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Fruit Quality and Plant Productivity of A Cherry Tomato (*Solanum lycopersicum* var. cerasiforme) Grown under Different Irrigation Regimes during the Reproductive Phase

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Abstract

The impact of water deficit severity and the specific growth stages at which water stress is applied have been found to have significant implications for both tomato yield and fruit quality. Recent findings have highlighted the influence of water deficits during the reproductive phase on tomato fruit quality. This study aimed to assess the effects of deficit irrigation on tomato fruit quality and overall plant productivity. Cherry tomatoes (*Solanum lycopersicum* var. cerasiforme) were grown in a greenhouse from August to November 2022. Three distinct watering regimes were implemented: Daily watering (T1), watering every 3 days (T2) and watering every 7 days (T3), starting from the flowering stage and continuing through subsequent plant development stages. The mean soil metric potentials (SMP) were −4.9, −29.7 and −52.8 kPa for T1, T2 and T3, respectively. Various traits of fruit size, fruit biomass, total soluble solids (TSS), water content, glucose content and lycopene content were measured. Additionally, the overall plant biomass and root-to-shoot ratio were evaluated. The results revealed that traits of the fruit size, such as diameter, length, volume and fresh weight, were most favorable when plants were subjected to the T2 watering regime, while higher and lower watering frequencies led to smaller fruit sizes. Interestingly, the TSS concentration had the most pronounced response to drought stress, indicating increased fruit sweetness. However, the fruit water content, glucose content and lycopene content remained unaffected by the different watering regimes. Furthermore, plants subjected to the T3 with the minimum SMP at −196.4 kPa exhibited enhanced development of the root system, prioritizing resource acquisition such as water and mineral nutrients over shoot components. In conclusion, this study provided valuable insights for agricultural practitioners, offering a range of alternatives that can inform optimal irrigation strategies that effectively enhance the quality of cherry tomato yields.

Keywords: Deficit irrigation, Flowering stage, Fruit size, Lycopene, Root to shoot ratio, Total soluble solid, Tomato, Water deficit

Introduction

Cherry tomatoes (*Solanum lycopersicum* var. *cerasiforme* Alef.) belong to the Solanaceae family. Tomatoes are globally recognized as a significant vegetable crop and have the largest area of cultivation of all vegetables [1]. As societal and economic conditions improve, there is a growing shift in consumer demand for tomatoes in terms of quantity and quality, particularly with regards to the potential human health benefits they offer. Tomatoes are important in human diets due to their abundant water content, soluble sugars, dietary fiber, proteins and other essential nutritional components such as acids, lipids, amino acids and carotenoids [2]. Notably, tomatoes contain substantial levels of various bioactive compounds, including phenolics, vitamin C and provitamin A, which are believed to have protective and potentially preventive effects against cancer [3]. Lycopene, the primary carotenoid present in ripe tomatoes, imparts the characteristic orange-red color to the outer pericarp of the fruit. Lycopene has demonstrated robust antioxidant properties both *in vitro* and *in vivo* [4]. Lycopene and other active compounds present in tomatoes have gathered significant attention in the scientific community for their potential human health benefits. These compounds have been the subject of extensive research owing to their notable biological and physicochemical properties, particularly their natural antioxidant properties. Therefore, when evaluating the quality of tomato fruits, it is imperative to consider not only their size, shape and taste but also the presence of these bioactive compounds.

Tomatoes exhibit a high degree of sensitivity to environmental factors such as temperature, light and water availability during their growth cycle [5]. The impact of environmental stresses extends beyond the physiological aspects of tomato plants and also affects the synthesis of secondary metabolites and bioactive compounds [6]. In particular, water scarcity exerts an immediate adverse influence on the efficiency of water use, photosynthesis, plant growth and fruit production. Under water-deficit conditions, plants respond by disrupting cellular pathways and overall plant functions [5], and this leads to growth and development delays and reduced yields [7-9]. However, it is noteworthy that a water deficiency can paradoxically contribute to the improved quality of tomato fruit; this is primarily attributed to elevated levels of TSS such as sugars, amino acids and organic acids, which are major elements that accumulates in the fruit [10,11]. Moreover, drought-induced stress has been found to enhance the content of lycopene [12,13]. The increases in soluble solids and lycopene content add value to fresh tomatoes and enhance the overall fruit quality by influencing factors such as flavor, taste, water content and potential health benefits.

The irrigation management of greenhouse-grown tomatoes is typically guided by a farmer's experience, with the aim of achieving the maximum yield. However, this approach often leads to excessive water usage, resulting in poor fruit quality and limited financial returns. The low market value of poor-quality tomatoes and the high cost of irrigation contribute to this issue. To enhance fruit quality, a more efficient irrigation strategy based on the relationship between water availability and fruit quality has been proposed [14]. The extent of the water deficit and the specific growth stages at which water stress is applied have been found to significantly impact the tomato yield and fruit quality. Water deficit during the flowering stage, fruit development stage and fruit maturation stage has been observed to affect the tomato yield, while water stress during the fruit maturation stage primarily influences the fruit quality [15]. The imposition of drought stress during the vegetative stage inversely did not yield any significant effects on either the fruit yield or quality in comparison to the application of drought stress during other crucial growth stages [16]. In this study, we aimed to verify the hypothesis that a certain degree of water deficit reduces the tomato yield but simultaneously improves the fruit quality [17-20]. To test this hypothesis, we conducted an experimental investigation using different watering regimes, including daily watering (T1), watering every 3 days (T2) and watering every 7 days (T3), starting from the flowering stage and continuing throughout subsequent stages of plant development. Our study focused on quantitatively assessing the impact of these watering treatments on cherry tomato fruit quality as well as overall plant productivity.

Materials and methods

Study site and experimental design

The experimental site was established at the greenhouse of the Department of Botany, Faculty of Science, Kasetsart University, Bangkok, Thailand. The experimental site is located at latitude 13°50′41.7″N; longitude 100°34′15.4″S. The study was designed using a completely randomized design (CRD) and involved 3 treatments: T1 (daily watering), T2 (watering every 3 days) and T3 (watering every 7 days) using a manual irrigation method with 3 L per plant. The reason for the selection of a shorter watering period was to investigate the potential consequences of excessive irrigation, occasionally observed in certain agricultural settings. Conversely, the longer watering period was implemented to assess the impacts of water-deficit conditions. Each treatment had 5 replications, with each replication consisting of a single cherry tomato plant.

Plant materials and the measurement of their environmental variables

Cherry tomato variety Reddy (East-West Seed, Nonthaburi) was selected in this study due to its relative resistance to high temperatures and its ability to readily set fruit. In the year 2022 plants were sown in September with peat moss and then transplanted in October into 30×22 cm^2 plastic pots containing coconut peat and sand (5:1). Throughout their vegetative stage, the plants were diligently watered on a daily basis to ensure they did not experience any water stress. Additionally, the plants received 2 rounds of fertilization - the first at the time of transplantation and the second at 1 month later. Each plant was provided with a fertilizer application of 5 g N:P:K (16:16:16). In November, when the initiation of the first inflorescences by the plants, the various watering treatments (T1, T2 and T3) were commenced. The soil matric potentials (SMP) for each watering treatment were measured using Watermark soil moisture sensors equipped with a data logger (Spectrum Technologies Inc., Illinois, USA). The mean SMP values were −4.9, −29.7 and −52.8 kPa, while the minimum SMP values reached −32.4, −71.1 and −196.4 kPa for T1, T2 and T3, respectively (**Figure 1**). We also recorded the air temperature, air humidity and photosynthetically active radiation (PAR) using a WatchDog Plant Growth Micro Station (Spectrum Technologies Inc., Illinois, USA). Throughout the experiment, the average temperature remained at 32.3 °C, the mean air humidity was 62.6 %, and the average PAR was 344.8 µmol m^{-2} s^{-1}. After a period of 46 days from the onset of anthesis, the fruits were selected for sampling to assess their attributes, including fruit size, fruit biomass and fruit sweetness, as well as the content of glucose and lycopene. The fruit samples were obtained using the RAL color chart (RAL Deutsches Institut für Gütesicherung und Kennzeichnung, Bonn, Germany) with the specific code RAL3013 (tomato red). This rigorous methodology ensured the uniform collection of fruit samples at a consistent stage of maturity and senescence.

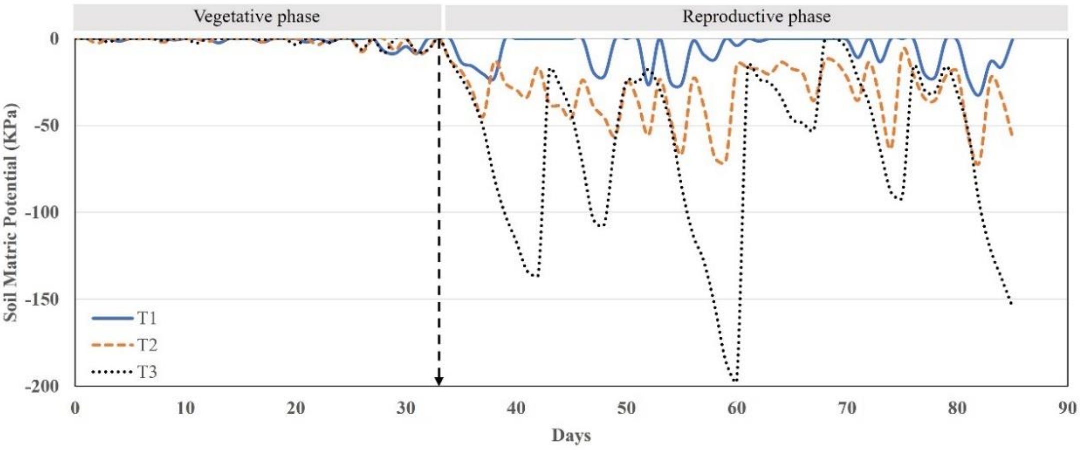

Figure 1 Soil matric potential under 3 watering treatments with blue solid line for T1: Daily watering, orange dashed line for T2: Watering every 3 days, and black dash-dotted line for T3: Watering every 7 days after the onset of anthesis. The arrow indicates the beginning of watering treatments when the first inflorescences initiated.

Analytical methods for fruit measurements

Fruit diameter and longitudinal length were measured with a digital caliper to 0.1 mm. Fruit volume was estimated as a cylinder from the length and the diameter of the fruit sample. Fresh weight (FW) was measured with a digital balance to 0.1 mg, and dry weight (DW) was measured after oven drying at 60 °C for 7 days. Fruit water content (WC) was calculated as given below [21]:

$$WC\ [\%] = [(FW - DW)/FW] \times 100$$

where all measurements were done with 3 replicates per plant.

Sweetness in fruit can be assessed using a Brix reflectometer [22]. Brix is a measurement unit that signifies the sugar content or TSS concentration in a solution. A Brix reflectometer determines the refractive index of a liquid, which correlates with its sugar concentration. In this study, fresh cherry tomato fruits were extracted by cutting and juicing them. The juice obtained from each fruit was examined for its TSS content using a Brix reflectometer. Three replicates were conducted for each fruit juice sample, and the measurements were duly recorded [23]. The mean values of individual fruits were statistically analyzed using 3 replicates per plant.

The content of glucose was conducted using the dinitrosalicylic acid (DNS) method [24]. The 1 mL of cherry tomato juice extract obtained from the TSS measurement, 2 mL of distilled water and 2 mL of DNS were added to the test tube. The tubes were placed in a water bath (100 °C) for 5 min and then cooled in frozen water. The mixture was incubated at room temperature for 15 min. When the tubes reached room temperature, 3 mL of the mixture of each test tube was transferred to a cuvette. Then the absorbance was read at a wavelength of 540 nm with a spectrophotometer. The content of glucose was calculated as given below:

$$\text{Glucose concentration (mg/mL)} = ((\text{Abs.}540 \times 0.2)/0.9441) + 0.1239,$$

where Abs.540 is the absorbance at a wavelength of 540 nm. All measurements were done with 3 replicates per fruit, and the mean values of individual fruits were statistically analyzed using 3 replicates per plant.

The lycopene content was determined by following the method of Anthon and Barrett [25]. Fresh fruit samples weighing 0.5 g were homogenized using a mortar and pestle. Subsequently, 15 mL of a hexane:ethanol:acetone mixture (2:1:1) was added to the homogenized samples. The tube was tightly capped, vigorously vortexed, and then incubated at room temperature away from bright light for 15 min. Following this, 10 mL of distilled water was added to each sample. The mixture was incubated at room temperature for an additional 15 min until all air bubbles had dissipated. The absorbance of the samples was measured at wavelengths of 444 and 503 nm using a spectrophotometer. The content of lycopene was calculated as given below:

Lycopene content (mg/kg) = ((6.95×Abs.503) – (1.59×Abs.444))×0.55×537 (V/W),

where Abs.444 and 503 are the absorbances at a wavelength of 444 and 540 nm, respectively; V is the volume of mixed solvent added; W is the weight of cherry tomato added; 0.55 is the volume ratio of the upper layer to the mixed solvents; and 537 g mol^{-1} is the molecular weight of lycopene [25].

Plant biomass measurement

After completing the measurement of fruit-related traits, the entire plants were harvested for the purpose of determining the biomass of the root and shoot components. The plants were carefully cut at the soil surface to separate the aboveground and belowground parts. The aboveground parts, consisting of stems, leaves and reproductive tissues, were weighed to obtain the fresh weight of the shoot. The pots containing the sampled plants were gently extracted from the soil, and the roots were meticulously separated from the soil mixture using a gentle stream of water [26]. The belowground parts, representing the roots, were weighed to determine the fresh weight of the root system. Both the shoots and roots were subsequently dried in an oven at 60 °C until a constant weight was achieved, enabling the measurement of their dry weight. The ratio of root to shoot (root:shoot) was calculated by dividing the dry weight of the root by the dry weight of the shoot.

Data analysis

The data and residuals were assessed for deviations from normal using the Shapiro-Wilk test. Non-normally distributed data were subjected to transformations in order to improve normality. If the transformation did not adequately stabilize the distribution, nonparametric statistics were employed. To satisfy the assumptions of ANOVA, namely the normally distributed residuals and homogeneity of variances, the shoot fresh weight was log-transformed, while all other variables remained untransformed. Differences among watering treatments for all elements, except the glucose content, were analyzed using the 1-way ANOVA for elements exhibiting normally distributed residuals. Elements with non-normally distributed residuals (in this case, the glucose content) were analyzed using the nonparametric Kruskal-Wallis test. In cases where the ANOVA indicated a significant difference among group means, a multiple-comparison Tukey's honestly significant difference (HSD) test was conducted to determine whether the trait values exhibited significant differences across the 3 watering treatments (T1, T2 and T3) for cherry tomatoes. This experiment was conducted with 5 replications for each treatment. To mitigate the issue of pseudoreplication, the mean trait values per plant were employed for measurements related to fruit traits. This approach was taken because we utilized 5 fruits per plant to assess fruit size and fresh weight, and 3 fruits per plant to determine fruit dry weight the content of water, TSS, glucose and lycopene.

Pearson correlations were computed to analyze the associations between fruit-related traits. The analysis utilized the mean trait value per plant, treating individual plants as independent data points. All statistical analyses were performed using R 4.1.1 (R Development Core Team 2021).

Results and discussion

Fruit size-related traits and fruit biomass

The amount of water received by plants throughout the cultivation period significantly influenced the fruit size. Our results revealed that cherry tomato plants subjected to watering every 7 days (T3) with minimum soil matric potential (SMP) at −196.4 kPa (**Figure 1**) had the smallest fruit size, as indicated by fruit length and fruit volume of 2.82 ± 0.09 and 8.03 ± 0.31 cm^3, respectively (**Table 1** and **Figure 2**). These results aligned with recent studies that tomato plants subjected to consistently lower quantities of water often exhibited fruit of significantly smaller size [27]. Contrary to the common prediction that increased water quantity positively affects fruit size, our findings contradicted this notion. In this study, we discovered that cherry tomato plants exposed to watering every 3 days (T2) exhibited significantly the largest fruit sizes with 12.90 ± 0.75 cm^3 and higher fresh weights with 8.99 ± 0.57 g, when compared to the plants exposed to daily watering (T1) with 9.88 ± 0.55 cm^3 and 6.76 ± 0.58 g in fruit volume and fresh weight. The mean SMP for T2 was −29.7 kPa (**Figure 1**). This level of water availability seems to be favorable for promoting optimal tomato fruit growth. Our findings align with previous research conducted by [28], which also recommended sufficient irrigation with the SMP at around −20 kPa for achieving optimal tomato growth. Moreover, studies focusing on other crops such as onion [29], radish [30] and potato [31] found that maintaining the SMP within the range between −20 and −35 kPa resulted in maximum productivity and enhanced water use efficiency.

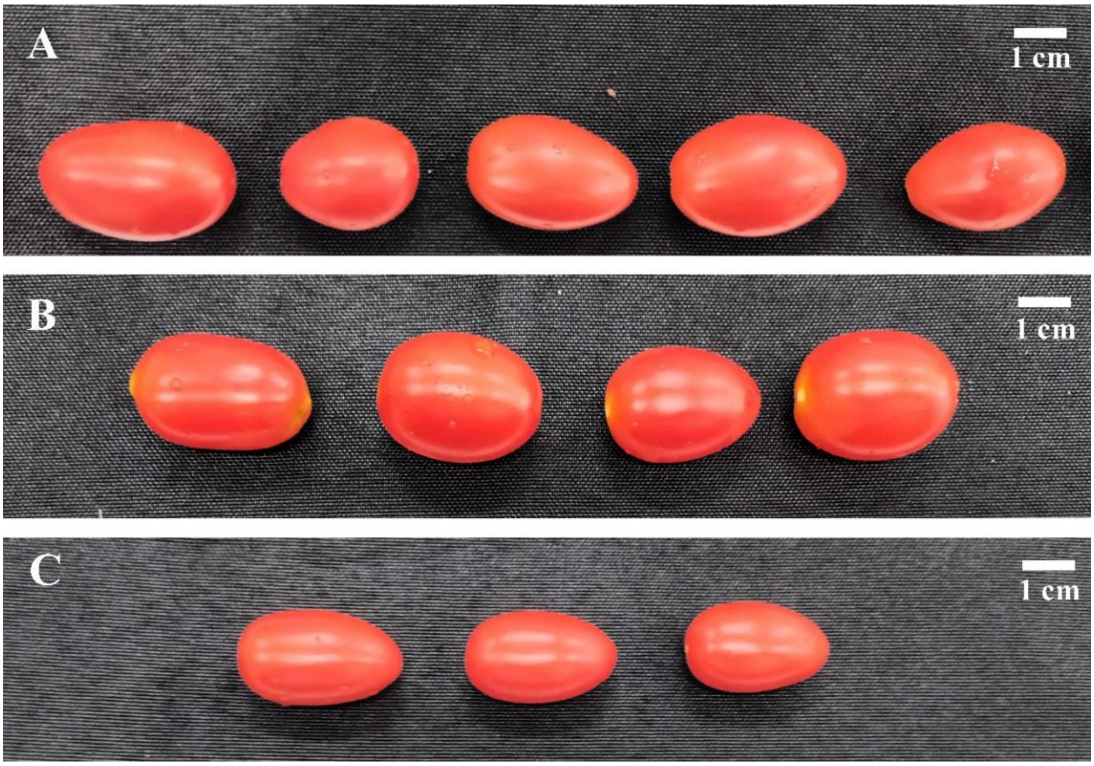

Figure 2 The fruit characteristics of cherry tomato plants grown under 3 different water regimes; T1: Daily watering (A), T2: Watering every 3 days (B), and T3: Watering every 7 days (C). Scale bars are 1 cm.

Table 1 Fruit size and biomass of cherry tomato plants grown under 3 different water regimes. Means ± SE, n = 5. Different letters in each column are significant at $p < 0.05$ according to Tukey's multiple comparison test. Significance levels of the analysis of variance (ANOVA) are ns $p > 0.05$; $p < 0.1$; $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

Watering treatment	**Fruit size**			**Fruit biomass**	
	Fruit diameter (cm)	**Fruit length (cm)**	**Fruit volume (cm^3)**	**Fresh weight (g)**	**Dry weight (g)**
T1	2.01 ± 0.04 b	3.08 ± 0.04 a	9.88 ± 0.55 ab	6.76 ± 0.58 b	1.04 ± 0.13
T2	2.22 ± 0.05 a	3.30 ± 0.06 a	12.90 ± 0.75 a	8.99 ± 0.57 a	0.82 ± 0.23
T3	1.92 ± 0.02 b	2.82 ± 0.09 b	8.30 ± 0.31 b	5.84 ± 0.24 b	0.75 ± 0.13
p-value	***	***	***	**	ns

Notes: T1: Daily watering; T2: Watering every 3 days; and T3: Watering every 7 days.

Fruit water content

The water content of fruit is a critical quality parameter in tomatoes. The highest fruit water content was observed at treatment T2, although no significant differences were observed among the various watering regimes, which ranged from 85 to 90 % (**Table 2**). This finding aligns with previous studies, which revealed that soil moisture content had no adverse effects on fruit water content in the mango [32] and tomato [16].

Table 2 Content of fruit water, TSS, glucose and lycopene of cherry tomato plants grown under 3 different water regimes. Means ± SE, n = 5. Different letters in each column are significant at $p < 0.05$ according to Tukey's multiple comparison test. Significance levels of the analysis of variance (ANOVA) are ns $p > 0.05$; $p < 0.1$; $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

Watering treatment	Water content (%)	Total soluble solids (Bx)	Glucose content (mg/mL)	Lycopene content (mg/kg)
T1	85.1 ± 0.47	5.87 ± 0.15 b	0.796 ± 0.003	98.30 ± 1.64
T2	90.8 ± 1.89	5.96 ± 0.43 b	0.821 ± 0.026	98.00 ± 3.15
T3	87.6 ± 1.95	7.69 ± 0.43 a	0.799 ± 0.003	98.50 ± 6.55
p-value	.	**	ns	ns

Notes: T1: Daily watering; T2: Watering every 3 days; and T3: Watering every 7 days.

Total soluble solids and glucose content

The sweetness-related traits in tomatoes are primarily determined by the TSS and soluble sugars [33]. Numerous studies have reported that deficit irrigation can enhance TSS concentrations [10] and soluble sugar content [15,16]. In our study, the concentration of TSS increased with drought stress for the plants exposed to watering every 7 days (T3), while the glucose content did not show significant differences among the treatments (**Table 2**). The TSS concentration for T3 was 7.69 Bx, whereas it was 5.87 and 5.96 Bx for T1 and T2, respectively. This suggests that cherry tomatoes in T3 potentially exhibited greater sweetness than those in other treatments. In addition to indicating the fruit sweetness, the TSS reflects the collective concentration of various dissolved compounds, including sugars, organic acids, amino acids and other soluble components. The accumulation of these solutes can result in a slight decrease in osmotic potential within plant tissues, particularly sugars and proline [34]. Proline and soluble sugars contribute to osmotic regulation in many plant species [35-37]. This phenomenon is commonly referred to as osmotic adjustment, an essential physiological mechanism that enables plants to tolerate water deficits [38]. During periods of water scarcity, plants experience water deficits, which can lead to reduced cell turgor pressure and impaired physiological processes. Osmotic adjustment facilitates the mitigation of these effects by modulating the osmotic potential of plant cells through solute accumulation [39]. This adjustment allows plants to maintain a higher solute concentration inside the cell compared with the surrounding environment. Consequently, water moves from areas of lower solute concentration (outside the cell) to areas of higher solute concentration (inside the cell) via osmosis [40]. This water movement preserves cell turgor [41] and enhances the plant's ability to survive in drought environments [42]. Glucose and fructose, which are considered important osmotic adjustment substances, exhibited a significant increase [43]. However, in contrast to their findings, our study did not observe any significant differences of glucose content among the deficit irrigation treatments ranged between 0.79 and 0.82 mg/mL (**Table 2**). Under water stress conditions, the breakdown of sucrose and starch is intensified, leading to a higher availability of hexose sugars [44] for involvement in osmotic adjustment processes [45]. The unexpected response observed in our study could possibly be attributed to the notion that glucose may not play a critical role as an osmolyte for osmotic adjustment in cherry tomato fruits.

Lycopene content

Many studies have presented conflicting findings regarding the impact of drought stress on lycopene accumulation in various tomato cultivars. Some studies have reported an increase in lycopene content under drought-induced stress conditions [12,13]. Conversely, other reports have suggested a decrease in lycopene content in response to drought stress [46]. Moreover, certain studies have indicated that specific tomato cultivars may not exhibit a significant response in lycopene content to increased drought conditions [47]. In the present study, we investigated the lycopene content across different watering regimes and found no significant differences, with an average content of 98 mg/kg (**Table 2**). These findings collectively suggest the complexity of reaching a definitive conclusion regarding the impact of drought-induced stress, resulting from water withholding, on lycopene biosynthesis in tomato plants.

The lack of significant differences in lycopene content among the various watering regimes in our study can be attributed to several factors. Generally, tomato fruits demonstrate a notable increase in lycopene content as they progress towards the red stage in comparison to the turning stage [48]. As climacteric fruits, tomatoes undergo changes in their respiration rate throughout the maturation process, with a climacteric peak followed by a decline. Ripening entails various transformations within the fruit, such as alterations in fruit peel color, starch conversion to sugar, softening of the fruit flesh and increased aroma. The color change in the fruit peel is directly associated with lycopene content [49]. Therefore, it is plausible that the cherry tomatoes sampled in our study were harvested at similar stages of fruit maturity, indicated by the consistent adherence to the same color code on the RAL chart for all fruit samples. This uniform fruit maturity likely contributed to the absence of significant variations in lycopene content among the different watering regimes.

Associations among fruit attributes

Pearson's correlation coefficients were employed to assess the significant linear associations among various fruit attributes (**Figure 3**). Strongly positive correlations were observed between fruit size-related traits and fresh weights, r ranged between 0.88 and 0.98, indicating their interdependence. However, neither the TSS concentration nor the lycopene content had significant correlations with other measured traits. Notably, a negative correlation was detected between fruit water content and dry weight ($r = -0.79$, p-value = 0.000398). The relationship between fruit water content and dry weight has critical implications for understanding fruit composition and quality. Fruit water content denotes the proportion of water present within the fruit, whereas dry weight represents the fruit's weight following the removal of all moisture. Generally, as the fruit water content decreases, the dry weight tends to increase. This phenomenon arises from the reduction in overall fruit weight as water is eliminated, while the solid components remain relatively constant. Consequently, fruits with lower water content tend to exhibit higher dry weights.

Assimilate transport from source to sink in most plants commonly occurs in the form of sucrose. Sucrose is enzymatically converted into glucose and fructose by sucrose invertase and sucrose synthase [50]. Carbon allocation and transformation in fruits are closely linked to the activity of metabolic enzymes during the fruit growth and development stages [51,52]. In our study, we observed a positive relationship between glucose content and both fruit size (r = 0.61 and 0.58, for fruit volume and diameter, respectively) and fruit biomass (r = 0.58 and 0.69, for fresh weight and dry weight, respectively) (**Figure 3**). The increased glucose in the fruit may serve as a source of energy and as building blocks for various metabolic processes. However, it is important to note that glucose likely does not function as an osmoregulator in the fruit (further details are discussed in the context of TSS). Throughout fruit maturation, glucose levels tend to rise, providing a crucial energy source for cellular respiration, the biosynthesis of other compounds and overall fruit metabolism.

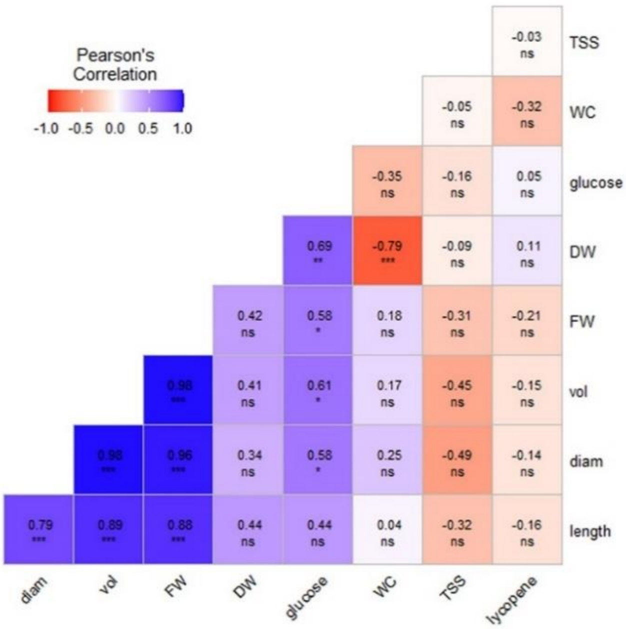

Figure 3 Correlations among fruit diameter (diam), fruit length (length), fruit volume (vol), fruit fresh weight (FW), fruit dry weight (DW), fruit water content (WC), TSS content, glucose content and lycopene content of cherry tomatoes grown under different water regimes. The correlation coefficients are shown. Color intensity is proportional to the correlation coefficient, with blue showing positive and red showing negative correlations. Significance levels of Pearson's correlations are ns $p > 0.05$; $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

Root and shoot biomass

The cherry tomato plants in T2 exhibited the highest fresh and dry biomass in the above-ground components, measuring 40.20 ± 2.59 and 9.71 ± 0.85 g, respectively. This was followed by the plants in T1, with 27.00 ± 2.59 and 7.26 ± 0.79 g, and T3, with 21.60 ± 3.45 and 6.10 ± 0.52 g (**Table 3**). Conversely, a contrasting result was observed regarding the fresh and dry biomasses of the below-ground components. Plants in T3 demonstrated the highest root biomass, measuring 28.90 ± 2.06 and 6.49 ± 0.25 g for the fresh biomass and dry biomass, respectively, followed by T2 with 11.50 ± 1.60 and 2.22 ± 0.31 g, and T1 with 3.17 ± 0.63 and 0.97 ± 0.12 g. Under optimal environmental conditions with the absence of stressors, plants tend to exhibit vigorous growth, leading to increased leaf and stem production, thereby enhancing their capacity to assimilate atmospheric carbon through photosynthesis. This growth response is evident in plants resembling those subjected to watering every 3 days (T2). Conversely, plants subjected to reduced watering in T3 responded by reducing above-ground production while concurrently prioritizing root development. This observed response aligns with the findings reported by Tejada-Alvarado *et al.* [27].

Table 3 Root and shoot biomass, and root-to-shoot ratio of cherry tomato plants grown under 3 different water regimes. Means ± SE, n = 5. Different letters in each column are significant at $p < 0.05$ according to Tukey's multiple comparison test. Significance levels of the analysis of variance (ANOVA) are ns $p > 0.05$; $p < 0.1$; $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

Watering treatment	Root		Shoot		Root: Shoot
	Fresh weight (g)	Dry weight (g)	Fresh weight (g)	Dry weight (g)	
T1	3.17 ± 0.63 c	0.97 ± 0.12 c	27.00 ± 2.59 ab	7.26 ± 0.79 ab	0.14 ± 0.02 b
T2	11.50 ± 1.60 b	2.22 ± 0.31 b	40.20 ± 2.59 a	9.71 ± 0.85 a	0.24 ± 0.04 b
T3	28.90 ± 2.06 a	6.49 ± 0.25 a	21.60 ± 3.45 b	6.10 ± 0.52 b	1.10 ± 0.11 a
p-value	***	***	**	*	***

Notes: T1: Daily watering; T2: Watering every 3 days; and T3: Watering every 7 days.

When comparing the root-to-shoot ratio among the 3 different watering regimes (**Table 3**), it was observed that the plants subjected to T3 with the mean SMP at −52.8 kPa displayed the highest root-to-shoot ratio at 1.10 ± 0.11 as relative to the other treatments, 0.14 ± 0.02 and 0.24 ± 0.04 for T1 and T2. The root-to-shoot ratio serves as an indicator of plant functional adaptation. Plants with an increased root-to-shoot ratio tend to allocate a greater proportion of biomass to the root system as opposed to the above-ground components, including stems, leaves and reproductive parts. Typically, the process of carbon assimilation, which governs the overall carbon uptake in plants, is predominantly regulated by fully expanded leaves [53]. However, the distribution of the assimilated carbon source within plants often occurs in an imbalanced manner, with unequal partitioning among various sinks [54], such as young leaves, meristematic tissues, flowers, fruits and roots. Under adverse environmental conditions that induce plant stress, certain plant species possess distinctive mechanisms for prioritizing the allocation of assimilates, deviating from the patterns observed under normal environmental circumstances [55]. An illustrative experiment conducted by Fondy and Geiger [56] involved subjecting sugar beet and bean plants to limited light exposure, allowing only a single leaf to receive sufficient light for carbon assimilation, thus facilitating solute translocation to other sinks. After approximately 8 h, diminished sugar uptake was detected in the roots, while the young leaves exhibited an increase in sugar content. This experimental evidence highlights the enhanced sink strength of young leaves in this particular scenario, surpassing that of the roots. The phenomenon can be attributed to the capacity of the primary sink to more rapidly extract sugars from the phloem transport system, thereby establishing a higher pressure gradient and facilitating a more efficient translocation of sugars toward the targeted sink.

In the present study, the findings revealed that cherry tomato plants subjected to a reduced watering frequency (T3) had an increased root-to-shoot ratio in comparison to those receiving more frequent watering. This observation signifies the adaptive response of cherry tomato plants, wherein they allocate greater resources toward the development of the root system rather than channeling them into the growth of stems, leaves or fruits. This emphasis on root system development facilitates an augmented capacity for water and nutrient absorption from the soil, consequently enhancing plant performance [40]. Hence, it can be inferred that under drought conditions, there is an alteration in assimilate partitioning, thereby conferring greater importance and strength on the root system as a primary sink, surpassing the shoot and other plant components. This response highlights the plant's ability to allocate resources strategically, prioritizing the development and functionality of the root system to cope with limited water availability and maintain vital physiological processes.

Conclusions

The findings of this investigation revealed that the application of different watering regimens from the flowering stage onward had a discernible impact on the quality attributes of cherry tomatoes. Specifically, traits related to fruit size, including diameter, length, volume and fresh weight, exhibited the highest values when plants were subjected to a watering frequency of every 3 days with the mean SMP at −29.7 kPa, while smaller fruit size was observed under higher and lower watering frequencies. Notably, the concentration of TSS emerged as the most responsive trait to drought stress, whereas fruit water content, glucose content and lycopene content remained unaffected. The elevation in TSS concentrations under high water deficit stress conditions of T3, with the minimum SMP at −196.4 kPa, implied enhanced sweetness and potential improvements in osmoregulation. Concurrently, in light of the overall productivity of the plants, those subjected to drought stress allocated carbon resources toward the development of a more extensive root system rather than shoot components, thus maximizing the acquisition of vital resources such as water and mineral nutrients. Consequently, the outcomes of this study hold considerable significance by offering agricultural practitioners a range of alternatives for making well-informed determinations concerning optimal irrigation approaches that can effectively enhance the quality of cherry tomato yields.

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