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Biochar from date palm enhances hydroponic growth of *Ocimum Basilicum* under arid conditions of Fujairah

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Arid regions are mainly characterized by extreme environmental conditions, which strongly affect crop production and therefore, could not allow to satisfy the high food demand. During the past decades, chemicals fertilizers have been intensively used to increase crop yield. However, significant applications of chemical fertilizers have showed adverse effects on the environment in many previous works. Therefore, this study attempts to convert plant parts of dates palm (leaflet, petiole, and fruits) into biochar. Furthermore, this work also aims to determine the physiochemical composition of the biomaterial and its potentialities in improving plant growth of *Ocimum basilicum* at different levels including 0, 1.5, and 3% hydroponically. Based on our results, physiochemical parameters of the tested biochar revealed that 3% fruit biochar had the highest water drainage (42 ml), while petiole biochar at the same concentration without Hoagland had the highest pH (8.38) and EC (3452.66 µS/cm). Electrical properties, such as voltage (2.93 V) and current (0.14 mA), and plant metrics, including shoot and root growth, showed significant improvement, particularly with 3% of leaflet biochar and Hoagland application. Strong correlations between electrochemical properties (voltage, current) and plant growth were observed, with values ranging from 0.62 to 0.98. These findings suggest that biochar derived from date palm can be a valuable amendment for improving hydroponic crop production, particularly in arid regions.

Keywords Biochar production, Dates palm tree, Hoagland, Plant growth, *Ocimum Basilicum*

In the past decades, soil was intensively used for agricultural purposes to satisfy the higher food demand and human population growth[1]. Intensive use of soil for crop production has been usually associated with excessive chemical fertilizers and pesticides applications[2]that in many cases it adversely affected the soil, plant, and ecosystem functioning[3]. Beyond soil degradation, chemical fertilizers have also been identified as key contributors to climate change[4]. Therefore, reducing their usage while maintaining or improving plant growth has become a major focus in sustainable agriculture. Biochar has gained attention for its potential benefits in enhancing soil properties and plant growth[5]. For instance, Schulz et al. found positive effects of biochar on plant growth of *Avena sativa* and its improvement on soil properties, which were further supported by Schulz and Glaser in their study[6,7] .

Biochar possesses distinctive physical characteristics, including high porosity, water retention capacity, which are critical for the soil aeration and moisture availability. Its quality strongly depends on the waste materials, plant species and plant part, pyrolyzing processes including temperatures, and its chemical composition[8–10]. These properties make biochar an effective soil amendment, enhancing fertility while reducing nutrient leaching. Additionally, biochar provides environmental benefits by sequestering carbon, reducing greenhouse gas emissions, and enhancing soil microbial activity, thus contributing to long-term soil health and sustainability. As reported in a previous study[11] biochar produced from maize contained higher nitrogen levels than biochar from meadow grass and wood mixtures. While previous studies have investigated the effects of electrical conductivity and voltage on plant growth[12]the research linking the electrochemical properties of biochar to plant development remains limited[13–16].

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Human population has adversely affected natural resources in many parts of the world and in recent decades this has been deteriorated with climate change[17–20]; such expansion in human population will inevitably have significant negative impacts on the natural resources. Therefore, with the main objective to increase food production, hydroponic systems and vertical farming have been introduced to address these issues and sustain food production. Hoagland solution is a widely used nutrient composition formulated to support plant growth in hydroponic systems by supplying essential macronutrients (e.g., nitrogen, phosphorus, potassium) and micronutrients (e.g., iron, zinc, manganese) in optimal proportion. Its flexibility allows nutrient concentrations to be adjusted based on plant species and growth stages, making it suitable for diverse experimental setups[21]. The applications of Hoagland solution extend beyond traditional hydroponics, as it is frequently used in plant nutrition studies, nutrient uptake experiments, and soil amendment research, particularly in evaluating alternative growing media such as biochar. As biochar is known to have stable and interesting properties for plant growth and environment health[22]considering biochar as media while implementing hydroponic systems for crops production could be more efficient in improving plant quality. However, only few studies have explored the use of biochar in the hydronic systems, leaving a critical research gap.

United Arab Emirates (UAE) is one of the world's leading producers of date palm[23]. However, the large volume of agricultural waste generated from date palm cultivation is not efficiently utilized due to the slow and complex composting process[24]. As per this, converting this waste into biochar and integrating in the processes of crops production could be ecofriendly and more efficient. Previous studies have showed the importance of biochar for plant growth with not much interest correlating biochar voltage and current on the plant growth. Moreover, several materials have been identified as media for hydroponic systems, but those materials might not be efficient compared to the biochar for improving plant growth. Despite biochar's established benefits for plant growth, only few studies have examined its electrical properties or its role as a hydroponic growing medium[25,26].

This study aims to produce biochar from different parts of the date palm tree (leaflets, petioles, and fruits) using a low-cost, sustainable method and evaluate its effects on the growth of *Ocimum basilicum* in the hydroponic system. Additionally, the study investigated the electrical properties (current and voltage) of date palm biochar and their potential influence on plant growth of *O. basilicum*. By addressing these aspects, this research contributes to the development of biochar-based hydroponic solutions for sustainable agriculture.

Materials and methods

Site study, biochar experimental design, and samples preparation

The present work was conducted in the Fujairah research Centre, United Arab Emirate (UAE) (25.1288° N, 56.3265° E) from November 2023 to March 2024. Plant specimens were collected from public land around Fujairah with permission obtained from the appropriate governing body. An authorization letter allowing sample collection has been submitted as supporting documentation. The collected dates palm trees plant parts were then grouped into three parts including two leaves parts (leaflet and petiole), and fruits (Fig. 1).

These plant materials were used to prepare the biochar following the methods described in previous studies with some modifications[27,28]. Briefly, collected samples were cut into 10 cm lengths for both leaflet and petiole, and the fruits samples were uncut, and then sundried. Thereafter, 15 kg of each sundried samples were loaded into the drum manually for the pyrolyzing processes. In contrast to previously reported methods 24, our biochar drum had no perforations, and the plant samples were not directly exposed to the fire during the pyrolyzing processes[29](Fig. 2). Then firewood collected from one of the most invasive plant species, *Prosopis juliflora* was used for the combustion at the button firing point of the drum. During the processes of pyrolyzing, plant materials were heated to a maximum 500–600 °C.

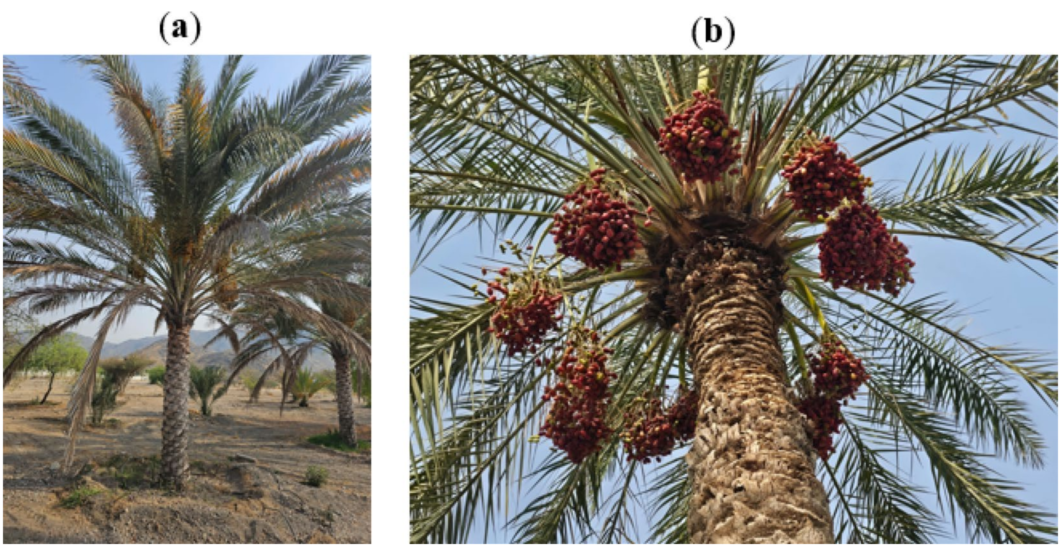

Fig. 1. Dates palm tree (*Phoenix dactylefera*) (**a**), and the dates palm bunches (**b**).

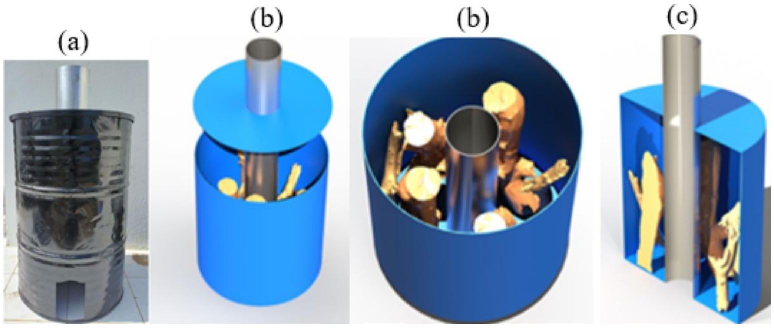

Fig. 2. Different views of the biochar drum, whole biochar drum (**a**), top view (**b**), and side view (**c**).

Dates palm biochar types	Physiochemical properties	Units
Leaflet Petiole Fruits	Current	(v)
	Voltage	(mA)
	pH	
	EC	(μS/cm)
	TDS	(mg/l)
	Drained water	(ml)
	Ca	(ppm)
	K	
	Mg	
	Na	
	Fe	
	Cu	
	Zn	

Table 1. Physiochemical properties of the tested dates palm biochar.

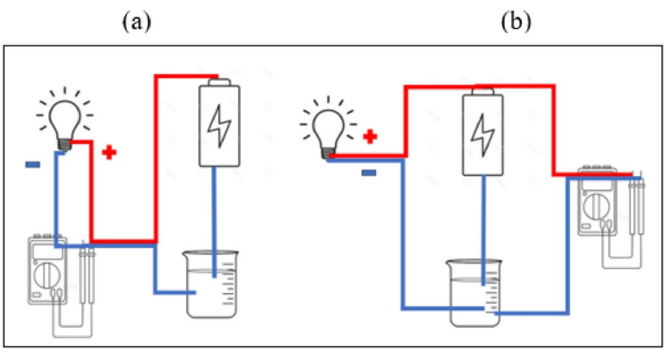

Fig. 3. Schematic illustration of the experimental systems to determine the current (**a**), and the voltage (**b**) of the different biochar.

After the pyrolyze process, the obtained biochars were physiochemically characterized for pH, electrical conductivity (EC), drained water, and total dissolved solids (TDS) using the established protocols[30]. Summarizing, 5 g of each biochar were transferred into a 150 ml beaker and, after adding 25 ml of distilled water, the mixture was shaken for 90 min, and the values of pH, EC, and TDS were recorded using Ohaus, Aquasearcher Instruments (Table 1). Water retention capacity of the biochar was assessed by oven-drying samples at 105 °C until a constant dry weight was achieved. Subsequently, 50 mL of distilled water was added to 5 g of dried biochar to measure drained water volume. Additionally, biochar samples were evaluated for their electrochemical properties including voltage and current. Experimental setups were designed and constructed to measure these parameters for each biochar type. (Fig. 3). Furthermore, the tested dates palm biochars were also analysed for minerals composition including calcium, potassium, magnesium, sodium, iron, copper, and zinc: The analyses of Na and K were performed according to the Association of Official Agricultural Chemist

No	Treatments	Concentrations (%)
1	Distilled water	0
2	Hoagland	10
3	Leaflet biochar	1.5
4	Leaflet biochar	3
5	Petiole biochar	1.5
6	Petiole biochar	3
7	Fruit biochar	1.5
8	Fruit biochar	3
9	Leaflet biochar and Hoagland	1.5 + 10
10	Leaflet biochar and Hoagland	3 + 10
11	Petiole biochar and Hoagland	1.5 + 10
12	Petiole biochar and Hoagland	3 + 10
13	Fruit biochar and Hoagland	1.5 + 10
14	Fruit biochar and Hoagland	3 + 10

Table 2. Tested treatments and the different levels.

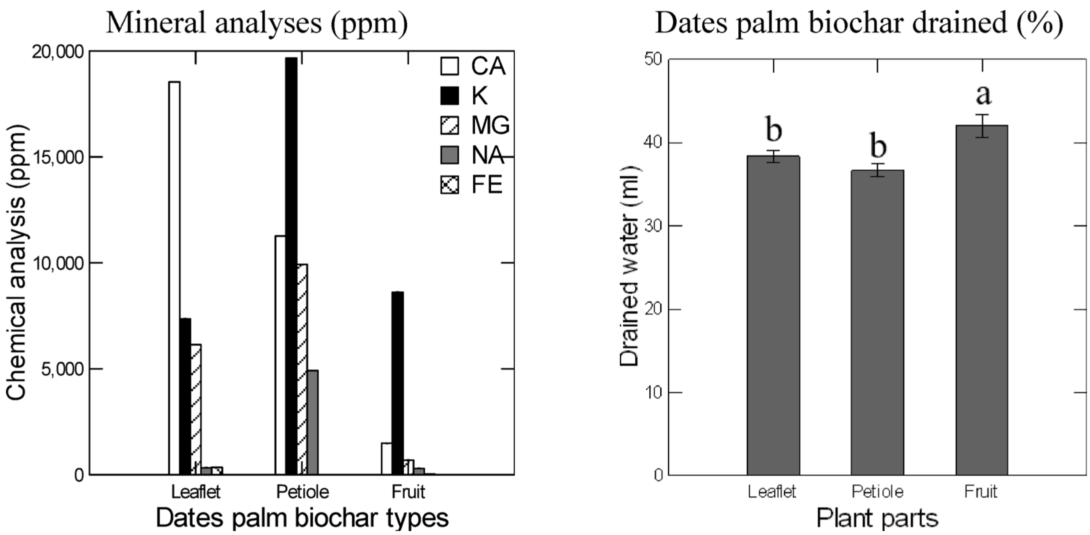

Fig. 4. *Ocimum basilicum* plants growing in the hydroponic system.

(AOAC 969.23) whereas, the analyses of calcium, potassium, magnesium, sodium, iron, copper, and zinc were conducted following the Official Agricultural Chemist (AOAC 2015.01).

Experimental design to test the effects of Biochar on *Ocimum Basilicum* plant growth

The methodology used in this study was adapted from a previously published protocol with some modifications[16]. This work was carried out using randomized block design, which consisted of 14 treatments of nutrients applications and 4 replicates per set. Seeds of *Ocimum basilicum*, (purchased from local market in Fujairah) were germinated in the plastic pots filled with a mixture of sand and peat moss and the seedlings were allowed to emerge inside the greenhouse. After germination, seedlings with two functional leaves were transferred to the hydroponic systems supplemented with the following treatments (Table 2).

The hydroponic system consisted of 50 mL Falcon tubes wrapped with aluminium foil (Fig. 4). Each tube was perforated with a 6 mm diameter hole, allowing plant roots to be hydroponically grown within the system.

After 30 days of greenhouse growth, the following plant growth parameters were measured: shoot and root length, number of leaves, longest leaf length, leaf width, shoot and root dry weights, and chlorophyll content using an SPAD meter.

Determination of the leaf chlorophyll using SPAD (Soil plant analysis Development), and plant dry weight measurements

The measurements of chlorophyll were performed according to protocol mentioned in previous studies[31]. To do this, one fully expanded leaf was selected for the recordings, always on the middle of one side of the leaf blade. The recordings were done on the third leaf from the apical bud using the SPAD CM-402 chlorophyll meter, Acculab, USA. For the plant dry weight, the tested plants were delicately pooled out from the hydroponic system,

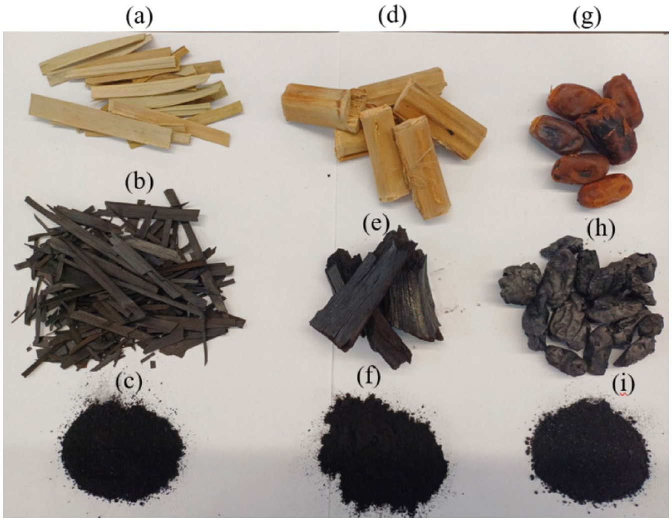

Fig. 5. Physiochemical analysis of the tested dates palm biochar (leaflet, petiole, and fruits).

Variables	df	Ca	K	Mg	Na	Fe	Water retention
Biochar types	2	9,646,655.5***	9,456,026.645***	4,734,174.594***	1,908,061.72***	15,054.438***	40.200***
Error	6						

Table 3. Results of ANOVA (F-Value) assessing the impacts of the dates palm parts on the chemical physiochemical analyses of the obtained biochar. ***$p < 0.001$.

washed with running tap water, and then rinsed with distilled water. Afterward, plant shoots were separated from the root, dried on the bench on a piece of tissue roll, and then allowed to dry in the oven adjusted at 70 °C until constant weight.

Data analysis
Three replicates were considered for the physiochemical properties of the tested biochars, while four replicated were emphasized for the other assessments. One-way ANOVA (analyses of variance) was conducted to test the effects of dates palm plant parts on the physiochemical parameters of the biochars. Furthermore, two-way ANOVA was performed to evaluate the impacts of dates palm plant parts biochar and the concentrations on the chemical analyses of the tested solutions, plant growth attributes, and total chlorophyll content. Moreover, scatterplot analyses were performed to test the levels and the types of associations between voltage, current, SPAD readings and the growth parameters. Tukey test (Honestly significant differences, HSD at $p < 0.05$) was used to identify significant difference between the means. All the data were analysed through SYSTAT version 13.0.

Results
Physiochemical analysis of the tested dates palm biochar (leaflet, petiole, and fruits)
Statically, dates palm plant parts had significant ($p < 0.001$) effects on the physiochemical analysis of the obtained biochar (Fig. 5. and Table 3). Overall, calcium and potassium were found to be greater in the dates palm leaflet (18538 ppm) and petiole biochar (19664.67 ppm) respectively than the other elements. The values of drained water were significantly higher in the dates palm fruits (42 ml) compared with the other types of biochar. The tested biochars were also investigated for copper and zinc analyses but these chemical elements were not detectable.

Impacts of the dates palm parts (leaflet, petiole, and fruits), and Biochars concentrations on the chemical and electrical parameters of the biochar of *Phoenix dactylifera* in the absence or presence of hoagland
Biochar produced from plant parts of *Phoenix dactyliflera* (leaflet, petiole, and fruits) has been shown in Fig. 6. Moreover, plant parts, Hoagland solution, concentrations of the biochar, and their interactions had significant effects on the values of voltage, current, pH, EC, and TDS (Fig. 7, and Table 4). 3% of the petiole biochar non-treated with Hoagland exhibited significantly higher values of pH (8.38), EC (3452.66 µS/cm) than the two controls and the other groups. The values of the voltage of the solutions treated with the petiole biochar regardless of the presence or absence of the Hoagland was slightly similar (2.93 v) and greater than the two controls and the other treatments. The recordings on the values of current (0.14 mA) and the TDS (1285.33 mg/l) were

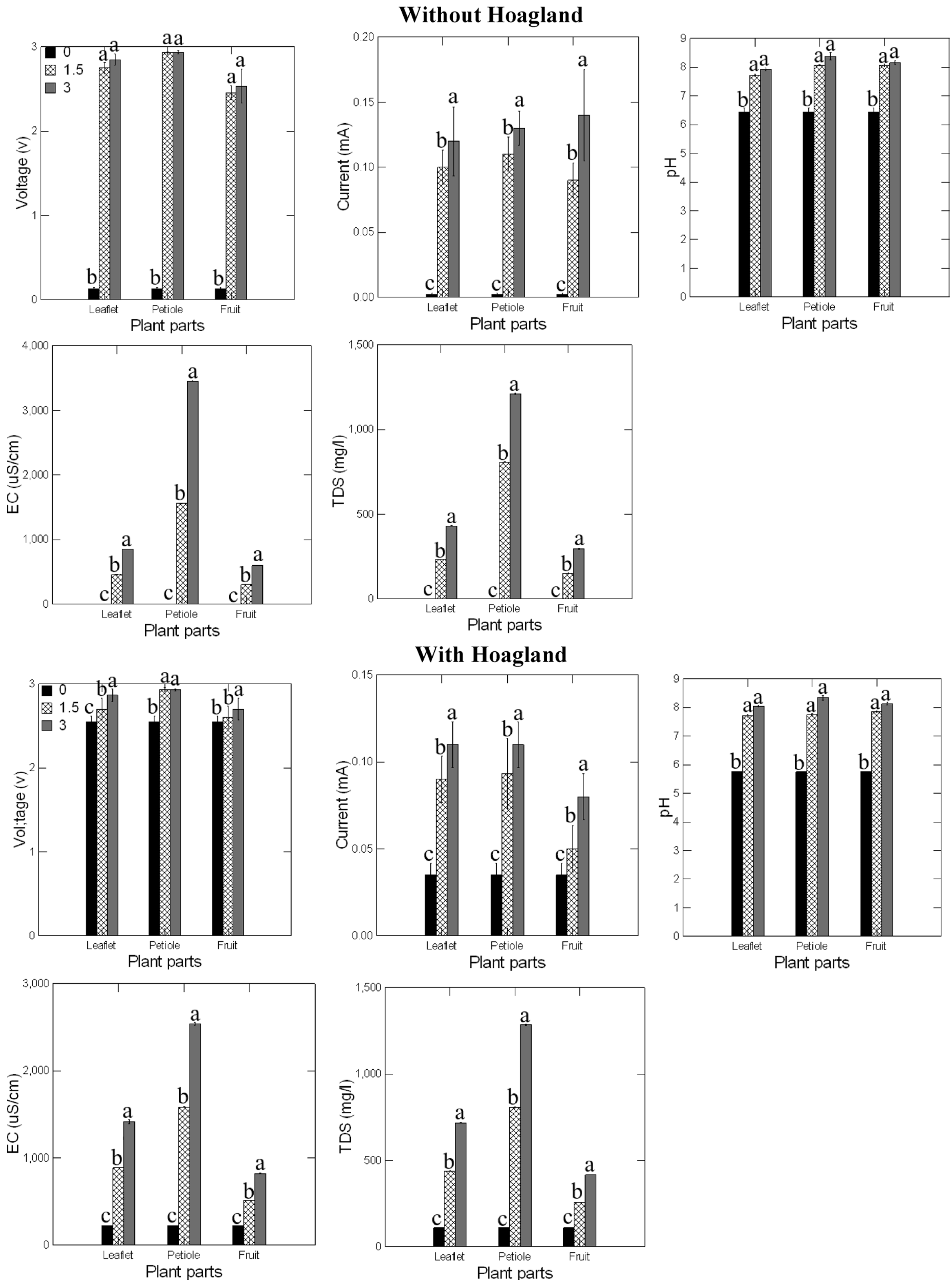

Fig. 6. Pieces of leaflet (**a**), leaflet biochar (**b**), leaflet biochar powder (**c**), pieces of petiole (**d**), petiole biochar (**e**), petiole biochar powder (**f**), fruits (**g**), fruits biochar (**h**), and fruits biochar powder (**i**) from the dates palm tree plant. Different letters indicate significant differences according to Tukey test at $p < 0.05$.

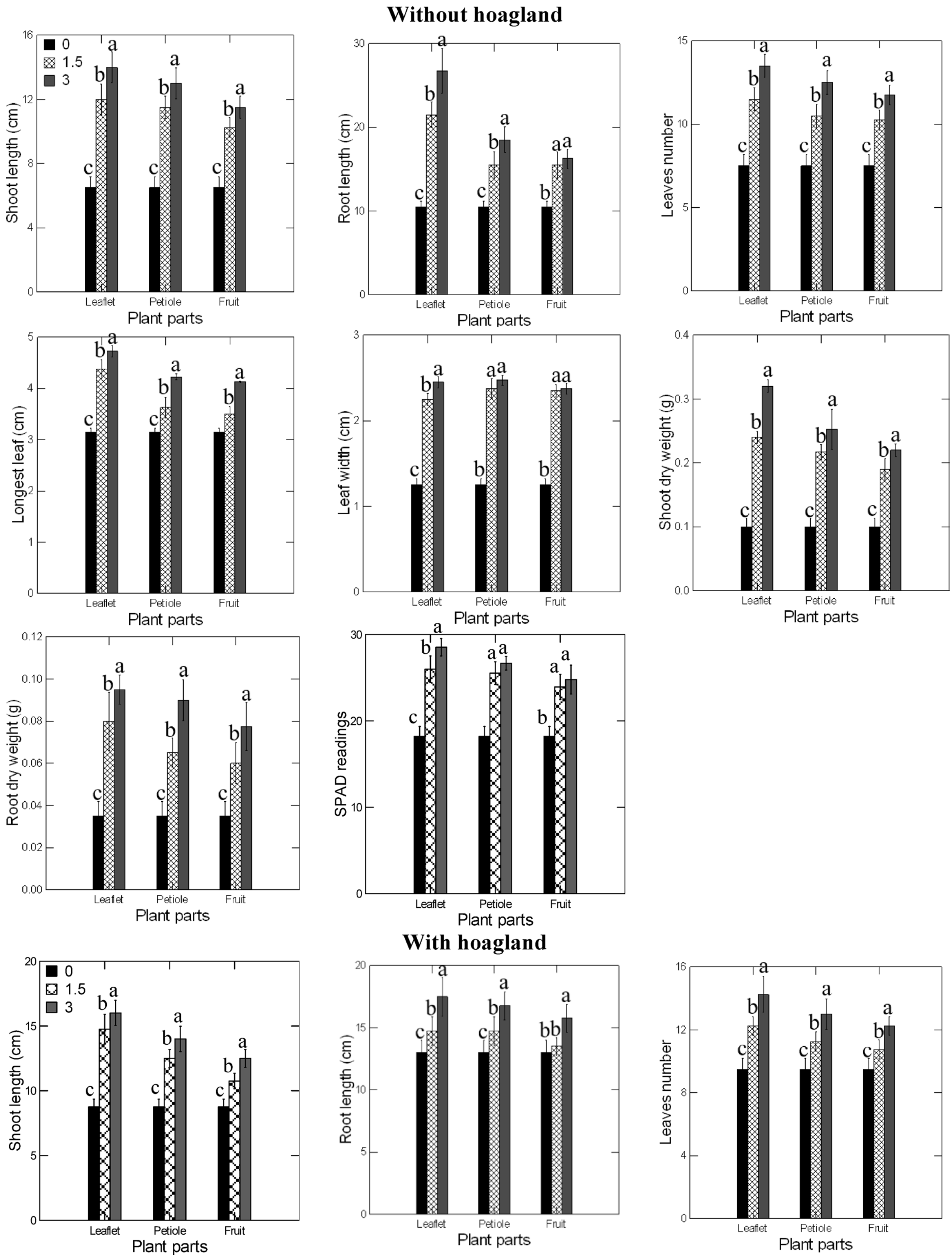

Fig. 7. Impacts of the dates palm tree part (leaflet, petiole, and fruits) and biochars concentrations on the chemical parameters of the biochar of *Phoenix dactyliflera* in the absence or presence of the Hoagland.

Source	df	Voltage (v)	Current (mA)	pH	EC (µS/cm)	TDS (mg/l)
Without Hoagland						
Plant parts (PP)	2	54.734***	0.600 ns	28.207***	1,259,081.542***	210,495.898***
Concentrations (C)	2	5,585.240***	240.478***	1,332.974***	1,467,635.355***	275,621.868***
PP*C	4	14.204***	1.499 ns	8.535***	462,220.409***	56,700.484***
Error	18					
With Hoagland						
Plant parts (PP)	2	17.361***	19.093***	37.802***	36,825.129***	174,995.869***
Concentrations (C)	2	41.045***	109.371***	18,892.816***	77,814.659***	369,332.610***
PP*C	4	5.543**	5.175**	36.060***	10,699.035***	50,385.578***
Error	18					

Table 4. Results of ANOVA (F-Value) assessing the impacts of plant parts (leaflet, petiole, and fruits) and biochars concentrations (0, 1.5, and 3%) on the chemical and electrical parameters of the biochar of Phoenix dactyliflera in the albescence and presence of Hoagland. EC electrical conductivity, TDS Total dissolve solids, $^{**}P<0.01$, $^{***}P<0.001$, ns non-significant.

Fig. 8. Impacts of *Phoenix dactyliflera* plant parts biochar (leaflet, petiole, and fruits) and biochars concentrations (0, 1.5 and 3%) on plant growth and phytochemical analyses of *Ocimum basilicum* in the absence or presence of Hoagland. Different letters indicate significant difference as per Tukey test at $p<0.05$.

more important in the solutions treated with 3% of the fruit and petiole biochar with or without the addition of Hoagland respectively.

Impact of biochar concentrations on the growth and phytochemical parameters of *Ocimum Basilicum* in the absence or presence of hoagland

Dates palm biochar, and Hoagland, and their interactions had significant effects on the plant growth and total chlorophyll content of *Ocimum basilicum* (Fig. 8; Table 5). Overall, *O. basilicum* plants treated with dates palm biochar revealed significant higher growth than the two controls (Fig. 9). In sum, treated plants with Hoagland and leaflet biochar at 3% revealed greater values of shoot length (16 cm), leaves number (14.25), longest leaf (4.79 cm), leaf width (2.48 cm), shoot dry weight (0.34 g), root dry weight (0.105 g), and SPAD values (31.52) than the other treatments and the two controls. Reversely, plant root length (26.75 cm) was found to be much higher when exposed to 3% of leaflet biochar in the group non-treated with Hoagland.

Source	df	SL	RL	LN	LL	LW	SDW	RDW	SAPD
Without Hoagland									
Plant parts (PP)	2	14.234***	71.167***	9.882**	86.975***	2.268 ns	43.200***	8.048**	10.068**
Concentrations (C)	2	299.553***	210.667***	252.618***	458.320***	1,352.707***	485.479***	145.190***	215.368***
PP*C	4	3.894*	21.167***	2.735*	24.196***	2.598 ns	15.111***	2.476 ns	3.246*
Error	27								
With Hoagland									
Plant parts (PP)	2	43.340***	3.815*	10.535***	134.578***	3.425*	39.303***	6.036**	10.068**
Concentrations (C)	2	215.681***	48.522***	101.372***	672.521***	974.166***	404.582***	98.179***	215.368***
PP*C	4	10.979***	1.125 ns	2.791*	36.879***	1.333 ns	13.601***	1.857 ns	3.246*
Error	27								

Table 5. Results of ANOVA (F-Value) testing the effects of *Phoenix Dactyliflera* plant part Biochar (leaflet, petiole, and fruits) and Biochar concentrations (0, 1.5 and 3%) on the plant growth, and phytochemical analyses of *Ocimum Basilicum* in the absence or presence of hoagland. SL = shoot length, RL = root length, LN = leaves number, LL = longest leaves, LW = leaf width, SDW = shoot dry weight, RDW = root dry weight, SPAD = soil plant analysis development, *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, ns = non-significant.

Fig. 9. Control negative and positive (**a** + b), treated with 1.5 and 3% of leaflet biochar (c + d), treated with 1.5 + 3% petiole biochar (e + f), treated with 1.5 + 3% fruits biochar (g + h), treated with 1.5 + 3% leaflet biochar + Hoagland (i + j), treated with 1.5 + 3% petiole biochar (k + l), and treated with 1.5 + 3% of fruits biochar (m + n) plant of *Ocimum basilicum.*

Correlation between the Biochar voltage and plant growth parameters of Ocimum Basilicum
The voltage of the biochar was strongly correlated with the plant growth of *Ocimum basilicum* regardless the different treatments and the effects were significant ($P < 0.01$ and $P < 0.001$) (Fig. 10; Table 6). The values of the coefficients of correlation ranging from 0.77 to 0.98 with higher values recorded in the leaf width when the tested plant was not exposed to Hoagland; and from 0.62 to 0.76 when the tested plants were exposed to Hoagland with higher values observed with shoot dry weight.

Correlation between the SPAD readings and the plant growth parameters of Ocimum Basilicum
Leaves SPAD values were found to be strongly correlated with plant growth parameters of *Ocimum basilicum* and the effects were significant ($P < 0.001$) (Fig. 11; Table 7). The correlation values ranging from 0.85 to 0.96 for the plant non-treated with Hoagland, and the higher values were recorded with shoot dry weight; and from 0.74 to 0.94 for those exposed to Hoagland and the higher values were observed with leaf width and shoot dry weight.

Correlation between the current of the Biochar and plant growth parameters of Ocimum Basilicum
Current values of the biochar were observed to be strongly correlated with plant growth of *Ocimum basilicum* and the effects were significant ($P < 0.001$) (Fig. 12; Table 8). The correlation coefficients values ranging from 0.73 to 0.95 when plants were not exposed to Hoagland with higher values found with leaf width; and from 0.778 to 0.91 when tested plants were exposed to Hoagland with higher values noticeable in the shoot length.

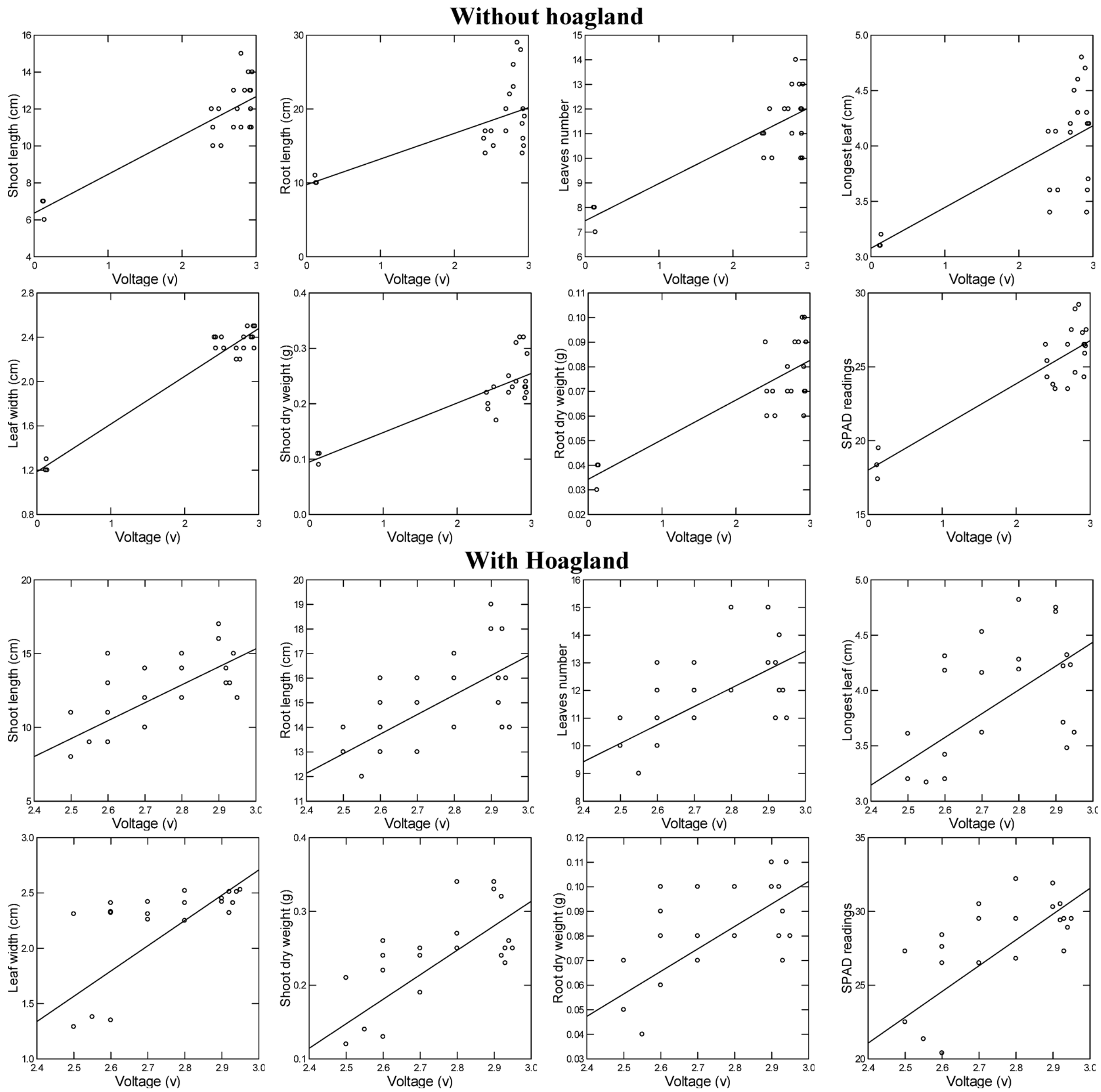

Fig. 10. Correlation between the biochar voltages and plant growth parameters of *Ocimum basilicum*.

Variables	Without hoagland		With hoagland	
	Correlation coefficients	F-Values	Correlation coefficients	F-Values
Shoot length	0.929	158.18***	0.74	31.60***
Root lengh	0.77	36.946***	0.68	21.48***
Leaves number	0.89	100.716***	0.65	18.59***
Longest leaf	0.80	46.625***	0.62	15.91**
Leaf width	0.98	911.46***	0.74	30.457***
Shoot dry weight	0.9	111.57***	0.76	34.95***
Root dry weight	0.88	94.004***	0.69	23.23***
	0.93	183.06***	0.73	29.76***

Table 6. ANOVA (F-Values) and correlation coefficients between Biochar voltages and plant growth parameters of *Ocimum basilicum*. $P < 0.01$, and $P < 0.001$.

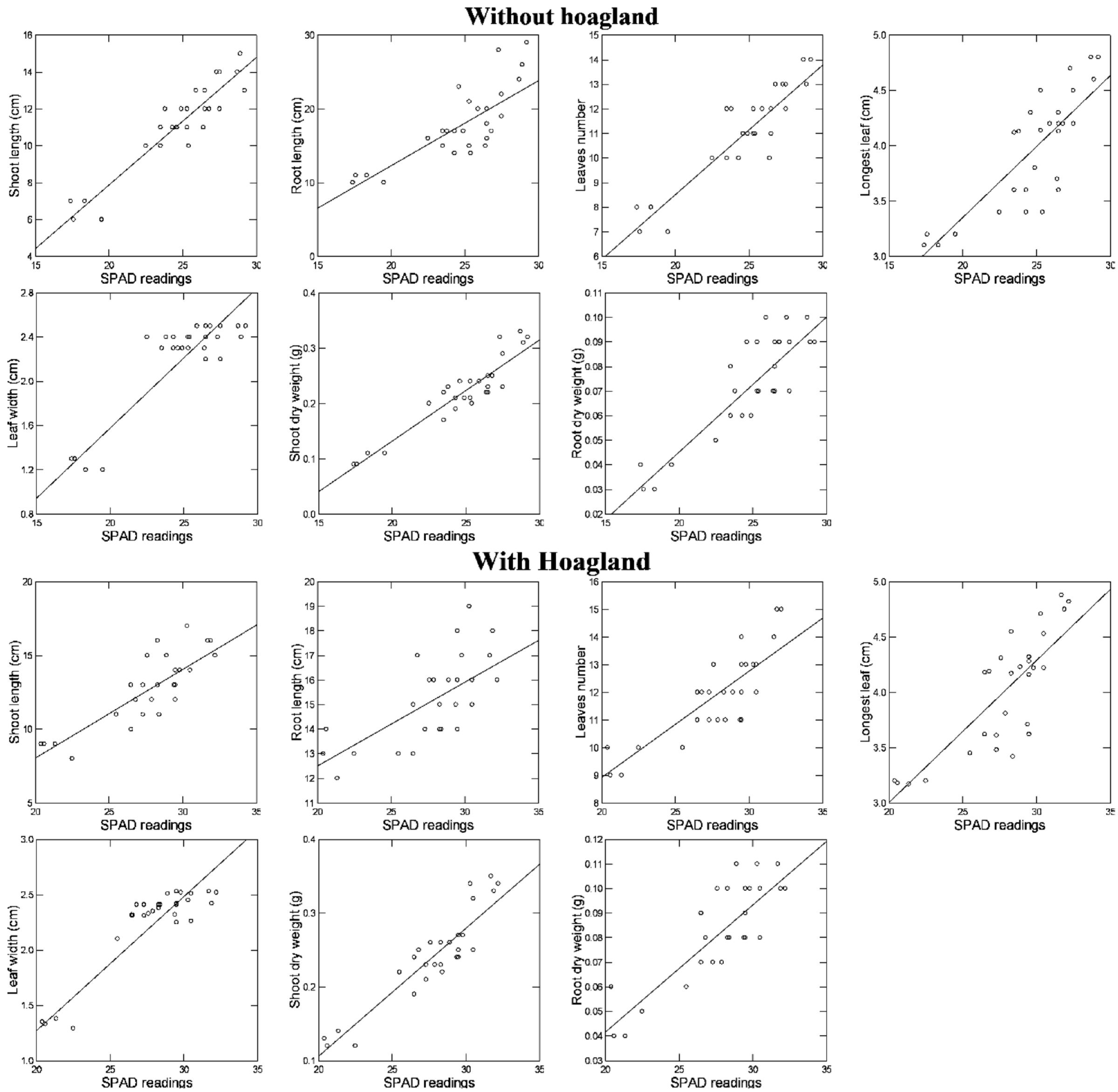

Fig. 11. Correlation between the SPAD readings and plant growth parameters of *Ocimum basilicum.*

	Without hoagland		With hoagland	
Variables	**Correlation coefficients**	**F-Values**	**Correlation coefficients**	**F-Values**
Shoot length	0.95	341.30***	0.88	121.17***
Root lengh	0.85	91.37***	0.74	42.46***
Leaves number	0.93	229.11***	0.887	124.87***
Longest leaf	0.88	120.399***	0.87	114.83***
Leaf width	0.92	202.78***	0.94	275.46***
Shoot dry weight	0.96	402.23***	0.94	290.77***
Root dry weight	0.91	172.23***	0.886	124.182***

Table 7. ANOVA (F-Values) and correlation coefficients between SPAD values and plant growth parameters of *Ocimum basilicum.* ****P* < 0.001.

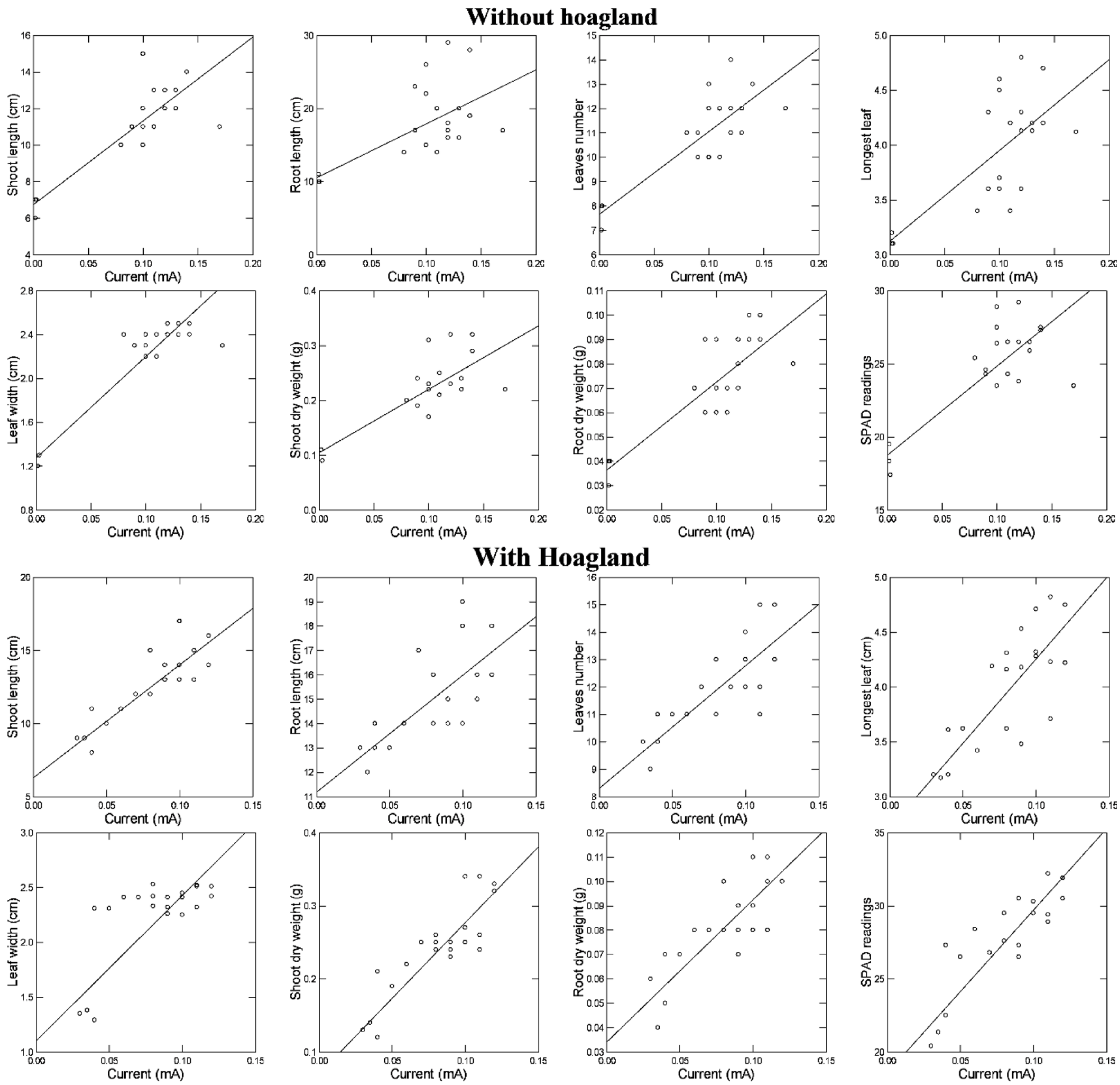

Fig. 12. Correlation between the biochar current and plant growth parameters of *Ocimum basilicum.*

Variables	Without hoagland		With hoagland	
	Correlation coefficients	F-Values	Correlation coefficients	F-Values
Shoot length	0.91	123.03***	0.91	122.54***
Root lengh	0.73	29.78***	0.788	41.07***
Leaves number	0.9	111.64***	0.84	61.54***
Longest leaf	0.81	50.07***	0.85	68.41***
Leaf width	0.95	250.63***	0.82	54.93***
Shoot dry weight	0.88	89.04***	0.91	129.68***
Root dry weight	0.89	105.04***	0.85	66.52***
	0.882	87.14***	0.9	112.57***

Table 8. ANOVA (F-Values) and the correlation coefficients between the Biochar current and plant growth parameters of *Ocimum basilicum. P* < 0.001.

Discussion

The present work examines the potential use of dates palm trees parts (leaflet, petiole, and fruits) to prepare the biochar and then use the obtained biochar at different levels (0, 1.5 and 3%) to improve plant growth of *Ocimum basilicum* hydroponically in combination with Hoagland. Physiochemical analyses of the tested biochar revealed important variations between the different plant parts of the dates palm tree. In addition, combining Hoagland and biochar showed significant variations on the analysed parameters compared with the two controls groups. Overall, the obtained leaflet and petiole biochars revealed higher values of calcium and potassium compared with the other elements. Furthermore, biochar water retention was found to be higher in the petiole than the leaflet and the fruits. These observations in the physiochemical analyses of the tested biochar induced significant changes in the experimental solutions compared to the non-treated. It was found that increasing the levels of biochar in the solution significantly affected the tested chemical parameters. 3% of the petiole and leaflet biochars had more impacts on the values of pH, EC, TDS, current, and voltages than the fruits biochar and the two controls. The chemical analysis values of the biochar obtained in the present study were higher than those reported in previous studies[32,33]. Notably, to the best of our knowledge, no prior research has evaluated the electrical current and voltage characteristics of biochar derived from date palm residues.

The variations observed between the tested biochar in this work may be attributed to the dates palm tree part used. Previous studies on the chemical analyses of the biochar reported that, varied proportions of hemicellulose, lignin, and cellulose levels in the tested materials greatly affect the conversion of the residue into biochar[28]. It has been reported that the leaflets of the date palm tree contain higher amounts of extractives, including cellulose, hemicellulose, and lignin, compared to other plant parts[34]. Therefore, the observable variations obtained in the present work on the current and the voltage values of the biochar could be associated to the chemical composition of the tested plant parts and the presence of Hoagland in the solutions. Moreover, petiole and leaflet biochars exhibited higher values of water retention than the fruits. The capacity of the biochars to fix water is very important for the chemical reactions, and nutrients availability. This would mean that, biochar with higher water retention would fix more particles than the other, which could importantly affect the electrical properties of the tested solution.

Plant attributes of *Ocimum basilicum* tested in this work were positively and significantly affected by the different treatments than the two controls. *O. basilicum* plants growing with the combination of Hoagland and biochar were more affected than those without Hoagland and the two controls, with highest plant performance observed at 3% of leaflet biochar. The values of SPAD were also greater in the groups treated with the combination of biochar and Hoagland than the non-treated, and the controls. Plant attributes of *O. basilicum* were found to be strongly and positively correlated with the current, the voltage, pH, TDS, and the SPAD values for all the tested biochar. A previous study observed that combining palm kernel biochar with hydroton significantly enhanced the growth of red lettuce compared to using palm kernel biochar alone[16]. Similar trends have also been reported in cabbage and lettuce plants[32]. The values of EC were greatly correlated with plant growth of *O. basilicum*, and these values increased with the increase of biochar levels and Hoagland application. Electrical conductivity is considered as an indicator for nutrients availability in the media. Therefore, the augmentation of the EC levels in the growing media will inevitably raise up the negative charges and therefore, allowing the retention of the positive charges which could provide more nutrients to the plant. It has been observed that increasing the EC of the nutrient solution led to a significant rise in nitrogen, phosphorus, potassium, and calcium content in lettuce plants[35]. Based on our study, leaflet and petiole biochars had greater values of physiochemical analyses. Calcium and magnesium were significantly higher in these two types of dates palm biochar than the other. Macro elements are essential and indispensable for plant growth and development, and any deficiencies could have adverse effects on the plants. For example, calcium is actively involved in the movements of stomata and many other physiological processes, while magnesium is involved in the chlorophyll synthesis, enzyme activation, and protein synthesis. As per this, this much growth observed in the *O. basilicum* plants could be attributed to the chemical elements of the tested biochars. Furthermore, water retention vales were seen to be greater in the same dates palm biochar parts. Water retention plays critical role in the nutrient availability and cation exchange capacity. As per this, leaflet and petiole biochars could have the capacity to fix more nutrients and make it available for the tested plant than the fruits biochar and the two controls.

Based on our findings, current, voltage, and TDS values of the tested biochar were strongly and greatly correlated with plant growth of *Ocimum basilicum*. Voltage is considered as electromotive force or the sum of energy transfer to the solution, while current is the rate of the electrical charges flow and TDS, the measure of dissolved solids in the solution. In the present study, there was a net increase in current, voltage and TDS values with the increase of the levels of biochar in the media. Therefore, significant levels of biochar in the solution could have potentially exerted significant pressure in the solution and the resultant could be observed on the movement of the particles present in the media. Justifiably, such phenomena would have increased the biochar buffer and therefore facilitated cations exchange capacity (CEC), which would have obviously promoted plant growth. Correlating cation exchange capacity and plant growth, previous studies observed that media emended with biochar had both higher values of CEC and plant biomass than the control[36]. Moreover, the tested properties of the dates palm biochar could have provided more effects on the current and voltage values. These two electrical parameters are much influenced by the quantity and the quality of the salt in the solution. Higher values of calcium and magnesium could have increased the movements of the particles in the solution, which could have improved nutrients up take by the tested plant.

The *Ocimum basilicum* plants exposed to biochar combined with Hoagland exhibited significant values of SPAD than the other group and the control. Furthermore, SPAD values were strongly and positively correlated with plant growth of *O. basilicum*. Although higher EC can alter plant physiology, important EC in the media means more nutrients. In our work, we found greater values of EC in the groups treated with biochar than the controls. Earlier study on the mineral composition of the biochar of dates palm tree and other biochar types showed that, this latter contained essential minerals including calcium, potassium, nitrogen, and sodium[32,37]. These essential minerals are known to play significant role in plant photosynthesis[38].

Conclusion

In this study, the three testing factors showed significant effects on the physiochemical analyses of the tested biochar. Calcium contents, and higher water retention were observed in the leaflet biochar, while potassium levels, voltage, pH, TDS, and EC values were importantly higher in the petiole biochar than the control groups. Contrastingly, the values of current were greater in the fruits biochar than the other treatments. Furthermore, combining Hoagland with biochar showed significantly higher and positive effects on the plant growth attributes of *Ocimum basilicum* than the other treatments and the non-treated plants. The interaction between biochar concentration and nutrient solution revealed notable effects on both biochar chemical composition and plant development. Moreover, strong correlations were observed between biochar electrical properties and plant health. Future research should explore optimizing biochar compositions and application methods to enhance plant growth and sustainability.

Data availability

All data supporting the findings of this study are available within the paper and its Supplementary data file.

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Declarations

Competing interests
The authors declare no competing interests.

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