. *= Significant effect on statistical test ($\alpha<0.05$), ns= no significant effect on statistical test ($\alpha>0.05$)

Similarly, stem diameter had the same pattern of no interaction (Table 3). Those two factors had no significant difference. Between days 8 and 20, stem diameter was insignificant in value. Measuring stem diameter ensures the main stem's strength and prevents plant lodging (Hussain et al., 2020). Heat stress can reduce the stem diameter of maize by up to 41% (Chukwudi et al., 2021). Stem diameter of cherry tomato plants is greatly reduced by the increase of ambient temperature, but other contributors of its change is from the quality of lights (Kong et al., 2021). From the other treatment, an exorbitant level of nitrogen application will suppress hemp's plant stem and root growth (Yang et al., 2021). On the other hand, adding mycorrhiza at high and medium nutrient applications can increase accumulation of nitrogen in cherry tomato plants, but the promoting effect is reduced at a low nitrogen level (Wang et al., 2022a). All the stem diameter had shown no significant value due to the low number of plant samples.

Table 3. Stem diameter of cherry tomato plants on days 8 and 20

	Day 8	Day 20
Treatment	Stem diameter (Cm)	Stem diameter (Cm)
Temperature		
Normal	1.37 a	3.27 a
High	1.21 a	2.53 a
Significance	ns	*
Nitrogen doses (ppm)		
55	1.38 a	3.05 a
110	1.22 a	2.83 a
165	1.28 a	2.83 a
Response	ns	ns
Interaction	ns	ns

Details: Data are presented as a mean from 3 replications. Day= Day after treatment. *= Significant effect on statistical test ($\alpha<0.05$), ns= no significant effect on statistical test ($\alpha>0.05$)

Based on the morphology data on day 20 (Table 4), there was no interaction between temperature and nitrogen doses. The best responses of root length, root fresh weight, root dry weight, shoot fresh weight, and shoot dry weight occurred upon the normal-temperature condition. Still, plant canopy diameter was opposite (Fig. 4). Furthermore, there was no significant difference among variables in temperature treatment.

Exploring root system size is beneficial for evaluates plants in nitrogen acquisition (De Pessemier et al., 2022) and a comparative look at abiotic stress (Hostetler et al., 2024). Root length is part of the root architecture which has a great plasticity as a response to high-temperature stress (Khan et al., 2016). The root length of tomato seedlings is found to decrease in high-temperature treatment (Nafees et al., 2019). Cell division in the root system is severely decreased by high-temperatures, and that condition suppress root growth (Gonzalez-Garcia et al., 2023). Declining of root length is possibly happened because of a minimum nitrogen supply (Ullah et al., 2021), but from this study was not happened. The increase of plant root architecture is still correlated to improve nutrient and water absorption. The fungal mycelium in the effect of trichoderma application produces substances that can increase plant-root architectures in branching capacity (Lopez-Bucio et al., 2015).

Sakamoto & Suzuki (2015) reported that the fresh root weight of tomato plants is decreased by elevated temperature. Restricted root growth is affected in heat-stress conditions, which it is occurred because of the decrease in nutrient uptake and assimilation (Giri et al., 2017). Nitrogen limitation decrease fresh weight of tomato plant root (Zhang et al., 2021). From this study, a significant variation did not exist in nitrogen treatments which was presumbaly caused by the genotype trait.

Root dry weight is commonly decreased as a response of high-temperature condition (Wang et al., 2017). Within the combination of heat and drought stress, a damage can be occurred on photosystem II and chloroplast structure (Zhou et al., 2018). Limiting nitrogen supply, which is similar on this study, is not significantly indicated by the vary growth of root dry weight in ambient CO_2 concentration (Cohen et al., 2019).

Shoot fresh weight of Minichal' and Dafnis' cultivars is reduced due to high temperature (Rajametov et al., 2021). Even with or without the combination of plant growth-promoting bacteria, the role of nitrogen availability is important in increasing shoot fresh weight (Masood et al., 2020). On this study, shoot fresh weight was not affected by the variation of nitrogen doses.

Zhou et al. (2018) reported that the dry weight of the shoot was highly decreased due to combination stresses of heat and drought. Applying spermidine to plants in the high-temperature conditions helps to reduce accumulation of reactive oxygen species and malondialdehyde contents (Sang et al., 2016). A decrease of shoot dry weight is occurred because of the lack of nitrogen availability (Cohen et al., 2019). Giving biochar amendment can increase shoot biomass by improving water status and leaf gas exchange under deficits of irrigation and nitrogen (Guo et al., 2021). Further, under the sufficient irrigation system, the high number of plant dry weights is modified into fruits when nitrogen application is reduced at the vegetative stage. High nitrogen application at the growth stage has a tremendous effect on allocating biomass to stem organ (Trujillo Marín et al., 2022). Based on the results, applying nitrogen in various doses was not significantly influencing to the change of shoot dry weight.

Canopy coverage is one of the aspects that will explain the availability of plant photosynthesis capacity (Liu et al., 2021). Elevated temperature is more impactful to decrease the canopy growth of tomato plants (Rangaswamy et al., 2021). Evaluating plant shoot expansion is important in assessing nitrogen regulations to shape plant architecture (Luo et al., 2020). Plant canopy structure of tomato is detrimentally influenced by low nitrogen input (Qin et al., 2023). From this study. all of plant canopy diameters were not significant in value so escalating the number of replications is crucial further.

Some researchers indicate that a high temperature will cause a decrease in growing aspects, which is correlated to the deformation of starch, sucrose, and soluble sugar (Jahan et al., 2021), the decline of carotenoid and chlorophyll content (Karkute et al., 2021), and a reduction of plant root growth (Giri et al., 2017). Heat stress highly damages chlorophyll a, chlorophyll, carotenoid, and protein synthesis. The activities of antioxidants, proteins, and lipids were increased by adding melatonin to induce a defence mechanism (Alam et al., 2022).

Table 4. Growth morphology of cherry tomato plants on day 20

	Day 20					
Treatment	Root length (Cm)	Root fresh weight (gram)	Root dry weight (gram)	Shoot fresh weight (gram)	Shoot dry weight (gram)	Plant canopy diameter (Cm)
Temperature						
Normal	12.81 a	0.19 a	0.05 a	2.62 a	0.26 a	29.25 a
High	9.1 b	0.07 b	0.02 b	1.38 b	0.14 b	23.97 a
Significance	*	*	*	*	*	ns
Nitrogen doses (ppm)						
55	13.15 a	0.15 a	0.04 a	2.18 a	0.24 a	28.31 a
110	10.52 a	0.13 a	0.03 a	1.91 a	0.20 a	26.96 a
165	9.20 a	0.11 a	0.03 a	1.91 a	0.17 a	24.56 a
Response	ns	ns	ns	ns	ns	ns
Interaction	ns	ns	ns	ns	ns	ns

Details: Data are presented as a mean from 3 replications. Day= Day after treatment. *= Significant effect on statistical test (α<0.05), ns= no significant effect on statistical test (α>0.05)

There was an interaction between two factors of root-shoot ratio (Table 5). Nitrogen availability and temperature had a similar effect on improving root-shoot ratio. Then, the highest root-shoot ratio response was recorded on nitrogen at 110 ppm with normal-temperature. The lowest response was noted on nitrogen at 110 ppm with high-temperature.

Essentially, increasing the root-shoot ratio is needed to survive and maintain favorable water (Edwards et al., 2016). Root-shoot ratio of tomato plants tended to decrease because the more extensive damage was largely happened on root organ as heat became escalating (Giri et al., 2017). Martins et al. (2019) reported that roots have more sensitivity to gibberellins which can improve plant tolerance from stress. The root-shoot ratio is increasing due to deficits of nitrogen and water (Machado et al., 2023), but this study showed different result.

Table 5. Root-shoot ratio of cherry tomato plants on day 20

Day 20	
Treatment	Root-shoot ratio
Nitrogen doses (ppm) – Temperature	
55 – Normal	0.18 ab
110 – Normal	0.19 a
165 – Normal	0.12 ab
55 – High	0.16 ab
110 – High	0.09 b
165 – High	0.18 ab
Response	*

Details: Data are presented as a mean from 3 replications. Day= Day after treatment. *= Significant effect on statistical test (α<0.05), ns= no significant effect on statistical test (α>0.05)

Growth indexes show no interaction between temperature and nitrogen application (Table 6). In temperature treatment, the normal condition responded better to the growth index than the high condition. Regarding the nitrogen trait, there was no significant difference between the treatments.

Plant growth index of tomato seedlings is decreasing because of high-temperature condition at 41°C (Wang et al., 2017). The increase of growth index is confirmed by applying sufficient nitrogen and proper irrigation (Niu et al., 2024). In this study, various-nitrogen treatments can not change growth index in significant difference because the number of sample was too few.

Table 6. Growth index of cherry tomato plants on day 20

Day 20	
Treatment	Growth index
Temperature	
Normal	0.37 a
High	0.30 b
Significance	*
Nitrogen doses (ppm)	
55	0.36 a
110	0.32 a
165	0.34 a
Response	ns
Interaction	ns

Details: Data are presented as a mean from 3 replications. Day= Day after treatment. *= Significant effect on statistical test (α<0.05), ns= no significant effect on statistical test (α>0.05)

The Pearson method is used for studying the linear relationships between two variables under low or high correlation values (Etaga et al., 2021). The correlation data (Table 7) shows a highly significantly positive correlation among all growth variables. Meanwhile, scatter diagrams (Fig. 3) depicts weak positive correlation among all parameters.

Table 7. Correlation among all growth variables of cherry tomato plants on day 20

Character	PH	LN	SD	RL	RFW	RDW	SFW	SDW	PCD
PH	1								
LN	0.76**	1							
SD	0.70**	0.90**	1						
RL	0.62**	0.72**	0.74**	1					
RFW	0.62**	0.82**	0.87**	0.83**	1				
RDW	0.60**	0.78**	0.75**	0.77**	0.92**	1			
SFW	0.73**	0.88**	0.95**	0.73**	0.86**	0.69**	1		
SDW	0.68**	0.87**	0.87**	0.75**	0.87**	0.92**	0.79**	1	
PCD	0.71**	0.66**	0.82**	0.64**	0.72**	0.70**	0.78**	0.81**	1

Details: **= Highly significant effect on statistical test (α<0.01), *= significant effect on statistical test (α<0.05). PH = plant height, LN = leaf number, SD = stem diameter, RL = root length, RFW = root fresh weight, RDW = root dry weight, SFW = shoot fresh weight, SDW = shoot dry weight, PCD = plant canopy diameter

According to Chen et al. (2021), the root dry weight was positively correlated with the aboveground parts' dry weight, and this study is similar (r = 0.92**). This indicated that the high-temperature stress and nitrogen levels did not suppress root dry and shoot dry biomass, but both of them help each other for growing. Seminal root number and total root length were highly associated with shoot biomass (Xie et al., 2017), and the same pattern occurred in this study (r = 0.73** and r = 0.75*). Apparently, root length and shoot biomass had a mutual-support trait, and the environment stress conditions did not affect them. In the present study, plant height was still highly associated with the root fresh or dry weight (r = 0.62** and r = 0.60**). Another study from Kong et al. (2021) reported that stem elongation was more related to chlorophyll production than root biomass. Doses of nitrogen and heat-stress conditons had not an impact to the increase of root weight and stem elongation. The level of correlation strongness from the data can be improved by increasing the number of replications in the next study.

Stem diameter, root dry accumulation, and shoot dry accumulation of cherry tomato plants c.v. 2019s were negatively affected by the addition of nitrogen at excessive levels (Cai et al., 2024). In this study, stem diameter, root fresh weight, root dry weight, shoot fresh weight and shoot dry weight were not significantly different among those three nitrogen doses (Tables 3 & 4). Even if the significant level was insufficient, root fresh and dry weights were reduced due to elevating nitrogen doses (Table 4). Root damage was caused by adding nitrogen at a toxic level, which will cause a decline in nitrogen absorption capability (Zhang et al., 2022).

In this study, the root-shoot ratio decreased on nitrogen 110 ppm + high-temperature conditions (Table 5). The root-shoot ratio was potentially decreased by adding nitrogen in high amounts to enhance the transpiration rate (Dziedek et al., 2016), and this study was similar to the theory, especially in the normal-temperature treatment. The nitrogen level possibly decreased the water relative content and water potential of leaves (Shi et al., 2020). The increase in transpiration rate is affected by the decrease of water potential in leaves that will promote mineral and water translocation dominantly in the shoot organ. Those conditions are impacted by the closing of the stomata when the hydraulic conductivity around the roots is dropped (Hayat et al., 2020).

This study found the best result for root length at normal temperature (Table 4). The high-temperature stress decreased the total root length and specific root length of common bean but increased stomatal conductance and declining leaf photosynthesis efficiency (Munoz et al., 2021). Root and shoot weight, relative water content, and chlorophyll content of wheat were significantly reduced because of high-temperature, whereas ascorbate peroxidase, osmotic potential, catalase, malondialdehyde, and proline were increased (Pandey et al., 2023). This study showed similar results to the theory.

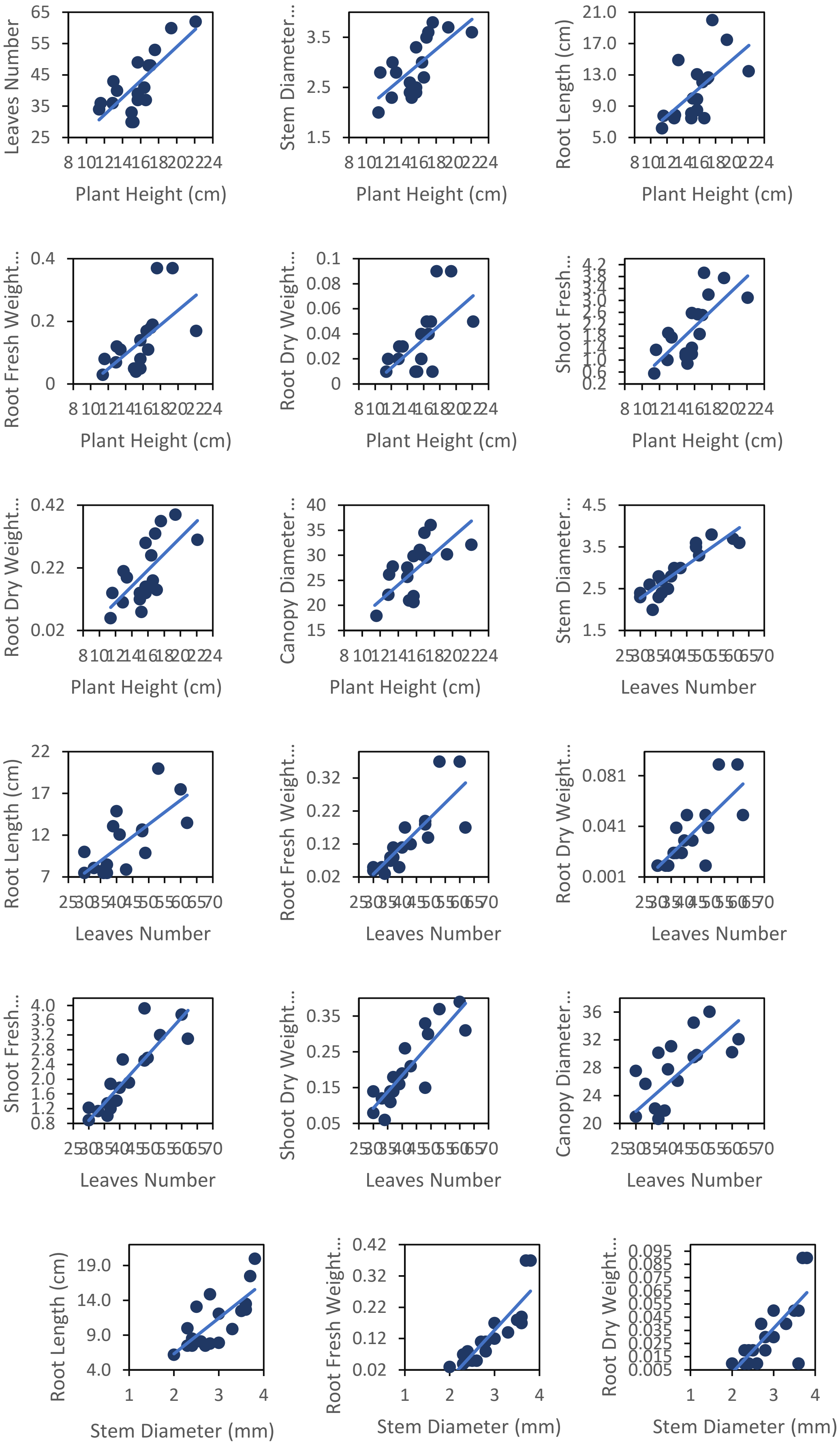

Fig. 3. Scatter plot graphs of the sperman correlation. Correlation among all the morphology variables was performed. The continuous line shows the linear regression

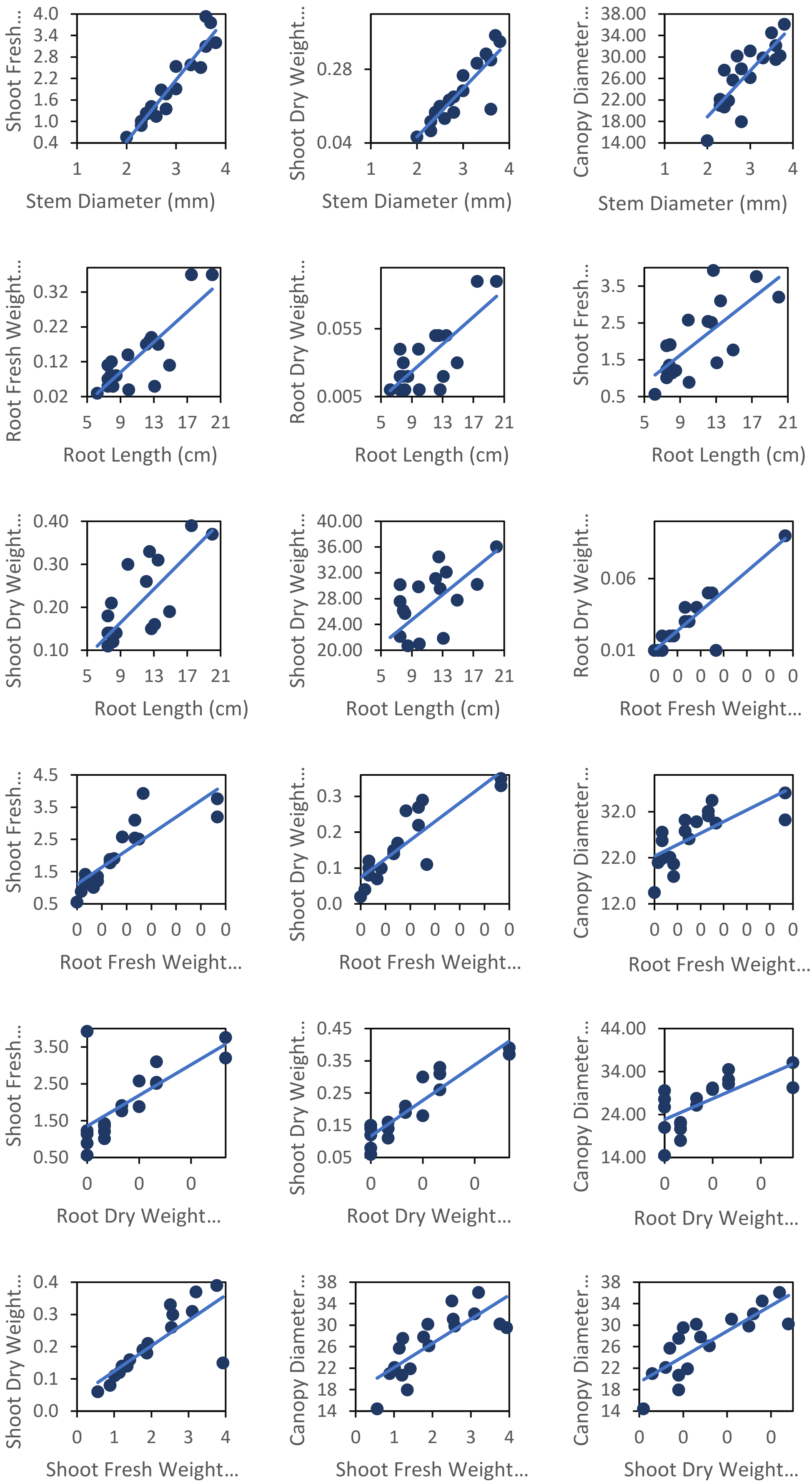

Fig. 3. (Continued)

https://doi.org/10.61511/jassu.v2i2.2025.1370

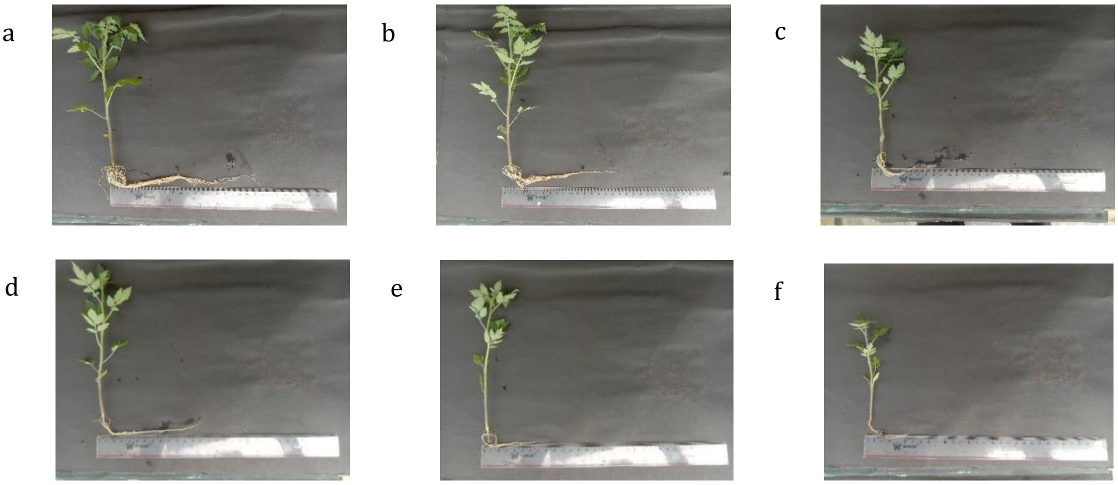

Fig. 4. (a) nitrogen 55 ppm + normal-temperature; (b) nitrogen 110 ppm + normal-temperature; (c) nitrogen 165 ppm + normal-temperature; (d) nitrogen 55 ppm + high-temperature; (e) nitrogen 110 ppm + high-temperature; (f) nitrogen 165 ppm + high-temperature. Plant age was 20 day after treatment

Inefficient fertilizer usage can diminish leaf chlorophyll contents, root dry weight, stem dry weight, and leaves dry weight, but others, namely plant height and steam diameter, were not highly impacted by it (Deng et al., 2020). Sufficient nitrogen can improve the tolerance of tomato plants in elevated-temperature conditions. The tolerance of tomato plants is equipped by appropriating nitrogen fertilizer to maintain photosynthetic efficiency, protein synthesis, and nitrogen efficiency (Luo et al., 2023). Other results have shown that nitrogen supply can increase leaf temperature and leaf cooling capacity of cucumber plants at high-temperatures (Wang et al., 2022b). Furthermore, sufficient nitrogen can decrease the severe effect of high temperatures during the filling of paddy grain (Xu et al., 2022). Based on the data, high temperatures could decrease cherry tomato plant growth (Table 6), so improving the broad doses of nitrogen and the type of nitrogen fertilizer are important for the following study to evaluate the adaptability of plants in high-temperature conditions.

Silicon is a nonessential element that can be used as a beneficial component to improve tolerant levels of plants in nutrient imbalance conditions. Silicon can increase dry biomass and photosynthesis activity, although the nitrogen level of soil is low. Regulating the activities of nitrogen metabolic enzymes in the leaf, increasing the nitrogen content under low N treatments and vice versa are occurred due to the role of silicons (Lei et al., 2024). Then, using exhausted cell culture media have a similar role to reduce nitrogen consumption in plants. Leaf area and shoot biomass are greatly increased by using exhausted media in the cultivation process. Moreover, chlorophyll content, nitrogen accumulation, functional genes that are related to N assimilation, transport, and oxidative stress are enhanced due to this potential biostimulants (Cannata et al., 2024). So, those two approaches are important strategies to reach sustainable goals by enhancing plant resilience against environment stress and decreasing nitrogen fertilizer usage.

Based on the data, cherry tomato plants was still growing in high-temperature condition. To tolerate the poor effect of high-temperatures, various mechanisms such as anatomical, morphological, physiological, and biochemical are involved in strategic adaptions of plants (John & Stephen, 2024). Besides that, potential of epigenetic modifications in breeding strategies is a new approach for plants to be more adaptable in heat stress conditions (Delarue et al., 2025). In fruiting phase, tolerant tomato tend to produce fruit with high quality properties and antioxidant compunds, such as total soluble solutes, titratable acidity, total phenol, and vitamin C (Dasgan et al., 2021). Thus the exploration of plant-tolerant mechanisms in a number of fields, namely anatomy, physiology, biochemical, and genetic is important for the next study.

In addition, genotypes that live in the long high-temperature conditions have great stem elongation and leaf area performances indicating the level of tolerance in plants. Another perspective shows that plants have low nitrogen use efficients and water contents under the high temperature. So water irrigation management on adequate amount is necessary to help plants surviving under long periods of heat stress (Park et al., 2023). Then, the increase of root dry weights of tomato plants is improved by quality levels of the light. Combinating red and blue spectrum can give a great response to dry weights of roots (Kong et al., 2021). Moreover, using the plant growth regulator, namely melatonin, can improve the plant tolerance against high-temperature stresses. Improving the tolerant performance of plants in high-temperature condition is showed by the increase of biomass, soluble protein and solid, antioxidant enzyme, ascorbate peroxidase, chlorophyll a and carotenoid contents, and auxin and abscisic acid contents (Jia et al., 2019).

From this study, nitrogen consumption efficiency is key to improving plant growth and decreasing farmer's cost. Wielemaker et al. (2019) study found that several urban agriculture cities in Netherlands have exceedingly consumed nitrogen on their daily farming system. An excessive consumption of nitrogen will negatively impact on environment, biodiversity, and human health (Tyagi et al., 2022). One strategy to minimize nitrogen use in agriculture activities is choosing optimum doses (Anas et al., 2020) and making policies (Daxini et al., 2019). Policies in the farm level are complicated to implement it on farmers who are a small actor in the long agri-food chain. The activities from the other actors are influencing too, such as fertilizer producers and wastewater companies. All of them can give an impact to nitrogen losses at the farm level and further stages. So, governments have a broader range of options to tackle the nitrogen consumption problems (Kanter et al., 2020). For instance, in China, the government made several policies that improve farmer's nitrogen management and increase food security and public health (Guo et al., 2020). Reducing fertilizer and pesticide inputs in cherry tomato production can decrease the energy depletion, water depletion, global warming, acidification, aquatic eco-toxicity, and soil toxicity. For more than 33.8% and 28.1% of the total environmental index and environmental damage cost are decreased, respectively (Guo et al., 2021).

4. Conclusions

Based on this study, on day 8, the number of cherry tomato plants increased significantly in normal-temperature conditions. Then, on day 20 and during normal-temperature treatment, leaf number and stem diameter were the best in terms of growth. The application of nitrogen 55 ppm on cherry tomato plants was the most significant response to maximize the number of leaves on day 8. Next, the other variables, such as root length, root fresh weight, shoot fresh weight, root dry weight, shoot dry weight, and growth index of cherry tomato plants, were presented as the best responses in the normal-temperature trait. Then, plants on nitrogen 55 ppm + normal-temperature treatment had the highest response of root-shoot ratio. Overall, the growth of tomato cherry plants is more effective in normal-temperature conditions and minimum nitrogen doses. As suggestions, maintaining the precision of ambient temperature, testing the nutrient level of soil and plant sample, increasing the number of replications, and measuring from other aspects such as anatomy, physiology, biochemistry, and molecular are better included for the next study.

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Author Contribution
Conceptualization, R.C.; Methodology, R.C.; Software, R.C.; Validation, R.C., A.D.S., and K.; Formal Analysis, R.C., A.D.S., and K.; Investigation, R.C.; Resources, R.C., A.D.S., and K.; Data Curation, R.C.; Writing – Original Draft Preparation, R.C.; Writing – Review & Editing, R.C.,

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Primary data is requested based on confidentiality or ethical constraints.

Conflicts of Interest
The authors declare no conflict of interest.

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