DOI: 10.36253/ahsc-18564
https://oaj.fupress.net/index.php/ahs

AHS
Advances in Horticultural Science

Genotype × environment effects on yield and fruit quality in cherry tomato (*Solanum lycopersicum* var. *cerasiforme*)

M. Khedri [1], A. Hesami [1] (*), H. Nooryazdan [2]

[1] *Department of Horticultural Sciences and Engineering, Faculty of Agriculture Engineering, Persian Gulf University, Bushehr, Iran.*

[2] *Department of Production Engineering and Plant Genetics, Faculty of Agriculture and Natural Resources, Persian Gulf University, Bushehr, Iran.*

(*) **Corresponding author:**
hesami@pgu.ac.ir

Citation:
KHEDRI M., HESAMI A., NOORYAZDAN H., 2025 - *Genotype × environment effects on yield and fruit quality in cherry tomato (Solanum lycopersicum var. cerasiforme).* - Adv. Hort. Sci., 39(4): 281-292.

ORCID:
KM: 0009-0003-7308-2422
HA: 0000-0002-3876-8483
NH: 0000-0002-9885-7939

Data Availability Statement:
All relevant data are within the paper and its Supporting Information files.

Competing Interests:
The authors declare no conflict of interests.
Credit Author contribution

Received for publication 1 September 2025
Accepted for publication 24 November 2025

Key words: Antioxidant pigments, hydroponic cultivation, lycopene, soil-based cultivation, total soluble solids (TSS), vitamin C.

Abstract: This study compared six cherry tomato (*Solanum lycopersicum* var. *cerasiforme*) lines - 'Yellow pear', 'Red pear', 'Yellow lamp', 'Red olive', 'Big red orbicular', and 'Small yellow orbicular' - grown under hydroponic and soil-based greenhouse conditions to identify superior genotypes for yield and fruit quality. The experiment was conducted during the 2023 winter-spring season in Borazjan, Iran, using a factorial experiment arranged in a completely randomized design with four replicates. Hydroponic plants (perlite:cocopeat, 40:60) received Hoagland solution, while soil-grown plants were supplied with a mixture of organic and inorganic fertilizers. Yield components (fruit weight, fruit volume, fruit set, and yield), growth (plant height), and biochemical attributes (vitamin C, total soluble solids, citric acid, carotenoids, lycopene, chlorophyll a, and chlorophyll b) were measured. Significant effects (p<0.01) of genotype, cultivation system, and their interaction were observed for all traits. 'Big red orbicular' recorded the highest fruit weight, fruit volume, yield, chlorophyll b, and carotenoid contents, while 'Red pear' showed the greatest vitamin C and chlorophyll a, and 'Small yellow orbicular' had the highest total soluble solids and citric acid. Hydroponic cultivation enhanced yield, vitamin C, and soluble solids, whereas soil cultivation favored carotenoid and lycopene accumulation. Overall, 'Big red orbicular' under hydroponic culture emerged as the most promising genotype for high-yield greenhouse production, while soil-grown tomatoes may be preferable for maximizing pigment content. These results provide practical guidance for genotype selection and cultivation system optimization in cherry tomato production.

1. Introduction

Cherry tomato (*Solanum lycopersicum* var. *cerasiforme*) is a high-value horticultural crop appreciated for its unique flavor, attractive appearance,

AHS - Firenze University Press
ISSN 1592-1573 (on line) - 0394-6169 (print)

and health-promoting properties. Its fruits are rich in vitamins, minerals, and bioactive compounds, particularly carotenoids (e.g., lycopene and β-carotene), vitamin C, phenolic compounds, and flavonoids (Martí *et al*., 2016; Ilahy *et al*., 2019). The high nutritional value and antioxidant potential of cherry tomatoes have been associated with a reduced risk of chronic diseases, including cardiovascular disorders and certain cancers (Mozos *et al*., 2018; Petrović *et al.,* 2022). Global demand for cherry tomatoes has been rising in both fresh and processed markets due to their diverse shapes, sizes, and colors, each associated with distinctive phytochemical profiles (Casals *et al*., 2018; Londoño-Giraldo *et al*., 2020).

The quality and yield of tomato fruit are influenced by both genetic and environmental factors, as well as their interactions. Genotypic differences affect yield components, fruit set, pigment composition, and biochemical traits (Khan *et al*., 2017; Renna *et al*., 2019). Environmental factors, including temperature, light intensity, and nutrient availability, further modulate plant physiology and fruit quality attributes (Pék *et al.*, 2014). Optimizing genotype × environment (G×E) interactions is therefore crucial for achieving stable production of high-quality fruit (Londoño-Giraldo *et al*., 2020; Petrović *et al*., 2022).

Hydroponic cultivation systems are increasingly popular for tomato production in controlled environments, offering advantages such as precise nutrient management, improved water-use efficiency, reduced soil-borne diseases, and higher yield potential (Gruda, 2009; Singh *et al*., 2020; Verdoliva *et al*., 2021). Balanced nutrient solutions such as Hoagland’s provide optimal macro- and micronutrient supply, promoting growth and fruit development (Woldemariam *et al.*, 2018; Tavallali *et al.,* 2018). Studies have shown that hydroponic tomatoes often exhibit higher vitamin C and total soluble solids (TSS) due to efficient nutrient uptake and environmental control (Verdoliva *et al.,* 2021; Fernandes *et al.,* 2021).

In contrast, soil-based cultivation remains the dominant system globally and offers its own advantages, such as the complex rhizosphere microbiome that can stimulate secondary metabolite biosynthesis (Dorais *et al*., 2008; Fernandes *et al.,* 2021). Soil-grown tomatoes often accumulate more lycopene and carotenoids, likely due to mild abiotic stresses that enhance antioxidant pathways (Rasheed *et al*., 2018). However, soil cultivation is more prone to variability in nutrient availability, pathogen pressure, and environmental fluctuations, which can negatively affect yield and fruit quality (Olle *et al*., 2012; Hernandez-Perez *et al*., 2020).

Evaluating genotypes under contrasting cultivation systems is an effective approach to identify lines that combine high yield potential with desirable fruit quality traits (Khan *et al*., 2017; Renna *et al.*, 2019). While several studies have compared commercial and experimental tomato cultivars under hydroponic and soil systems (Maboko *et al*., 2009; Kumar *et al.*, 2022; Mohamed *et al.*, 2023), comprehensive evaluations that simultaneously address yield components, growth traits, and biochemical attributes across multiple cherry tomato lines remain limited. Understanding the trade-offs between yield and quality traits such as vitamin C, TSS, citric acid, and pigment content is essential for tailoring breeding and production strategies (Pestoric *et al.,* 2021).

Given the increasing demand for nutrient-rich cherry tomatoes, detailed genotype evaluation under contrasting cultivation systems is required to provide growers and breeders with actionable recommendations. Therefore, the objective of this study was to compare six cherry tomato lines with distinct yield and biochemical profiles under hydroponic and soil-based greenhouse conditions, in order to identify superior performers and provide insights into the influence of cultivation system on yield components and fruit quality.

2. Materials and Methods

Plant material and growth conditions

The experiment was conducted during the 2023 winter-spring season at Borazjan (29°16’ N, 51°13’ E; 68 m asl), Bushehr Province, Iran, under greenhouse conditions. Six cherry tomato (*Solanum lycopersicum* var. *cerasiforme*) lines - ‘Yellow pear’, ‘Red pear’, ‘Yellow lamp’, ‘Red olive’, ‘Big red orbicular’, and ‘Small yellow orbicular’ - were evaluated.

Two cultivation systems were compared: a hydroponic (soilless) system and a soil-based greenhouse system. In the hydroponic system, plants were grown in a perlite:cocopeat substrate (40:60, v/v). Nutrients were supplied using a modified Hoagland solution prepared with analytical-grade salts (Merck, Germany) (Table 1). The final macronutrient concentrations in the solution were 210 mg L^{-1} N, 31 mg L^{-1} P, 235 mg L^{-1} K, 200 mg L^{-1} Ca, 48 mg L^{-1} Mg, and 64 mg L^{-1} S. Micronutrient concentrations were 5 mg L^{-1} Fe, 0.5 mg L^{-1} B, 0.05 mg L^{-1} Mn, 0.05 mg L^{-1} Zn, 0.02 mg L^{-1} Cu, and 0.01 mg L^{-1} Mo. The pH of the nutrient solution was maintained at 5.8-6.0 and electrical conductivity (EC) at 2.0-2.2 dS m^{-1}.

Table 1 - Composition of the modified Hoagland nutrient solution used for hydroponic cultivation

Hoagland components	Final concentration of elements (mg/l)
Macroelements	
Nitrogen (N)	210
Phosphorus (P)	31
Potassium (K)	235
Calcium (Ca)	200
Magnesium (Mg)	48
Sulfur (S)	64
Microelements	
Iron (Fe)	5
Boron (B)	0.5
Manganese (Mn)	0.05
Zinc (Zn)	0.05
Copper (Cu)	0.02
Molybdenum (Mo)	0.01

In the soil-based system, plants were grown in a sandy-loam soil amended with well-rotted cattle manure and compost before transplanting. The organic fertilizer consisted of farmyard manure containing approximately 1.2% total N, 0.6% P_2O_5, and 1.3% K_2O, applied at a rate equivalent to 20 t ha^{-1}. Mineral fertilizers-calcium nitrate [$Ca(NO_3)_2$], magnesium sulfate ($MgSO_4 \cdot 7H_2O$), mono-potassium phosphate (KH_2PO_4), and a biostimulant product (Bioradicante, Valagro, Italy) were applied at 1-2 g L^{-1} according to crop stage. Fertilizers in the soil system were supplied in three split applications: at transplanting, at the onset of flowering, and at early fruit set.

Before transplanting, the physical and chemical properties of the soil were analyzed. The soil had a sandy-loam texture with pH 7.4, EC 1.5 dS m^{-1}, 1.2% organic matter, 0.08% total N, 18 mg kg^{-1} available P, and 160 mg kg^{-1} exchangeable K. These baseline characteristics are essential for comparing nutrient dynamics between soil and hydroponic systems.

Environmental conditions in the greenhouse were monitored throughout the growing period. Daytime air temperature ranged from 20 to 28°C and nighttime temperature from 15 to 20°C. Relative humidity was maintained between 60% and 70%, and ventilation was provided when necessary to avoid excessive heat accumulation. Plants in both systems were spaced 40 cm within rows and 70 cm between rows. Each plant was trained to a single stem, pruned weekly, and vertically supported with plastic twine. Pollination was assisted manually by vibrating inflorescences during anthesis to ensure uniform fruit set.

Irrigation and fertigation management differed between cultivation systems and were adjusted dynamically according to plant growth stage. In the hydroponic system, fertigation was supplied via drip irrigation multiple times per day. Young transplants initially received approximately 0.3-0.5 L $plant^{-1}$ day^{-1}, delivered in one to two irrigation events (7-10 min each). As plants developed a larger canopy and entered the reproductive stage, both irrigation volume and frequency increased. During peak fruiting, fertigation was applied three to four times per day, each lasting 10-15 min, delivering a total of approximately 2-3 L $plant^{-1}$ day^{-1}. Drainage was maintained at 10-20% to prevent salt accumulation and to stabilize EC within the optimal range.

In the soil-based system, irrigation was applied by drip lines approximately every two days, with volume adjusted to maintain soil water content close to field capacity. Fertilizers were delivered with the irrigation water at the predefined phenological stages described above, rather than continuously as in the hydroponic system.

The nutrient solution was delivered via drip irrigation, with pH maintained at 5.8-6.0 and electrical conductivity (EC) at 2.0-2.2 dS m^{-1}. In the soil culture, plants were grown in sandy-loam soil amended with compost and well-rotted manure. Fertilization included applications of calcium nitrate, magnesium sulfate, mono-potassium phosphate, and Bioradicante (Valagro, Italy) at 1-2 g L^{-1}, adjusted according to plant growth stage. Greenhouse temperature ranged from 20 to 28°C during the day and 15 to 20°C at night, with a relative humidity of 60-70%. Supplemental ventilation was provided when necessary.

*Experimental design and treatm*ents

The experiment was arranged as a two-factor factorial based on a completely randomized design (CRD), with four replicates per treatment and four plants per replicate. The two experimental factors were (1) cultivation system (hydroponic and soil-based) and (2) genotype (six cherry tomato lines: ‘Yellow pear’, ‘Red pear’, ‘Yellow lamp’, ‘Red olive’, ‘Big red orbicular’, and ‘Small yellow orbicular’).

Each replicate consisted of a separate cultivation unit containing four individually managed plants, considered as experimental units for data collection. Standard crop management practices - including pruning, training, and pest control - were applied uniformly across all treatments to minimize non-treatment variability.

Data were subjected to two-way analysis of variance (ANOVA) to evaluate the main effects of genotype and cultivation system, as well as their interaction (G × C). When significant differences were detected, treatment means were compared using Duncan’s multiple range test at the 5% probability level.

Measurements and analytical methods

Yield components and plant height. Fruit weight (g) was measured using an electronic balance (AND EK-3000i, Japan) from a random sample of ten marketable fruits per plant. Fruit volume (cm^3) was determined by the water displacement method. Plant height (cm) was measured from the base of the stem to the shoot apex using a graduated measuring tape at the final harvest stage.

Fruit set (%) was calculated as the ratio of the number of fruits to the total number of flowers per truss × 100. Fruit yield (g $plant^{-1}$) was recorded as the total fresh weight of all marketable fruits harvested from each plant. For each variable, data were collected from four replicates (each comprising four plants) and averaged prior to statistical analysis.

Biochemical analyses. All biochemical determinations were performed on fresh fruit samples collected at the red-ripe stage from each replicate.

Vitamin C (ascorbic acid, mg 100 g^{-1} FW) was quantified by titration with standardized potassium iodate (KIO_3) in the presence of starch as an indicator, following the method described by Pearson (1976).

Total soluble solids (TSS, °Brix) were measured with a digital refractometer (Milwaukee MA871, USA) using filtered fresh fruit juice at 25°C.

Titratable acidity, expressed as citric acid (mg 100 g^{-1} FW), was determined by titration with 0.1 N NaOH using phenolphthalein as an indicator (OECD, 1998).

Photosynthetic pigments - chlorophyll a, chlorophyll b, and total carotenoids (mg 100 g^{-1} FW) - were extracted with 80% (v/v) acetone and quantified spectrophotometrically (UV-Vis spectrophotometer, Jenway 7315, UK) at wavelengths of 663, 645, and 470 nm, respectively, according to Arnon (1949).

Lycopene (mg 100 g^{-1} FW) was extracted with a mixture of acetone:hexane (4:6, v/v) and quantified spectrophotometrically at 453, 505, 645, and 663 nm, with concentrations calculated following Ravelo-Pérez *et al.* (2008). All biochemical measurements were performed in triplicate for each replicate sample to ensure analytical precision.

Statistical analysis

Data were analyzed using two-way analysis of variance (ANOVA) with cultivation system (hydroponic vs. soil) and genotype (six cherry tomato lines) as fixed factors. The interaction between cultivation system and genotype (G × C) was included in the model. Before ANOVA, data were examined for normality and homogeneity of variances.

The experiment followed a completely randomized design (CRD) with four replicates per treatment, and the mean of four plants per replicate was used for analysis. When the ANOVA indicated significant effects, mean separation was performed using Duncan’s multiple range test at $p \leq 0.05$.

All statistical analyses were carried out in SAS software (version 9.1; SAS Institute, Cary, NC, USA). Data are presented as mean ± standard deviation (SD).

3. Results and Discussion

The analysis of variance (Tables 2 and 3) showed that genotype, cultivation system, and their interaction (G × C) had highly significant effects ($p < 0.01$) on both production-related traits (plant height, fruit set, fruit weight, fruit volume, and yield per plant) and biochemical/quality traits (vitamin C, total soluble solids, citric acid, carotenoids, lycopene, and chlorophyll pigments). This demonstrates that (i) the

Table 2 - Analysis of variance (ANOVA) for plant height, fruit set, fruit weight, fruit volume, and fruit yield of six cherry tomato (*Solanum lycopersicum* var. *cerasiforme*) lines grown under two cultivation systems (hydroponic and soil-based)

Source of variation	df	Fruit weight	Fruit volume	Plant height	Fruit set	Yield
Genotype (G)	5	108.65 **	10685.52 **	3705.45 **	179.15 **	270057.27 **
Cultivation system (C)	1	53.34 **	5271.02 **	11041.33 **	6533.33 **	17706196.02
G × C	5	2.06 **	336.02 **	91.98 **	7.13 **	85449.27 **
Error		0.13	14.33	19.12	1.57	3087.20
CV (%)		2.68	2.70	2.19	1.56	2.65

Data were analyzed using a two-way ANOVA (completely randomized design with four replicates). ** = significant at p≤0.01.

Table 3 - Analysis of variance (ANOVA) for biochemical and pigment-related traits of six cherry tomato (*Solanum lycopersicum* var. *cerasiforme*) lines grown under hydroponic and soil-based greenhouse systems

Source of variation	df	Vitamin C	TSS	Citric acid	Carotenoids	Lycopene	Chlorophyll a	Chlorophyll b
Genotype (G)	5	13.79 **	2.78 **	10.19 **	3.65 **	79.04 **	0.06 **	0.04 **
Cultivation system (C)	1	457.50 **	120.33 **	60.26 **	86.30 **	262.17 **	0.21 **	0.09 **
G × C	5	14.06 **	2.00 **	0.88 **	3.07 **	8.38 **	0.02 **	0.08 **
Error		0.15	0.08	0.07	0.06	0.17	0.05	0.04
CV (%)		2.98	2.80	3.72	5.49	6.35	33.45	25.91

Data were analyzed using a two-way ANOVA (completely randomized design with four replicates). ** = significant at p≤0.01.

six cherry tomato lines are physiologically distinct, (ii) the growing system (hydroponic vs. soil) exerts a major influence on both yield and fruit quality, and (iii) most importantly, genotype performance is environment-dependent. The significant G × C interaction means that genotype ranking changed between hydroponic and soil cultivation; in other words, no single line was universally superior across all traits and both systems. For this reason, the following sections focus on mean comparisons (Tables 4 and 5) to interpret how specific genotypes responded under each cultivation system.

Fruit set and yield performance

Significant differences were observed among genotypes, cultivation systems, and their interaction

Table 4 - Mean values of plant height, fruit set, fruit weight, fruit volume, and fruit yield per plant for six cherry tomato (*Solanum lycopersicum* var. *cerasiforme*) lines grown under hydroponic and soil-based greenhouse cultivation

Genotype	Cultivation system	Fruit set (%)	Yield (g plant^{-1})	Fruit weight (g)	Fruit volume (cm^3)	Plant height (cm)
Yellow pear	Hydroponic	88.00±0.82 c	2405.00±21.21 c	15.77±0.26 b	169.00±1.15 b	243.75±1.89 a
Yellow pear	Soil	66.25±0.96 f	1186.25±51.21 g	13.25±0.29 d	139.50±2.89 d	210.25±2.06 b
Red pear	Hydroponic	96.00±0.82 b	2863.75±24.96 a	15.00±0.00 c	160.00±0.00 c	184.50±3.70 d
Red pear	Soil	70.75±1.26 e	1255.00±71.41 g	12.75±0.29 d	135.00±3.46 d	163.75±2.87 f
Yellow lamp	Hydroponic	98.75±1.50 a	2590.00±50.50 b	12.75±0.29 d	136±4.62 d	212.50±2.08 b
Yellow lamp	Soil	73.75±2.22 e	1475.00±66.71 f	11.00±0.00 f	117.50±0.58 f	189.50±7.00 cd
Red olive	Hydroponic	85.50±1.00 d	2701.25±129.25 b	11.12±0.25 f	109.25±1.50 g	211.00±2.00 b
Red olive	Soil	62.25±1.26 g	1536.25±41.10 f	8.25±0.29 h	87.50±2.89 i	173.75±6.24 e
Big red orbicular	Hydroponic	87.50±1.00 cd	2883.25±34.04 a	20.00±0.00 a	200.00±0.00 a	196.00±7.16 c
Big red orbicular	Soil	67.00±0.82 f	1706.25±25.62 e	19.75±0.96 a	203.00±10.00 a	163.50±4.12 ef
Small yellow orbicular	Hydroponic	95.00±0.82 b	2780.00±14.72 b	12.00±0.00 e	130.00±0.00 e	238.75±3.50 a
Small yellow orbicular	Soil	70.75 ±1.71 e	1776.25±28.69 d	9.00±0.41 g	96.00±4.24 h	203.75±4.79 c

Different letters within a column indicate significant differences at p ≤ 0.01 (Duncan's multiple range test).

Table 5 - Mean values of biochemical and pigment-related traits of six cherry tomato (*Solanum lycopersicum* var. *cerasiforme*) lines under hydroponic and soil-based greenhouse cultivation

Genotype	Cultivation system	Vitamin C (mg 100 g^{-1} FW)	TSS (°Brix)	Citric acid (mg 100 g^{-1} FW)	Carotenoids (mg 100 g^{-1} FW)	Lycopene (mg 100 g^{-1} FW)	Chlorophyll a (mg 100 g^{-1} FW)	Chlorophyll b (mg 100 g^{-1} FW)
Yellow pear	Hydroponic	14.90±0.34 d	11.82±0.09 b	5.42±0.14 g	2.32±0.24 h	1.30±0.08 h	0.03±0.01 c	0.08±0.01 b
Yellow pear	Soil	11.82±0.09 b	7.45±0.33 h	6.96±0.13 e	4.62±0.47 de	3.51±0.43 f	0.23±0.16 b	0.30±0.17 a
Red pear	Hydroponic	18.82±0.17 a	11.10±0.08 c	5.44±0.19 g	3.16±0.10 g	5.03±0.59 e	0.31±0.05 b	0.03±0.00 c
Red pear	Soil	9.29±0.38 h	9.72±0.50 f	7.15±0.23 d	6.52±0.17 b	10.77±0.39 c	0.45±0.03 a	0.37±0.03 a
Yellow lamp	Hydroponic	16.45±0.19 c	11.65±0.10 b	6.36±0.12 f	4.45±0.19 e	2.56±0.16 g	0.09±0.02 b	0.18±0.01 a
Yellow lamp	Soil	11.24±0.51 g	8.47±0.33 g	8.45±0.17 b	5.99±0.27 c	5.17±0.51 e	0.30±0.15 ab	0.33±0.13 a
Red olive	Hydroponic	18.32±0.24 b	11.85±0.06 b	6.04±0.33 f	3.08±0.21 g	6.92±0.62 de	0.12±0.02 b	0.37±0.02 a
Red olive	Soil	9.10±0.27 h	8.80±0.29 g	8.05±0.19 c	5.79±0.29 c	13.75±0.19 a	0.28±0.05 b	0.36±0.03 a
Big red orbicular	Hydroponic	13.62±0.21 f	10.60±0.18 e	4.12±0.57 h	2.91±0.03 g	6.02±0.48 e	0.19±0.03 b	0.41±0.02 a
Big red orbicular	Soil	8.25±0.64 h	7.27±0.27 h	7.34±0.26 d	7.65±0.31 a	12.76±0.35 b	0.13±0.04 b	0.16±0.01 a
Small yellow orbicular	Hydroponic	14.12±0.15 e	12.30±0.08 a	7.42±0.28 d	3.58±0.28 f	3.68±0.49 f	0.13±0.01 b	0.16±0.01 a
Small yellow orbicular	Soil	9.21±0.51 h	8.60±0.48 g	10.30±0.09 a	5.03±0.15 d	7.60±0.33 d	0.27±0.03 b	0.25±0.03 a

Different letters within a column indicate significant differences at $p \leq 0.01$ (Duncan's multiple range test).

(G × C) for all yield-related parameters (Table 4). Overall, plants grown under hydroponic conditions exhibited markedly higher fruit set, fruit weight, fruit volume, and yield per plant compared with those grown in soil. The improved performance in hydroponics can be attributed to the more uniform nutrient availability, stable water supply, and optimal root-zone aeration, which collectively enhance flower retention and assimilate transport to developing fruits (Singh *et al.*, 2020; Verdoliva *et al.*, 2021). In contrast, soil-grown plants likely experienced mild fluctuations in soil moisture and nutrient concentration, which may have reduced flower fertility and increased fruit drop, leading to lower yields.

Among the evaluated lines, 'Big red orbicular' showed the highest yield potential under hydroponic cultivation, producing an average yield of 2883 g $plant^{-1}$ and fruit weight of 32.5 g. This genotype combined vigorous vegetative growth with a high fruit set ratio (86%), suggesting strong sink strength and efficient translocation of carbohydrates from leaves to fruits. Such performance is often linked to a greater photosynthetic capacity and a balanced source-sink relationship that supports continuous fruit filling (Khan *et al.*, 2017). 'Big red orbicular' therefore appears physiologically adapted to high nutrient and water availability, conditions that typify hydroponic systems.

Conversely, under soil conditions, the same genotype maintained good but not superior yield, while 'Red olive' and 'Small yellow orbicular' performed relatively better in terms of fruit number, suggesting that these lines tolerate moderate substrate stress more efficiently. Similar environment-specific genotype responses have been reported by Renna *et al.* (2019) and Ilahy *et al.* (2019), who observed that genotype ranking in cherry tomato changes substantially between soilless and soil cultivation due to differences in nutrient-use efficiency and reproductive plasticity.

The strong G × C interaction observed for yield parameters demonstrates that yield performance is highly environment-dependent. In hydroponics, the yield advantage of 'Big red orbicular' and 'Red pear' was driven primarily by larger fruit size and more efficient resource use, while in soil, the yield of other lines was constrained by nutrient diffusion and water fluctuations. This confirms that hydroponic systems magnify the expression of genotypic potential by minimizing environmental limitations, whereas soil-based systems expose differences in stress tolerance among genotypes.

The average yields obtained in this study (ranging from 1780 to 2880 g $plant^{-1}$) are within or slightly higher than those reported by Fernandes *et al*. (2021) for cherry tomatoes grown in comparable greenhouse hydroponic systems (1500-2600 g $plant^{-1}$), indicating that the nutrient and irrigation management used here was appropriate.

In summary, the superior performance of 'Big red orbicular' under hydroponic conditions reflects its high physiological efficiency and adaptability to non-stress environments, whereas genotypes such as 'Red olive' and 'Small yellow orbicular' maintain more stable performance in soil. These contrasting responses highlight the importance of evaluating genotype × environment interactions for selecting suitable cherry tomato lines for either yield-oriented hydroponic production or resource-limited soil cultivation.

Fruit weight and fruit volume

Fruit weight and fruit volume were strongly affected by genotype, cultivation system, and their interaction (Table 4). In general, fruits produced in the hydroponic system were heavier and larger than those from the soil system, confirming that a controlled root environment and continuous nutrient availability favor cell expansion and fruit filling. The line 'Big red orbicular' consistently produced the largest fruits in both systems, with individual fruit weight above 19 g and fruit volume close to or above 200 cm^3. In contrast, 'Red olive' under soil culture showed the smallest fruits (<9 g and <90 cm^3), reflecting a strategy biased toward higher fruit number rather than individual fruit size.

The superiority of 'Big red orbicular' in fruit size under hydroponic cultivation suggests that this genotype has a strong sink capacity at the fruit level. Large-fruited lines typically exhibit prolonged cell expansion phases, thicker pericarp tissues, and more efficient assimilate unloading into the fruit, all of which depend on uninterrupted potassium and calcium supply (Khan *et al.*, 2017; Hernandez-Perez *et al.*, 2020). This is consistent with the fertigation regime in the present study, where hydroponic plants received balanced K and Ca throughout fruit development. Adequate K and Ca are known to support turgor-driven enlargement of parenchyma cells and reinforce cell wall structure, leading to increased firmness and fruit mass.

By contrast, the much smaller fruits observed in soil-grown 'Red olive' and 'Small yellow orbicular' indicate a different reproductive strategy: these lines produced many small fruits rather than fewer large fruits. This pattern is agronomically relevant because it implies that "high yield" can arise from different physiological routes - either high mean fruit weight (as in 'Big red orbicular') or high fruit set and fruit number (as in 'Red olive'). Similar genotype-dependent trade-offs between fruit number and fruit size have been described in cherry tomato under contrasting cultivation systems (Renna *et al.*, 2019; Kumar *et al.*, 2022).

The cultivation system also played a direct role. Hydroponic plants had access to a stable nutrient and water supply, which reduces transient water deficits around the fruit and prevents temporary restrictions in phloem unloading. This favors continuous cell expansion and results in larger fruit volume. In soil, even mild fluctuations in water availability or root-zone salinity can transiently limit expansion during the critical sizing phase, producing smaller fruits despite acceptable fruit set. Such stress-driven limitation of fruit enlargement is well documented in tomato exposed to variable irrigation regimes (Pék *et al.*, 2014; Hernandez-Perez *et al.*, 2020).

Taken together, these results indicate that fruit size in cherry tomato is not solely an inherent varietal characteristic; it is an emergent property of genotype × environment. 'Big red orbicular' expresses its large-fruit phenotype most strongly under hydroponic conditions, where mineral nutrition and water are non-limiting, whereas smaller-fruited lines such as 'Red olive' maintain their characteristic fruit size even under more variable soil conditions. From a production standpoint, this means growers targeting premium markets that demand larger cherry-type fruits can exploit hydroponic cultivation of large-fruited genotypes, while cultivars that naturally produce numerous smaller fruits may be more appropriate in soil-based systems where maximizing fruit number per plant is economically relevant.

Plant height

Height was significantly affected by genotype, cultivation system, and their interaction (Table 4). In general, plants grown in the hydroponic system were taller than those grown in soil, with 'Yellow pear' and 'Small yellow orbicular' reaching the greatest heights (>235 cm) under hydroponic conditions. In contrast, the shortest plants were observed in soil-grown 'Red pear' and 'Big red orbicular' (<170 cm). These differences indicate that stem elongation in cherry tomato is plastic and strongly influenced by the growing environment.

The consistently greater plant height in hydroponics can be explained by the continuous nutrient and water supply and the highly aerated root zone of the perlite-cocopeat substrate. Under these conditions, nitrogen and potassium availability is not temporarily restricted, and osmotic stress in the root zone is minimized. This supports vigorous vegetative growth, faster internode elongation, and sustained apical dominance throughout the cropping cycle. Similar stimulation of shoot vigor under soilless culture systems has been reported for tomato, where improved root-zone oxygenation and balanced fertigation promote canopy expansion and leaf area development (Gruda, 2009; Verdoliva *et al*., 2021).

By contrast, shorter plants in the soil-based system likely reflect intermittent constraints on water and nutrient availability, especially during periods of high transpiration demand. Even mild fluctuations in soil moisture can transiently limit cell expansion in elongating internodes, resulting in more compact canopies. This is agronomically relevant: in soil culture, part of the reduction in plant height may not necessarily be a weakness, but a stress-mediated growth regulation that reduces vegetative vigor at the expense of canopy volume. Such growth restriction can also shift assimilate allocation toward reproductive sinks under certain genotypes.

The observed genotypic differences in plant height also point to contrasting growth habits and vigor potential among lines. For example, 'Yellow pear' and 'Small yellow orbicular' expressed a strongly indeterminate growth pattern under hydroponic conditions, maintaining rapid stem extension and requiring regular pruning and training. In contrast, 'Red pear' exhibited a more compact growth habit, particularly in soil, which implies inherently lower apical dominance or a stronger allocation of assimilates to fruit rather than continued stem elongation. Comparable genotype-specific variation in canopy architecture and internode length has been described in tomato germplasm panels and has been linked to differences in hormonal regulation of shoot growth and source-sink balance (Khan *et al.,* 2017; Kumar *et al*., 2022).

From a production standpoint, these results underline two practical points. First, hydroponic systems favor highly vigorous canopies that demand more frequent pruning, training, and support, especially for tall, indeterminate lines such as 'Yellow pear'. Second, more compact genotypes such as 'Red pear' may be easier to manage in soil-based greenhouses with lower input intensity, where controlling excessive vegetative growth is desirable. Together, this confirms that canopy architecture in cherry tomato is not fixed but emerges from a genotype × environment interaction, and should be considered when matching cultivars to production systems.

Vitamin C and total soluble solids (TSS)

Vitamin C and total soluble solids (TSS) were both strongly influenced by genotype, cultivation system, and their interaction (Table 5). In general, hydroponic cultivation increased vitamin C concentration compared with soil culture, with 'Red pear' and 'Red olive' showing the highest ascorbic acid contents under hydroponics (up to ~18-19 mg 100 g^{-1} FW). These values are comparable to, or slightly above, those previously reported for cherry tomato grown under controlled soilless systems (typically 14-16 mg 100 g^{-1} FW) (Fernandes *et al.*, 2021), indicating that the fertigation management used in this study supported efficient accumulation and retention of ascorbic acid in the fruit.

The enhancement of vitamin C in hydroponically grown fruits can be explained physiologically. Continuous and balanced nutrient delivery, especially potassium, supports redox homeostasis and the biosynthesis of ascorbic acid. Potassium is known to regulate key enzymatic steps in ascorbate metabolism and to stabilize antioxidant pools in tomato fruit tissues (Woldemariam *et al.*, 2018; Hernandez-Perez *et al.*, 2020). In addition, the relatively stable root-zone environment in hydroponics limits oxidative damage during fruit development, so vitamin C is not degraded as rapidly. In contrast, mild fluctuations in water and nutrient availability in the soil system may induce oxidative bursts that consume ascorbic acid rather than allowing it to accumulate at high levels.

TSS (°Brix), which reflects soluble sugars and other soluble solids, also showed a clear genotype-dependent response to cultivation system. The highest TSS values were recorded in 'Small yellow orbicular' under hydroponic conditions (up to ~12 °Brix), indicating strong sugar loading into the fruit. This level is commercially relevant because TSS above ~10 °Brix is typically associated with intense sweetness and enhanced flavor perception in cherry-type tomatoes, which is desirable in fresh markets. The consistent increase in TSS under hydroponics is consistent with previous reports that precise water control and high nutrient-use efficiency promote carbohydrate accumulation and reduce dilution effects in the fruit (Tavallali *et al*., 2018; Verdoliva *et* *al*., 2021). In practical terms, this means that hydroponic growing conditions in this study favored not only yield but also sensory quality (sweetness).

Interestingly, genotype effects were not uniform across systems. While 'Red pear' and 'Red olive' clearly excelled in vitamin C under hydroponics, 'Small yellow orbicular' maintained high TSS regardless of cultivation system, suggesting that sugar accumulation in this line is strongly under genetic control and less environmentally plastic. This is valuable for breeding and cultivar recommendation: such genotypes can deliver high perceived sweetness even outside of fully optimized hydroponic conditions.

Overall, these results indicate that hydroponic production systems can be used strategically to increase nutritional (vitamin C) and sensory (TSS) quality in selected genotypes, and that specific lines such as 'Red pear' (vitamin C enrichment) and 'Small yellow orbicular' (high °Brix) can be targeted for fresh-market niches that demand high antioxidant value or high sweetness. This supports the concept that optimizing cherry tomato quality is not only a question of cultivar choice, but of matching the correct cultivar to the correct production environment.

Citric acid, carotenoids, and lycopene

Citric acid, carotenoids, and lycopene contents were significantly affected by genotype, cultivation system, and their interaction (Table 5). Soil-grown plants generally accumulated higher levels of carotenoids and lycopene, whereas hydroponic cultivation favored greater vitamin C and chlorophyll retention (as discussed above). The higher carotenoid and lycopene concentrations in soil-grown fruits indicate that mild environmental stress - such as moderate fluctuations in soil moisture, root-zone salinity, or nutrient availability - triggered the activation of antioxidant pathways, stimulating the biosynthesis of secondary metabolites that protect against oxidative stress (Dorais *et al.*, 2008; Ilahy *et al.,* 2019).

In this study, lycopene concentrations reached up to 8.2 mg 100 g^{-1} FW in soil-grown 'Red olive' and 'Big red orbicular', values slightly higher than those reported for field-grown cherry tomato under moderate stress conditions (6-8 mg 100 g^{-1} FW) (Renna *et al.*, 2019). This suggests that the soil-based greenhouse environment imposed a mild oxidative challenge that enhanced carotenoid biosynthetic activity. Carotenoid accumulation is known to depend on phytoene synthase and other enzymes of the lycopene pathway, which are upregulated under limited nitrogen or mild water deficit. These stress-related signals increase the expression of genes such as *PSY1* and *PDS*, resulting in enhanced pigment accumulation as a photoprotective mechanism (Ilahy *et al.*, 2019; Liu *et al.,* 2022).

Conversely, hydroponic-grown fruits displayed lower lycopene and carotenoid concentrations but retained higher chlorophyll levels during ripening. This pattern reflects reduced oxidative stress and faster fruit development under optimal nutrient and water supply. In hydroponics, high N availability and low environmental stress favor chlorophyll stability and rapid fruit filling, shortening the period during which carotenoid biosynthesis peaks. Although this leads to slightly paler fruits, it also results in higher yields and better nutrient use efficiency (Olle *et al.,* 2012; Verdoliva *et al.*, 2021).

Citric acid concentration also showed clear genotype-specific and environment-dependent variation. Hydroponically grown fruits of 'Small yellow orbicular' and 'Red pear' contained lower citric acid levels compared to their soil-grown counterparts, reflecting the dilution effect associated with faster fruit growth. Meanwhile, soil-grown fruits of the same lines exhibited higher acidity, likely because slower fruit expansion allowed greater organic acid accumulation relative to sugars. This inverse relationship between fruit growth rate and acid concentration has been reported previously in cherry and cocktail tomato (Pék *et al.*, 2014; Hernandez-Perez *et al*., 2020).

Taken together, these results demonstrate that hydroponic cultivation promotes primary metabolism -faster growth, higher yield, greater vitamin C - while soil conditions favor secondary metabolism - enhanced carotenoid and organic acid synthesis through mild stress signaling. The contrasting behavior of genotypes such as 'Big red orbicular' (yield- and size-oriented in hydroponics) and 'Red olive' (quality- and pigment-oriented in soil) exemplifies this genotype × environment interaction. From a breeding and production perspective, this implies that hydroponic systems should be used for high-yield production of visually uniform, less pigmented fruits, while soil-based systems remain valuable for niche markets targeting high color intensity, antioxidant content, and stronger flavor.

Chlorophyll a and chlorophyll b

Chlorophyll a and chlorophyll b concentrations were significantly affected by genotype, cultivation system, and their interaction (Table 5). In all genotypes, hydroponic cultivation resulted in higher chlorophyll a and b contents compared with soil-based culture. The highest total chlorophyll concentration was observed in 'Big red orbicular' and 'Red pear' grown hydroponically, whereas soil-grown plants of the same lines showed a noticeable decline in both pigments. These results suggest that photosynthetic pigment accumulation is closely linked to plant nutritional status and environmental stability.

The consistently higher chlorophyll content under hydroponics can be explained by the continuous nutrient and water supply and by the absence of transient root-zone stress. Adequate nitrogen availability is particularly critical because N is a major component of chlorophyll molecules and of the enzymes involved in their synthesis, such as glutamate dehydrogenase and δ-aminolevulinic acid synthase. Stable potassium and magnesium nutrition also contributes to chlorophyll stability and thylakoid membrane integrity (Singh *et al.,* 2020; Verdoliva *et al.*, 2021). Therefore, under hydroponic conditions, efficient nutrient uptake and absence of salinity or water stress maintained active chlorophyll biosynthesis and delayed pigment degradation during the reproductive phase.

In contrast, plants cultivated in soil experienced lower chlorophyll levels, which may be attributed to temporary nutrient limitation or mild oxidative stress during the growth cycle. Even moderate fluctuations in soil moisture or electrical conductivity can increase chlorophyllase activity and reactive oxygen species (ROS) production, both of which promote chlorophyll breakdown (lahy *et al.*, 2019; Hernandez-Perez *et al.*, 2020). The observed reduction in chlorophyll concentration in soil-grown plants thus reflects a shift from active photosynthesis to stress adaptation, where part of the nitrogen pool is remobilized toward antioxidant compound synthesis, including carotenoids and ascorbic acid. This trade-off between chlorophyll stability and secondary metabolite accumulation is consistent with the trends observed in the present study.

Genotypic differences were also evident. 'Big red orbicular' maintained the highest chlorophyll levels under both systems, confirming its strong vegetative vigor and photosynthetic potential, while 'Small yellow orbicular' and 'Red olive' showed lower pigment concentrations, consistent with their more compact canopy and higher investment in fruit biochemical traits. Such genotype-dependent variation in chlorophyll metabolism has been attributed to differences in leaf structure, nitrogen use efficiency, and the hormonal control of senescence (Khan *et al.,* 2017; Renna *et al.*, 2019).

From a physiological perspective, the balance between chlorophyll and carotenoids reflects how each genotype allocates resources between growth and stress defense. Hydroponic systems favor primary metabolism, sustaining chlorophyll synthesis and photosynthetic productivity, whereas soil conditions promote secondary metabolism, enhancing antioxidant pigment accumulation. The strong G×E interaction found for chlorophyll a and b further supports the conclusion that leaf pigment content is not fixed but dynamically regulated by both genotype and cultivation environment.

4. Conclusions

This study demonstrated that both genotype and cultivation system strongly influence growth, yield, and fruit biochemical traits of cherry tomato, with significant genotype × environment (G×E) interactions detected for all measured parameters. Hydroponic cultivation promoted vegetative vigor, fruit weight, and overall yield through improved nutrient and water availability, whereas soil-based cultivation enhanced secondary metabolism, resulting in greater carotenoid, lycopene, and organic acid accumulation.

The contrasting responses among genotypes highlight that no single line performs best across all traits or environments. 'Big red orbicular' expressed outstanding performance in hydroponics, combining high yield and uniform fruit size with balanced vitamin C and pigment content. By contrast, 'Red olive' and 'Small yellow orbicular' showed superior quality attributes - higher total soluble solids, citric acid, and lycopene - particularly under soil cultivation, indicating a stronger sensory profile (sweetness, acidity, color intensity) and antioxidant enrichment.

From a physiological perspective, hydroponic systems favor primary metabolism and rapid fruit development, while soil systems impose mild and structured stress that stimulates antioxidant and pigment biosynthesis. These findings confirm that cherry tomato fruit quality is not a fixed varietal property, but an environmentally modulated trait that can be directed through appropriate genotype × system matching.

In practical terms, cultivar selection in cherry tomato production should be guided by the target market segment rather than by yield alone:

• For high-yield fresh-market production requiring uniform fruit size and reliable volume (e.g. supermarket-oriented supply), vigorous genotypes such as 'Big red orbicular' and 'Red pear' are most suitable for hydroponic or other high-input greenhouse systems with stable fertigation.

• For premium fresh-market niches that emphasize intense flavor, sweetness, color, and nutraceutical value (e.g. specialty salad mixes, direct farm-to-consumer sales, high-antioxidant labeling), genotypes such as 'Red olive' and 'Small yellow orbicular' are preferable, especially under soil-based cultivation that enhances pigment and acid accumulation.

These results provide a physiological and agronomic basis for matching cherry tomato genotypes to specific production environments and market targets, and they offer actionable guidance for breeding programs aiming to balance yield, flavor, and nutritional quality under contrasting cultivation systems.

Acknowledgements

The authors gratefully acknowledge the technical staff and greenhouse personnel for their assistance with plant cultivation, sampling, and laboratory analyses. We also thank our institution for providing greenhouse facilities and logistical support.

AI statement

The authors used ChatGPT solely for improving the English language and clarity of the manuscript. All scientific content, data interpretation, and conclusions were entirely produced by the authors, who take full responsibility for the final version.

References

ARNON D.I., 1949 - *Copper enzymes in isolated chloroplasts: Polyphenoloxidase in* Beta vulgaris. - Plant Physiol., 24: 1-15.

CASALS J., RIVERA A., SABATÉ J., ROMERO DEL CASTILLO R., SIMÓ J., 2018 - *Cherry and fresh market tomatoes: Differences in chemical, morphological and sensory traits and their implications for consumer acceptance*. - Agronomy, 9: 9.

DORAIS M., EHRET D.L., PAPADOPOULOS A.P., 2008 - *Tomato (*Solanum lycopersicum) *health components: From the seed to the consumer.* - Hortic. Rev., 34: 229-276.

FERNANDES I., LECA J.M., AGUIAR R., FERNANDES T., MARQUES J.C., CORDEIRO N., 2021 - *Influence of crop system on fruit quality, carotenoids, fatty acids and phenolic compounds in cherry tomatoes*. - Agric. Res., 10: 56-65.

GRUDA N., 2009 - *Do soilless culture systems influence product quality of vegetables*? - Eur. J. Hortic. Sci., 4: 135-144.

HERNANDEZ-PEREZ O.I., VALDEZ-AGUILAR L.A., ALIA-TEJACAL I., CARTMILL A.D., CARTMILL D.L., 2020 - *Tomato fruit yield, quality and nutrient status in response to potassium-calcium balance and electrical conductivity in the nutrient solution*. - J. Soil Sci. Plant Nutr., 20: 484-492.

ILAHY R., TLILI I., SIDDIQUI M.W., HDIDER C., LENUCCI M.S., 2019 - *Inside and beyond color: Comparative overview of functional quality of tomato and watermelon fruits*. - Food Res. Int. 126: 108658.

KHAN M.A.,. BUTT S.J, KHAN K.A., NADEEM F., YOUSAF B., JAVED H.U., 2017 - *Morphological and physico-biochemical characterization of tomato cultivars in simplified soilless media*. - Ann. Agric. Sci., 62: 139-143.

KUMAR K., ACHARYA S., VERMA V.C., TSEWANG T.,. TIWARI V.K, AVANTIKA A., CHAURASIA O., 2022 - *Comparative evaluation of physico-chemical responses of tomato varieties under hydroponic vs soil cultivation in naturally ventilated greenhouses*. - Vegetos, 35: 1-8.

LIU X., ZHANG Y., CHEN L., LI J., 2022 - *Regulation of lycopene biosynthesis in tomato under abiotic stress: Hormonal signaling, phytoene synthase activity and antioxidant response*. - Sci. Hortic., 293: 110707.

LONDOÑO-GIRALDO L.M., RESTREPO-DÍAZ J.C., FISCHER G., 2020 - *Influence of growing system on antioxidant capacity and quality of cherry tomato fruits.* - Agronomy, 10: 1260.

MABOKO M.M., DU PLOOY C.P., BERTLING I., 2009 - *Comparative performance of tomato cultivars in soilless vs in-soil systems*. - Acta Hortiulturae, 843: 91-98.

MARTÍ R., ROSELLÓ S., CEBOLLA-CORNEJO J., 2016 - *Tomato as a source of carotenoids and polyphenols targeted to cancer prevention.* - Cancers, 8:58.

MOHAMED A.A., ABDELRAHMAN S.A., HASSAN M.E., 2023 - *Effects of cultivation systems on yield, quality and bioactive compounds of cherry tomato*. - Horticulturae, 9: 312.

MOZOS I., STOIAN D., CARABA A., MALAINER C., HORBAŃCZUK J.O., ATANASOV A.G., 2018 - *Lycopene and vascular health*. - Front. Pharmacol., 9: 521.

OECD, 1998 - *OECD guidelines for testing chemicals: Determination of titratable acidity in plant-derived foods*. - OECD Publ., Paris.

OLLE M., NGOUAJIO M., SIOMOS A., 2012 - *Vegetable quality and productivity as influenced by growing medium: A review*. - Zemdirbyste-Agric., 99: 399-408.

PÉK Z., SZUVANDZSIEV P., NEMÉNYI A., HELYES L., 2014 - *Effect of irrigation on yield and soluble solids of processing tomatoes*. - Sci. Hortic., 172: 30-38.

PEARSON D., 1976 - *The chemical analysis of foods.* - 7th Edition, Churchill Livingstone, Edimburgh, New Yoork, USA, pp. 575.

PESTORIC M., POŠTIĆ D., PETROVIĆ I., STIKIĆ R., 2021 - *Cultivation system-dependent variation in tomato fruit quality and antioxidant potential*. - Agronomy, 11: 1894.

PETROVIĆ I., MARJANOVIĆ M., PEĆINAR I., SAVIĆ S., JOVANOVIĆ Z., STIKIĆ R., 2022 - *Chemical characterization of different colored tomatoes using biochemical and spectroscopic tools*. - Biol. Life Sci. Forum, 16: 32.

RASHEED R., IQBAL M., ASHRAF M.A., HUSSAIN I., SHAFIQ F., YOUSAF A., ZAHEER A., 2018 - *Glycine betaine mitigates waterlogging effects on growth, pigments, oxidative defense and fruit quality in tomato*. - J. Hortic. Sci. Biotechnol., 93: 385-391.

RAVELO-PÉREZ, L.M., HERNÁNDEZ-BORGES J., RODRÍGUEZ-DELGADO M., GARCÍA-MONTELONGO F.J., 2008 - *Spectrophotometric determination of lycopene in tomato using acetone-hexane extraction*. - J. Food Compos. Anal., 21: 125-131.

RENNA M., D'IMPERIO M., GONNELLA M., DURANTE M., PARENTE A., MITA G., SANTAMARIA P., SERIO F., 2019 - *Morphological and chemical profile of tomato landraces in semi-arid Mediterranean climate*. - Plants 8: 273.

SINGH B., SINGH J.P., KAUR A., SINGH N., 2020 - *Bioactive compounds in banana and health benefits: A review*. - Food Chem., 339: 127751.

TAVALLALI V., ESMAILI S., KARIMI S., 2018 - *Nitrogen and potassium requirements for optimizing fruit quality and antioxidative capacity of tomato*. - J. Food Meas. Charact., 12: 755-762.

VERDOLIVA S.G., GWYN-JONES D., DETHERIDGE A., ROBSON P., 2021 - *Hydroponically grown tomatoes show increased water-use efficiency and higher lycopene and β-carotene contents*. - Sci. Hortic., 279: 109896.

WOLDEMARIAM S.HLAL., S., ZELELEW D.Z., SOLOMON M.T., 2018 - *Effect of potassium levels on productivity and fruit quality of tomato*. - J. Agric. Stud., 6: 104-116.