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Evaluation of using geothermal water and local growing media for soilless culture in conventional and organic systems

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ABSTRACT

Although organic hydroponics is not certifiable in many parts of the world, it remains possible to use organic materials in soilless production systems. These materials can be used as substrates, added to nutrient solutions, or applied as foliar fertilizers. Therefore, the influence of two organically certified composts: (1) date palm trunk compost (OPT); and (2) 70% date palm wastes + 30% sheep manure compost (ODM) used as soilless growing media was investigated in randomized blocks to compare tomato performance and productivity through unfertilized, organic, and conventional methods with coconut fiber and organic farm soil as positive and negative controls, respectively. The conventional growing media (CPT) and (CDM) were made of the same composition as the organic media OPT and ODM, respectively. Substrates and fertigation regime interacted to influence yield, with significantly lower yield in unfertilized treatments and higher yield under conventional fertigation in CDM, coconut fiber, and CPT substrates. Plants grown in CPT that received mineral fertilizers improved total polyphenol content (22 mg/100 g DW) and total soluble protein (750 mg/100g FW) more showed higher total polyphenol content (22 mg/100 g DW) and total soluble protein (750 mg/100 g FW) than the other combination treatments. Total soluble solids content in organically fertilized tomatoes grown in OPT (6.9 °Brix) and ODM (7 °Brix) was significantly higher. Values of photosynthesis parameters: stomatal conductance, CO_2 assimilation, and transpiration rate were the highest for plants grown in CDM and CF.

Keywords: tomato, growing media, yield, photosynthesis parameters

INTRODUCTION

Introduced in southern Tunisia, the hydroponic growing system relies exclusively on chemical nutrient solutions. Essential mineral elements for crop production are blended at specific concentrations with chemical fertilizers and diluted in irrigation water to produce nutrient solutions. This technique is most suitable for dry countries, as it has numerous advantages over soil-based plantations, such as conserving water (Rajendran et al., 2024), preventing soil-borne diseases, enabling vegetable cultivation in infertile lands (Woznicki et al., 2021), and ultimately improving vegetable growth (Yang et al., 2021; Sgherri et al., 2010) and quality (Levine and Mattson, 2021; Machado et al., 2006).

In recent years, there has been a surge in healthy living, leading to changes in diet and, in turn, increased consumer influence over acceptable food quality standards. Owing to the beneficial health attributes associated with organic crops, many consumers now prefer them to conventionally grown vegetables (Mowa et al., 2018).

A study by Hsieh et al. (2018) found that using organic fertilizers in hydroponics can be advantageous for growing crops in space habitats. Concentrated solutions of organic nutrients are commonly used in hydroponic systems and are typically diluted for use. By adhering to the recommended rates, a high yield can be obtained using only organic nutrient sources (Rodríguez, 2020). Organic hydroponics is a sustainable solution to various challeng-

es, including limited land space, decreasing water levels, and the toxic effects of chemical fertilizers on crop productivity. Furthermore, the future success of protected cultivation will largely depend on the development of cost-effective production systems that can compete with open-field agriculture. This study compared the effect of organic growing media and fertilizers on hybrid tomato F1 "Murano" growth, yield, and fruit quality with conventional and control methods. The performance of compost made from date palm waste was also evaluated to determine its effectiveness as a substitute for imported growing media, rather than for commercially available coconut fiber.

MATERIALS AND METHODS

Study site and environmental conditions

The experimental station of the Technical Center of Protected and Geothermal Crops, where this research was conducted, is located in southern Tunisia (33°53′42.0″ N, 9°52′ 31.0″ E). The station is located at an elevation of 72 meters above sea level in Chenchou, a place known for its subtropical desert climate. During summer, Chenchou experiences intense weather conditions, including high temperatures and aridity. Winter in Chenchou is characterized by cold, dry, and very windy weather. The annual precipitation in this area is 16.98 mm, and the average yearly temperature ranges from 6 °C to 34 °C. Rarely does the temperature drop below 3 °C or exceed 39 °C. On average, the temperature is 23.98 °C per year.

Experimental design and treatments

The study followed a factorial experimental design with two factors: growing media and fertilization regime.

Factor 1 – Growing media

Five substrates were evaluated:

1. OPT: Organically certified date palm trunk compost
2. ODM: Organically certified compost (70% date palm wastes + 30% sheep manure)
3. CPT: Conventional compost with a composition identical to OPT
4. CDM: Conventional compost with a composition identical to ODM
5. CF: Coconut fiber (positive control)
6. Soil: Organic farm soil (negative control)
7. Conventional farm soil (negative control).

Factor 2 – Fertilization regime

Three fertilization strategies were applied:

- Conventional fertigation: Mineral nutrient solution + chemical plant protection
- Organic fertigation: Compost tea + organic liquid fertilizers
- Unfertilized control: Geothermal water only.

Throughout 2021, hybrid tomato plants (F1 "Murano") were cultivated in a completely randomized block design in a 5.5-meter-high greenhouse covered with a 200 µm polyethylene film and divided into three compartments. Each compartment contained 300 plants grown in trenches lined with plastic film and equipped with perforated PVC tubes for drainage collection. The trenches were filled with a thin layer of gravel, then the substrate.

Plants in the first compartment were grown on conventional substrates and received mineral fertilization and chemical plant protection. In the second compartment, plants were grown on organic substrates, with compost tea as the primary fertilizer. Finally, in the third compartment, the plants used as the control received only geothermal water (without fertilizers).

Irrigation and nutrient solution

Plants were grown under an open soilless cultivation system with a drainage fraction of 30-35%. Conventional and organic treatments received a standardized nutrient solution consisting of 17.81 mM NO_3^-,0.71 mM NH_4^+, 1.74 mM $H_2PO_4^-$, 9.5 mM K^+, 4.73 mM Ca^{2+}, 2.4 mM Mg^{2+}, 2.25 mM SO_4^{2-}; and micronutrients: 15 µmol Fe, 10 µmol Mn, 5 µmol Zn, 30 µmol B, 0.75 µmol Cu, and 0.5 µmol Mo. The electrical conductivity of the nu-

trient solution was about 4 mS/cm, and the pH was between 5.8 and 6.5.

Physicochemical properties of the substrates and irrigation water

Several analyses were conducted on the substrates to evaluate their pH levels, total organic carbon, total nitrogen, EC, K-exchangeable, P-available, and Ca-exchangeable. The Walkley-Black method with dichromate oxidation and the titrimetric method were used to analyze total organic carbon. Total N was determined by the Kjeldahl titrimetric method using a Kjeldahl apparatus. The pH and electrical conductivity were determined using 1:5 extraction methods (Estefan et al., 2013). The Olsen method, using colorimetric and spectrophotometric techniques (Olsen and Sommers, 1982), was employed to analyze P-availability. For the determination of K and Ca-exchangeable, extraction with 1.0 M NH_4OAc at pH 7.0 was carried out, and their contents were assessed by flame photometry as described by Soltanpur and Workman (1979). Bulk density and water-holding capacity (field capacity) were analyzed according to the standard European norms described by Tittarelli et al. (2009).

To assess the quality of irrigation water, various methods were employed. The sulfate content was estimated gravimetrically using $BaCl_2$ solution following the method described by Piper (1947). The concentration of Cl^- ions was determined by titration using $AgNO_3$, following the method mentioned by Jackson (1962). Bicarbonates were also assessed using the titration method, as described by Pierce et al. (1958). Additionally, the concentrations of Na^+ and K^+ cations were determined using flame photometry, whereas the concentrations of Ca^{2+} and Mg^{2+} were measured using a spectrophotometer.

Plant growth and yield

Plants were grown for seven months, and growth indices, including stem diameter (mm), plant height (cm), and number of leaves, were measured after three months. At each harvest, we collected ripe fruits and recorded their weight to calculate marketable yields (kg/number of plants).

Leaves water parameters

Leaf water content (*WC*) provides information about the hydration of plant tissues and is used as an indicator of crop water stress. It is determined by the difference between fresh weight (*FW*) and dry weight (*DW*), according to the following equation:

$$WC(mLH_2O / g\ DW) = (FW - DW) \div DW$$

Relative water content (*RWC*) is an indicator of the water content of the leaf tissue according to its maximum water absorption capacity. Leaves were weighed to determine their fresh weight (*FW*). They were then placed at a low temperature in distilled water overnight. Weights of turgid leaves (*SW*) were taken, followed by oven drying at 60°C for 24 hours to determine *DW*. *RWC* is calculated using the following equation:

$$RWC(\%) = [(FW - DW) \div (SW - DW) \times 100]$$

as described by Turner (1981).

Leaf water potential (Ψ_w) represents an important indicator of water stress experienced by plants. All measurements were taken on fully developed leaves using Scholander-type pressure chambers (PMS Instrument Company, Corvallis) and are expressed in megapascals (MPa).

Immediately after the Ψ_w measurement, the osmolality (Ψ_π) of the extracted juice was measured at 25°C using an osmometer (Vapro 5600, Wescor, Logan, UT). The vapour-pressure osmometer (Vapro 5520, Wescor, USA) measures the osmolality (C) and the osmotic potential is calculated from the Van't Hoff equation:

$$\Psi_s = -C(mosmol / Kg) \times 2.58 \times 10^{-3}$$

The turgor potential (Ψ_p) is calculated as the difference between Ψ_w and Ψ_π.

$$\Psi_p\ (MPa) = \Psi_w - \Psi_\pi$$

Gas exchanges

Internal CO_2 concentration, stomata conductance, transpiration rate, and photosynthetic rate were measured with a LI-COR6400 portable photosynthesis system (LI-COR, Lincoln, Nebraska, USA).

The physicochemical analyses of fruits

In March 2022, fruit samples were collected to evaluate their quality. Each replicate consisted of 20 tomato fruits selected from 10 plants per treatment. The fruits were stripped of the rachis and weighed to determine their mean weight. Using a penetrometer, firmness was measured. Thereafter, six tomatoes were sliced into quarters, and one quarter from each was combined to form a complete replicate. Finally, a handheld blender was used to homogenize the six quarters. On the same day of harvest, the resulting homogenate was used to measure Brix and pH. A manual refractometer was used to measure total soluble solids (TSS), expressed as °Brix.

Total polyphenols content (TPC)

The method of Farrés-Cebrián et al. (2016) was used to estimate the total polyphenol content. To 3 mL of 80% ethanol, 0.5g of tomato juice was added. The mixture was agitated for 2 min, centrifuged for 5 min at 3500 rpm, and then left in the dark for 24 h. The filtered extract was then diluted with 80% ethanol to 15 mL. Next, 0.8 mL of Na_2CO_3 and 0.1 mL of Folin-Ciocalteu were combined with 0.2 mL of the extract. The mixture was shaken vigorously for 2 min. After centrifugation (3500 rpm/5 min), the extracts were analyzed directly. The spectrophotometer was set to zero with a blank, and optical density was taken (a measure of absorbance) at 660 nm.

Total soluble protein content

The Folin–Lowry method was used to estimate the protein content of each selected sample. Tomato juice and distilled water (10 mg/10 ml) were combined in test tubes to prepare various dilutions. The final volume in each test tube was adjusted to 50 mL. Then, 0.1 mL of each sample was diluted with distilled water to a final volume of 5 mL. 1 mL of copper sulfate reagent was added. These solutions were incubated at room temperature for 10 min. Then, 0.1 mL of freshly prepared Folin–Ciocalteu reagent was added to each sample, and the samples were incubated for 30–60 min in the dark. After incubation, the optical density was measured at 660 nm.

Data analysis

Statistical analyses were performed using XLSTAT 2016. All data were analyzed using factorial ANOVA (fertilization × substrate) followed by the parametric Tukey's test at $P \leq 0.05$.

RESULTS AND DISCUSSION

Hydrochemical characteristics of irrigation water

Table 1 presents the findings of the hydrochemical analysis of a geothermal water sample. The irrigation water was slightly alkaline, as seen by its pH value (7.63). The electrical conductivity (EC) value was greater than 1.5 dS/m, which is the permitted limit (Richards, 1954). According to the EC classification, the groundwater sample is questionable for irrigation (Fipps, 2003). The major ion concentrations were reported in the following order according to the hydrochemical characteristics mentioned in Table 1:
$Ca^{2+} > Na^{2+} > Mg^{2+} > K^{+}$ and $SO_4^{2-} > Cl^{-} > HCO_3^{-}$.

The SAR value indicates that geothermal water samples are excellent for irrigation (SAR<10) according to the SAR classification (Oster and Sposito, 1980). According to the permeability index (PI), the water sample was classified as a good class. Kelly's index indicated normal sodium content in the water and that the sample fell into the good class, making it acceptable for irrigation (Wilcox, 1955). According to Freeze and Cherry (1979), water samples are of a brackish type, and based on Davis and Dewiest (1966), they are useful for irrigation. The magnesium hazard value of<50% revealed that the groundwater samples from the study area were safe for irrigation.

The Ca^{2+} concentration of the collected sample shows that it is the dominant cation, followed by Na^{+}; these values are acceptable for irrigation according to Ayers and Westcot (1985). SO_4^{2-} was the dominant anion, and it is within the acceptable limit for irrigation according to Ayers and Westcot (1985). The Cl^{-} content, with a mean value of 400 mg/L, was within acceptable limits for irrigation (0.0–1050 mg/L) according to Ayers and Westcot (1985).

Table 1. Hydrochemical characteristics of geothermal water

Sample	pH	EC dS/m	TDS g/l	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-	Sodium Adsorption Ratio (SAR)	Sodium percent (Na %)	Magnesium Hazard (MH)	Total Hardness (TH)	Kelly's Index (KI)	Permeability index (PI %)
				meq/l												
Geothermal Water	7.63	3	2.98	15.21	0.83	17	9.5	11.28	12.6	2.31	4.17	37	35	26.5	0.57	40

Table 2. Chemical composition of irrigation water and nutritive solution for tomato culture (meq/l)

	$N0_3^-$	NH_4^+	K^+	Ca^{2+}	Mg^{2+}	$H_2PO_4^-$	SO_4^{2-}
Irrigation water	0	0	0.83	17	9.5	0	12.6
Fertilization norm	17.8	0.7	9.5	9.4	4.8	1.5	4.5
Nutritive solution	17.8	0.7	8.67	0	0	1.5	0

Physiochemical characteristics of substrates

The physical and chemical properties of the growing media are shown in Table 3. The pH of the growing media and the soil measured at transplanting was slightly acidic to neutral. Relatively lower pH values were found in OPT and CPT than in other growing media and soil. According to Ghehsareh et al. (2011), a pH range of 6 to 6.5 is optimal for growing tomatoes. Hernando et al. (1989) found that composts generally have a near-neutral pH or slight alkalinity with a strong buffering capacity. Higher pH levels can reduce nutrient availability through conversion of phosphate to unavailable forms, loss of ammonia, and precipitation of micronutrients (Azeez and Van Averbeke, 2012).

The EC values of substrates and soil were in the range of 2.3 - 4.5 mS/cm. EC is a key property that can indicate nutrient deficiency or an elevated risk of salt stress. In our study, the highest and lowest EC values were recorded in CDM and coconut fiber, respectively. Both Dhen et al. (2018) and Ghehsareh et al. (2012) confirmed that substituting peat with date palm fronds generated an increase in the pH values and the salinity contents of the mixtures. This study revealed that substrates based on date palm had pH values ranging from 6.4 to 7, and an electrical conductivity (EC) from 3 to 4.5 mS/cm.

Based on the analysis, CDM had the highest organic matter content (54%) and the lowest bulk density (0.15 g/cm^3) among the substrates. According to Nelson (1994), bulk density refers to the substrate mass per unit volume. The results indicate that all substrates' bulk densities were below that of the negative control (soil). The standard nursery substrate, comprising sand, clay, and silt in varying amounts, results in excessively high bulk densities exceeding 1.6 g/cm^3. CDM, on the other hand, showed the lowest bulk density of (0.15 g/cm^3), making it the most economical option for intensive substrate potted plants. According to Deboodt and Verndock (1972), the optimal bulk density range for container substrates is 0.2-0.5 g/cm^3. In the current study, all substrates except soil were found to fall within this range. High bulk density can lead to weight gain, decreased porosity, and reduced air volume in containers. Conversely, extremely low bulk densities cause excessive substrate aeration, which hinders plant access to water (Huang et al., 2013; Fernandes and Cora, 2004).

Table 3. Mean of initial chemical and physical indices of growing media measured at transplanting

	Organic growing media				Conventional growing media			
	OPT	ODM	CF	Organic Soil	CPT	CDM	CF	Conventional Soil
%OM	39	49	70	1.5	35	54	70	0.7
%N	1.30	2.57	0.9	0.1	1	2.25	0.9	0.05
C/N	17.4	11.05	45	8.7	20	14	45	8.1
%P	0.41	1.46	1.32	0.08	1	0.76	1.32	0.03
%K	1.7	2.14	1	1	1.5	1.5	1	0.7
%Ca	2	3.55	0.4	7	1.5	4.67	0.4	5
%Mg	0.7	0.92	0.32	1	0.5	0.86	0.32	0.3
pH	6.4	6.67	6,7	7.3	6.5	7	6,7	7.1
CE (mS/cm)	3	4	2,3	4.4	3.5	4.5	2,3	3.9
BD (g/cm^3)	0.3	0.17	0.16	1.1	0.26	0.15	0.16	1.4
WHC %	70	50	79	25	65	46	79	20

WHC: water holding capacity; BD: Bulk density; CE: Electrical conductivity.
OPT: date palm trunk compost; ODM: date palm wastes + sheep manure compost; CF: Coconut fiber.

Nitrogen is critical in plant growth and development and is an essential component of amino acids, proteins, nucleic acids, and many enzymes. ODM contained the highest total nitrogen, which was 2.57%, followed by CDM at 2.25%. Compost can be considered stable when the C/N ratio is approximately 17 (Silva et al., 2007). If the ratio is more than 20, it negatively affects plants and damages seed germination (Ghehsareh et al., 2011). In the present research, coconut fiber showed a higher C/N ratio when compared to date palm waste-based compost, which had ratios ranging from 6.78 to 17.4. A high C/N ratio is associated with immature compost, which can lead to nitrogen deficiency in plants.

Coconut fiber showed the highest water holding capacity (79%). The optimal water holding capacity (WHC) range for container substrates is suggested to be from 45% to 65% (Bilderback et al., 2005). This study revealed that WHC varied with the type of growing medium, with soil having the lowest and coconut fiber having the highest water holding capacity. Frequent watering needs in soil can lead to nutrient leaching and compromise plant growth and root development. Conversely, excessive WHC can impede gas exchange necessary for healthy growth, as seen in fine-textured substrates.

Growth parameters

The values recorded for tomato plants for stem height, stem diameter, number of leaves and distance from the soil to the first truss across the different substrates are presented in Table 4. The interaction of media and fertilizers was significant for all morphological response variables (Table 4). A general examination of the main effects suggests that fertilizer use resulted in larger plants compared to unfertilized crops, regardless of media type (Table 4). At 12 weeks after transplanting, the tallest plants (208.6 cm) were attained in coconut fiber irrigated with mineral fertilizers followed by CPT and CDM. The shortest plants (131 cm) were obtained in tomato grown in unfertilized soil. The results showed that plants in the organic-fertilized media were significantly shorter than those in mineral-fertilized treatments.

Table 4. Plant height, stem diameter, leaf number and first truss at 12 weeks after transplanting of tomato plants grown on four growing media: coconut fiber, compost of date palm trunk, compost of date palm residues (70%) + animal manure (30%) and sandy loam soil, with unfertilized, organic and conventional fertilization

	Growing media	Plant height (cm)	Stem diameter (cm)	Leaves number	Soil-first truss (cm)
Organic treatments	CF	170.7^{c}	1.4^{a}	27.5^{bc}	33.3^{ab}
	OPT	170.5^{c}	1.4^{a}	27.3^{bc}	36.7^{ab}
	ODM	171.8^{c}	1.1^{d}	28.7^{b}	31.9^{bc}
	Organic soil	169.6^{c}	1.2^{c}	26.2^{cd}	32^{bcd}
Conventional treatments	CF	208.6^{a}	1.4^{a}	32.4^{a}	34.3^{b}
	CPT	206.5^{a}	1.4^{a}	33^{a}	34.1^{b}
	CDM	205.7^{a}	1.3^{b}	33.3^{a}	38.7^{a}
	Soil	197.9^{b}	1.2^{c}	31.6^{a}	37.1^{ab}
Unfertilized treatments	CF	141.2^{d}	0.9^{de}	25.7^{cd}	27.7^{e}
	CPT	138.6^{de}	0.8^{e}	24.8^{d}	28de
	CDM	133.8^{de}	0.8^{e}	17.73^{e}	28de
	Soil	131^{e}	0.7^{e}	16.4^{e}	29.3^{cd}
Media		*	***	***	**
Fertilization		***	***	***	***
Media × fertilization		**	***	***	**

Within each column, means followed by different letters are significantly different according to the Tukey test (P<0.05).

There were significant medium × fertilizer interaction effects on stem diameter, with treatment means ranging from 0.7 to 1.4 cm (Table 4). The tomato stem diameter was significantly (P < 0.05) different among the media. Plants grown in coconut fiber substrate and in palm trunk and leaves compost in organic and conventional treatments produced the highest stem diameter (1.4 cm), while the lowest stem diameter (0.7 cm) was recorded in those grown in unfertilized soil (Table 4). In compost from date palm waste (70%) + sheep manure (30%), the highest stem diameter (1.3 cm) was observed in the conventional treatment, and the lowest (0.8 cm) was obtained in the unfertilized plants.

The number of leaves was significantly affected by the fertilizer type, with a notable interaction between fertilizer type and media treatment. As expected, organic and mineral fertilization increased the number of leaves per plant compared with unfertilized plants. Notably, the media treated with conventional fertilizers produced more leaves than the other media.

In a study conducted by Rahbarian et al. (2011), various growing media were tested for their effect on plant growth. The results indicated that palm peat substrate was as effective as peat moss for plant growth, suggesting that the substrate can replace peat moss. In a similar study, Ghehsareh et al. (2011) found no significant difference in plant height and fruit yield of tomatoes grown in date palm substrate compared to other growing media.

The fertilizer type significantly affected plant growth, and the application of chemical fertilizers increased plant height and leaf number compared to organic fertilizers. These findings contradict those of Kashem et al. (2015), who reported that tomato growth performance in organically amended soil was better than in inorganic fertilizer-amended soil.

Smith (2018) conducted a study with several objectives, including comparing the long-term effects of organic and synthetic fertilizers on maize crop growth, focusing on sustainability. Organic fertilizers led to slower but sustained growth, resulting in higher total biomass production at the end of the growing season.

Tomato fruit yield

The mean data of the yield are shown in Table 5. Differences in plant nutrition significantly affected total plant yield. Mineral and organic fertilization significantly increased the yield compared to the control (without fertilizer) in all growing media, except the soil, which belongs to the same group of unfertilized growing media. Plants grown in CDM, coconut fiber, and CPT received mineral fertilizer and had a higher total yield than the other combination treatments. There were significant fertilizer × media interactions for total yield.

During the early yield period (12/4/2021-25/4/2021), the highest yield was achieved with plants grown on date palm waste and sheep manure compost, followed by date palm trunk and leaves compost receiving mineral fertilization. Significant differences were obtained during the mid-yield period (8/5/2021-20/5/2021) and the late yield period (2/6/2021); the highest yield was obtained in the conventional compartment. This could be attributed to the difficulty in delivering soluble organic fertilizers due to repeated clogging of the fertigation emitters. When emitters became clogged, plants did not receive an adequate supply of nutrients.

Our findings are in agreement with Peet and Welles' observations in 2005, which demonstrated that organic nutrient solutions led to a decrease in plant yield. However, Rippy et al.'s research in the same year found no significant effect of organic fertilizers on total yield.

Table 5. Organic, conventional and control treatment means and analysis of variance (ANOVA) results of harvest yields (g) of tomato plants grown on four growing media: coconut fiber, compost of date palm trunk, compost of date palm residues (70%) + animal manure (30%) and sandy loam soil

	Growing media	12/4/2021	25/4/2021	8/5/2021	20/5/2021	2/6/2021	Total yield
Organic treatments	CF	7544^{b}	7130^{b}	8023^{b}	6854^{bc}	5887^{a}	35439^{ab}
	OPT	10056^{a}	7522^{b}	7103^{c}	5640^{c}	5330^{a}	35652^{ab}
	ODM	9825^{ab}	7806^{b}	7353^{bc}	7200^{b}	4545^{ab}	36730^{ab}
	Organic soil	7856^{b}	5210^{c}	7117^{c}	4760^{d}	5860^{a}	30804^{b}
Conventional treatments	CF	7379^{b}	7582^{b}	1045^{a}	8980^{a}	5432^{a}	39823^{a}
	CPT	10765^{a}	9456^{a}	9649^{a}	6606^{bc}	5277^{a}	41753^{a}
	CDM	11824^{a}	9840^{a}	8839^{ab}	7732^{ab}	5329^{a}	43564^{a}
	Soil	7856^{b}	5240^{c}	7017^{c}	4750^{d}	5152^{a}	30015^{b}
Unfertilized treatments	CF	7386^{b}	4420^{cd}	6727^{cd}	3600^{e}	3700^{b}	25833^{c}
	CPT	8056^{ab}	4230^{cd}	6257^{d}	3820^{e}	3660^{b}	26023^{c}
	CDM	7856^{b}	5210^{c}	7217^{bc}	4760^{d}	3800^{b}	28843^{c}
	Soil	7356^{b}	3470^{d}	6347^{d}	3500^{e}	3080^{b}	23753^{c}
Media		**	***	**	***	NS	*
Fertilization		**	***	***	***	**	***
Media × fertilization		*	***	**	***	*	*

Within each column, means followed by different letters are significantly different according to the Tukey test ($P<0.05$).

The significant differences in plant response and produce characteristics may be partially attributed to differences in nutrient uptake. Varied availability of nutrient elements at the rhizosphere level is possible, implying that distinct mechanisms affect the nutritional status of organically fertilized plants.

Physicochemical and phytochemical properties of tomato fruit

The fruit quality parameters measured in this study were significantly affected by the type of fertilizer, the medium, and the interaction between medium and fertilizer (Table 6). Unfertilized treatments showed significantly lower soluble solid content, firmness, polyphenols, fruit weight and total sugar. This indicates that low nutrient concentrations in the growth solution directly affect the quality traits of tomato fruits. Plants grown in CPT that received mineral fertilizer showed higher total soluble protein and total sugar than the other combination treatments. Total polyphenol content and total soluble solids (°Brix) in organically fertilized tomatoes grown in OPT and ODM were significantly higher. Most data suggest that plants grown without agrochemicals contain more secondary metabolites and other beneficial substances. This may be attributed to plants being exposed to a certain level of stress, which could lead

Table 6. Total soluble solids (TSS), pH, firmness, fruit weight, total polyphenol content, total soluble protein and total sugar of fruit of tomato plants grown on four growing media: coconut fiber, compost of date palm trunk, compost of date palm residues (70%) + animal manure (30%) and sandy loam soil, under organic, conventional and control treatments

	Growing media	Total soluble solids (°Brix)	pH	Firmness (Kg/cm²)	Fruit weight (g)	Total polyphenol content (mg/100 g DW)	Total soluble protein (mg/100g FW)	Total sugar (mg/100g FW)
Organic treatments	CF	6.35^{ab}	4.1^{a}	2.3^{bc}	87^{b}	19^{ab}	717^{c}	37^{ab}
	OPT	6.9^{a}	4.1^{a}	2.3^{bc}	87^{b}	22^{a}	710^{c}	32^{cd}
	ODM	7^{a}	4.2^{a}	2.2^{bc}	88^{b}	21^{a}	710^{c}	30^{d}
	Organic soil	6.45^{ab}	4.2^{a}	2.9^{ab}	85^{bc}	12^{c}	700^{cd}	30.67^{d}
Conventional growing media	CF	6.4^{ab}	3.9^{b}	2.2^{bc}	104^{a}	12^{c}	720^{ab}	35^{bc}
	CPT	6.45^{ab}	4^{ab}	2.6^{ab}	94^{ab}	15^{b}	750^{a}	39.67^{a}
	CDM	5.7^{bc}	4.1^{a}	3.3^{a}	93^{ab}	16^{b}	735^{b}	32.67^{cd}
	Soil	6.1^{b}	4.1^{a}	3.2^{a}	94^{ab}	12^{c}	712^{c}	31.67^{cd}
Control	CF	5.9^{bc}	4.1^{a}	2.1^{bc}	55^{c}	6.6^{d}	688^{d}	26^{e}
	CPT	5.9^{bc}	4.1^{a}	2.2^{bc}	55^{c}	9^{cd}	680^{d}	24^{e}
	CDM	5^{c}	4^{ab}	2^{c}	57^{c}	7^{d}	680^{d}	24^{e}
	Soil	5^{c}	3.9^{b}	2.2^{bc}	55^{c}	7^{d}	660^{e}	25^{e}
Media		***	**	***	*	**	**	***
Fertilization		**	NS	***	*	***	***	***
Media × fertilization		*	*	**	*	**	**	**

Within each column, means followed by different letters are significantly different according to the Tukey test ($P<0.05$).

to greater synthesis of these compounds as a defense mechanism (Mie et al., 2017). However, various studies reported that the crop method does not necessarily affect the nutritional composition (D'Evoli et al., 2016).

Our results indicate that tomato fruits from the organic system had higher °Brix values compared to those from the other two treatments. This difference could be due to the stress and EC levels present in the organic nutrient solution, which were not present in the balanced and buffered conventional nutrient solution. These findings are consistent with previous research by Helyes et al. (2006) and Oliveira et al. (2013), who found that cultivation methods and organic farming systems can increase the total soluble solids (°Brix) in tomatoes. Additionally, Barrett et al. (2007) found higher °Brix values in organic tomatoes in a one-year study of four commercial organic and conventional processing tomatoes.

Tomatoes cultivated on CDM, with the highest EC value, showed higher fruit firmness compared to those grown on the other media (Table 6). The purchasing decision of consumers is greatly influenced by the firmness of the tomato fruit, thus making softer fruit less preferred (Batu, 2004). Interestingly, the level of EC in the media they are grown in impacts the tomato's firmness (Stamatakis et al., 2003).

The weight of tomato fruit is also influenced by media types and the availability of nutrients in varying solutions, which is limited by stress conditions. Pieper and Barrett's (2009) research supports the theory that less-stressed plants produce fruit with higher moisture content, ultimately resulting in larger and heavier tomatoes. This explains why unfertilized plants yielded only smaller fruits, as the geothermal water alone lacked the necessary mineral nutrients, causing a deficiency of vital nutrients for growth.

Gas exchange in tomato plant leaves

The results of the internal concentration of CO_2 (Ci), stomatal conductance (gs), CO_2 assimilation (Pn), and transpiration rate (E) are displayed in Figure 1. Values of gs, Pn and E were the highest for plants grown in CDM and CF. The status of stomata is determined by stomatal conductance; when this parameter decreases, it indicates that the stomata are closed, resulting in a decrease in the exchange of carbon dioxide and oxygen between the mesophyll and the atmosphere. This parameter decreased significantly with OPT and soil.

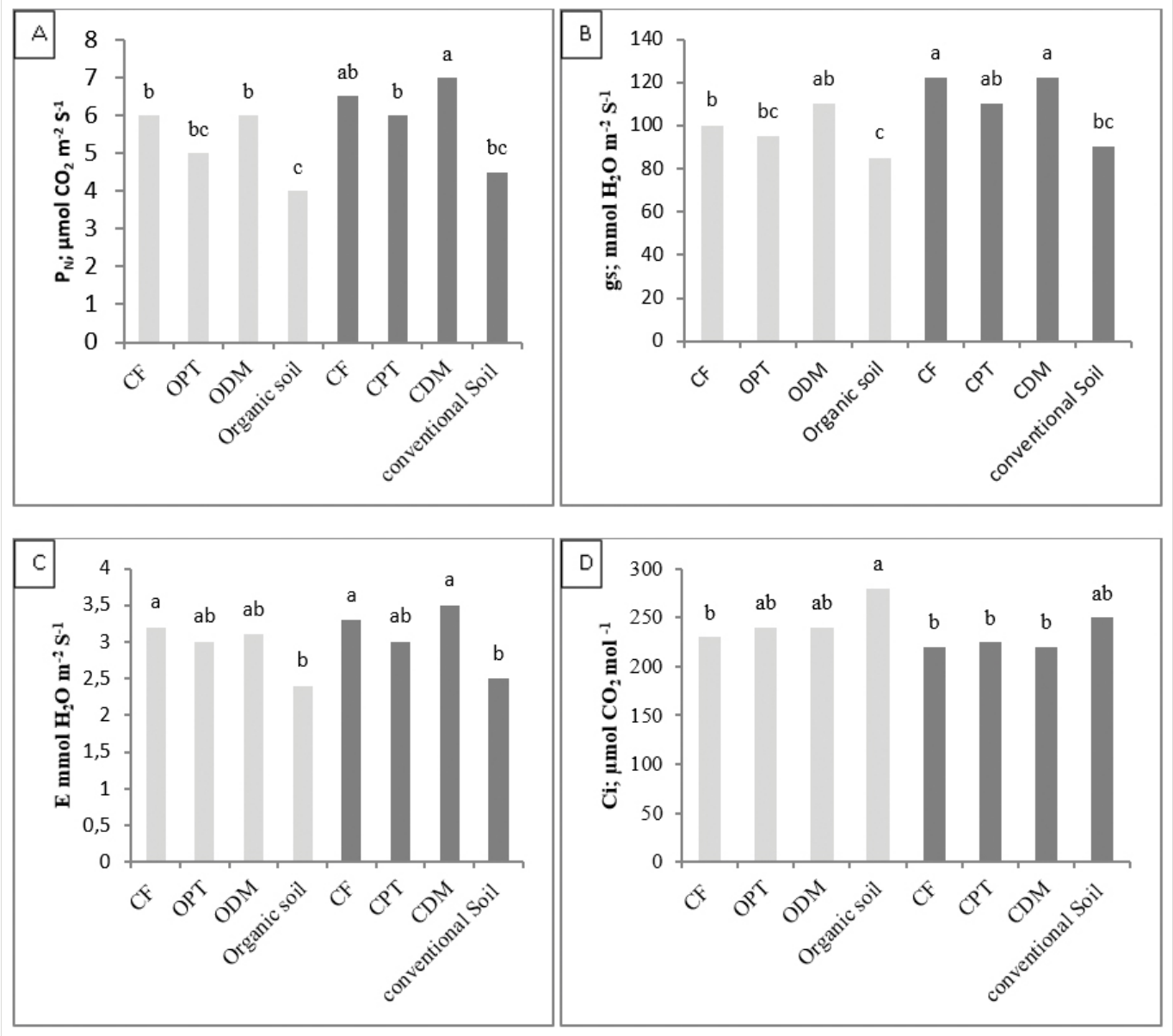
Features related to photosynthetic processes are a valuable resource for assessing plant performance. According to our findings, plants grown in conventional treatments had higher levels of stomatal conductance. The decrease in internal CO_2 concentration confirmed that improved physiological characteristics can result in an increase in CO_2 assimilation for photosynthesis. A higher number of leaves paired with a higher photosynthetic pigment indicate improved photosynthetic efficiency.

Water parameters in tomato plant leaves

The water content of leaf tissues, measured by the relative water content (RWC) is shown in Figure 2C. There were significant effects on RWC when comparing plants grown under organic and conventional treatments. RWC in tomato leaves decreased slightly when cultivated in a soil substrate, reaching 83%.

Leaf water potential (Ψ_w) is an important indicator of plant water status as it reflects the combined influence of environmental factors such as soil water availability and evaporative demand, and physiological processes within the plant, including root water uptake, xylem transport, and stomatal regulation. The results presented in Figure 2B indicated that the substrate and fertilization significantly affected Ψ_w.

Plants cultivated on positive and negative controls (CF and soil, respectively) showed a decrease in Ψ_w when compared to the composts, with average values ranging from -1.3 to -1.2 and from -1.8 to -1.5 MPa, respectively. The osmotic potential of leaf tissue (Ψ_S) was also affected by growing media and fertilizer type. Plants grown on CF and ODM exhibited significantly lower Ψ_S values. Conversely, plants cultivated in soil substrate demonstrated higher Ψ_S.



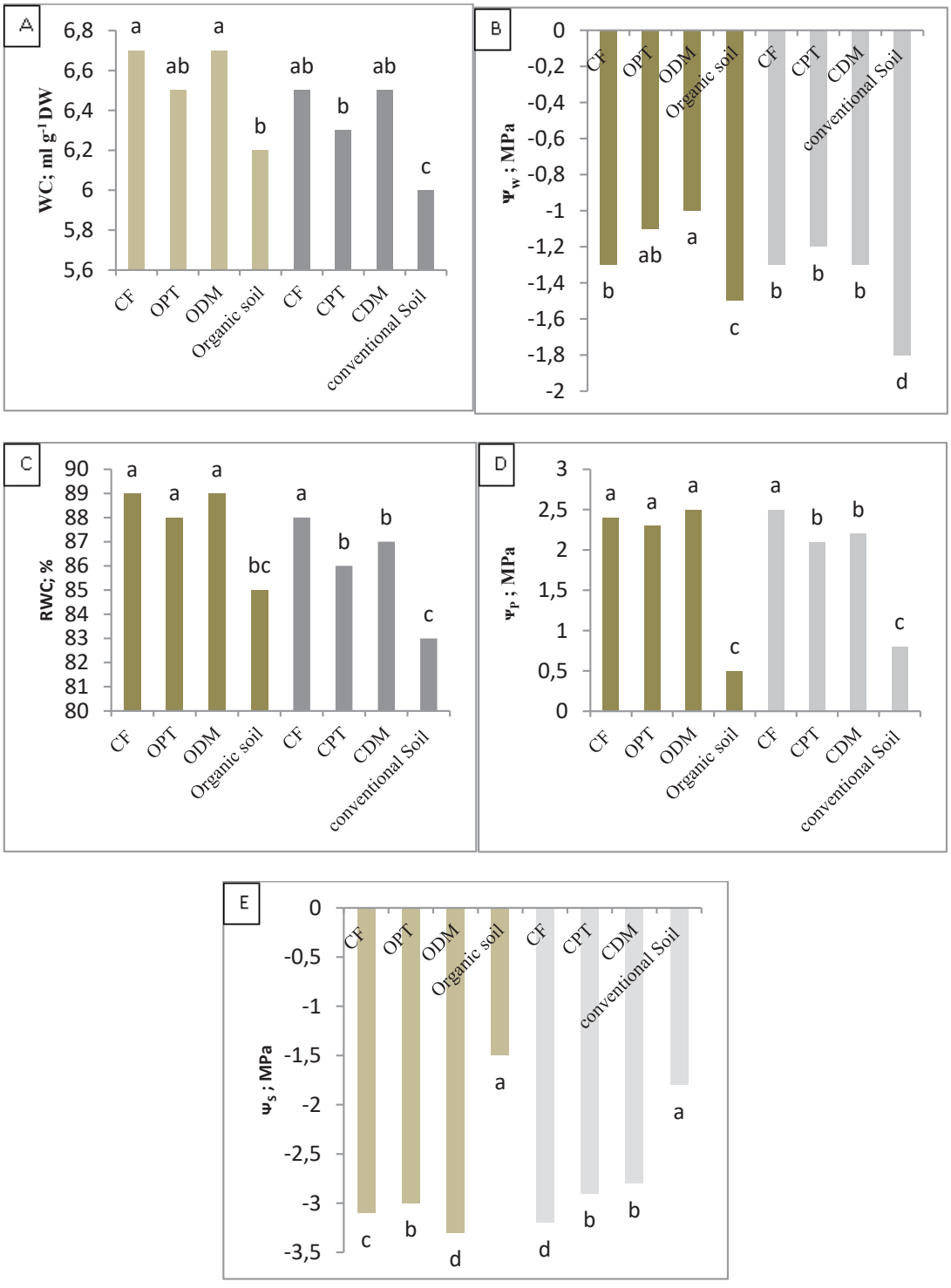
OPT: Organic Date palm trunk and leaves compost; ODM: Organic compost of 70% date palm wastes + 30% sheep manure; CPT: Conventional Date palm trunk and leaves compost; CDM: Conventional compost of 70% date palm wastes + 30% sheep manure; CF: coconut fiber, compared with soil substrate. (A): photosynthetic assimilation rate (PN: µmol (CO_2)/m^2 per second); (B): transpiration rate (E: mmol (H_2O)/m^2 per second); (C): stomata conductance (gs: mmol (H_2O)/m^2 per second); (D): intercellular CO_2 concentration (Ci: µmol (CO_2)/mol). The plants were 3 months old. Results are the mean of ten replicates. Numbers followed by a different letter are significantly different at $P<0.05$ according to the least significant difference (LSD) analysis.

Figure 1. Effects of the crop media and fertilization on photosynthesis parameters in tomato plant leaves

The type of growing media used affected the turgor potential (ψ_p) of leaf cells. The pressure reached a minimum of 0.4 MPa, but increased to over 2.4 MPa when using CF and ODM.

The significance of water content in leaf tissues was highlighted in the organic treatments, suggesting more effective absorption and transport of water. Because coconut fiber and date palm waste compost had lower bulk density than soil (Table 3), plant roots could occupy more volume in the growing media and increase their access to water.

The relative water content (RWC) assesses the current water content of the tissues in comparison to the most water they can hold at full turgidity. According to the results, plants grown on the organic substrates had more turgescent leaves than those grown on soil.



OPT: Organic Date palm trunk and leaves compost; ODM: Organic compost of 70% date palm wastes + 30% sheep manure; CPT: Conventional Date palm trunk and leaves compost; CDM: Conventional compost of 70% date palm wastes + 30% sheep manure; CF: coconut fiber, compared with soil substrate (A): water content (WC: mL / g DW); (B): Water potential (ψ_w; MPa); (C): Relative water content (RWC: %); (D): Pressure (turgor) potential (ψ_p; MPa); (E): Solute potential (ψ_s; MPa). The plants were 3 months old. Results are the mean of ten replicates. Numbers followed by a different letter are significantly different at $P<0.05$, according to LSD analysis.

Figure 2. Effects of the crop media and fertilizers on water parameters in tomato plant leaves

This confirms that these plants have more access to water. Previous studies on wheat, bean, and lettuce plants grown on organic substrates have shown enhanced leaf RWC (Omara et al., 2022; Duri et al., 2020).

According to Choat et al. (2012), the leaf water potential (Ψ_w) is a key indicator of the water status of plants, root water uptake, xylem transport, and stomatal regulation. The highest values were found in local compost substrates in both organic and conventional treatments (OPT, ODM, CPT, and CDM). Plants grown in soil had the lowest Ψ_w, suggesting a reduced capacity to absorb water.

CONCLUSION

The findings of this study revealed that date palm waste-based composts can be successfully used as growing media in soilless tomato production systems. Substrate type and fertilization regime significantly influenced plant growth, yield, physiological performance, and fruit quality. Plants cultivated in CDM, coconut fiber, and CPT substrates under conventional fertigation achieved the highest yield, whereas unfertilized treatments consistently resulted in reduced productivity in all media.

Organically fertilized tomatoes grown in OPT and ODM substrates showed significantly higher total soluble solids (°Brix), while mineral fertilization combined with CPT enhanced total polyphenol and soluble protein contents. Gas exchange measurements indicated superior physiological activity in CDM and coconut fiber substrates, as reflected by higher stomatal conductance, CO_2 assimilation, and transpiration rates.

These findings confirm that locally produced date palm composts are a technically viable alternative to imported substrates such as coconut fiber. Their use supports sustainable waste valorization and ensures satisfactory agronomic performance and fruit quality. Although conventional fertigation produced the highest yields, organic fertilization based on compost tea, organic liquid fertilizers, and geothermal water maintained acceptable productivity levels, highlighting its potential for environmentally friendly greenhouse production systems.

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Authors Nadia Elabed and Asma Boukhris contributed equally to this paper.

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