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Original research

Biochar: A Surrogate Approach to Modulating Soil Chemical Properties and Germination Parameters of Barley Seedlings Grown in Saline-Calcareous soil

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Abstract:

Owing to its unique features, biochar (BCH) is an excellent sustainable tool for improving the chemical properties of soil with undesirable characteristics. Under multiple abiotic stresses (ECe = 10.8 vs. 10.7 dS m^{-1}; $CaCO_3$ = 19.1 vs. 18.8%; soil pH = 8.15 vs. 8.13), a potted study was conducted to investigate the potential positive effect of three palm tree frond BCH rates (0, 28, and 56 g pot^{-1}, labeled as BCH_0, BCH_{28}, and BCH_{56}) prepared at three different pyrolysis temperatures (350, 500, and 700 °C, labeled as PYT_{350}, PYT_{500}, and PYT_{700}), totaling seven PYT × BCH treatments. In a randomized complete block design with three replications, the seven PYT × BCH treatments (BCH_0 as a control, PYT_{350} × BCH_{28}, PYT_{350} × BCH_{56}, PYT_{500} × BCH_{28}, PYT_{500} × BCH_{56}, PYT_{700} × BCH_{28}, and PYT_{700} × BCH_{56}) were evaluated during the 2020-21 and 2021-22 seasons. The results indicated that both the PYT_{700} × BCH_{56} and PYT_{700} × BCH_{28} treatments had the highest impact on the soil chemical properties, soil nutrient status, and leaf nutrient contents, except for the soil pH, which was positively affected by PYT_{350} and BCH_{28} in both seasons, and the available potassium content in the first season. Regarding the germination parameters, the data reveal that PYT_{350} × BCH_{56} and PYT_{700} × BCH_{56} were the superior treatments for the germination percentage and the mean germination time, while PYT_{500} x BCH_{56} led to notable elevations of seed vigor in both seasons. The heat map illustrating the studied soil chemical properties fluctuates between positive and negative. In short, the application of BCH has profoundly desirable effects on the soil chemical properties depending on the PYTs and BCH addition rates.

Keywords: Soil amendment; pyrolysis temperature; biochar-addition rate; Barley germination parameters.

1- Introduction

Egypt is among the developing countries that depend on agriculture, which is considered to be the backbone of the national economy. In recent decades, the agricultural sector has faced some challenges that are impeding sustainable agricultural development.

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The most important of these obstacles is the widening gap between production and consumption resulting from extreme population growth **(Awad et al. 2022)**, coinciding with limited arable land. The cultivated area in Egypt does not exceed 4% of the total area of one million km^2, thus 96% of the total area is still desert land **(Al-Soghir et al. 2022)**. In addition, there is obvious deterioration in a large part of the arable land as a result of inappropriate agricultural practices. The most important of which are salinity and calcification, which are considered major constraints to achieving the goal of sustainable agriculture **(Awad and Sweed, 2020)**. Soil salinity has been become a major progressive environmental constraint, threatening soil quality and productivity **(Yu et al. 2010)**. Globally, the total saline soil areas exceed 831 million ha and is increasing annually rate of 4×10^4 ha **(Saad El-Dien and Galal, 2017; Sun et al. 2018)**. The negative influences of salinity include nutritional imbalance and decreased osmotic stress, causing water deficits and reducing nutrient uptake **(Agbna et al. 2017)**. At the same time, the influence of soil calcification is no less severe than that of salinity due to the undesirable effects on plant growth, including high soil pH, which causes low nutrient availability, particularly phosphorus (P) and micronutrients, as well as low cation exchange capacity (CEC) and soil organic matter (SOM) **(Aboukila et al. 2018; Wahba et al. (2019)**. Additional factors include the presence of impermeable layers, which hinders plant root growth, and the horizontal and vertical movement of water within the soil layers.

One of the suggested solutions to modify undesirable soil characteristics is to apply soil amendments. In the past few years, the recycling of plant-based waste to produce soil amendments, referred to as biochar (BCH), has gained attention. Several studies have described BCH as a stable carbonaceous organic compound produced by the pyrolysis of raw materials under conditions of limited or no oxygen (O) **(Dissanayake et al. 2020; Foong et al. 2020; Xu et al. 2021)**. In Egypt, especially in upper Egypt, the date palm *(Phoenix dactylifera)* is one of the oldest cultivated trees and the main crop. According to statistics issued by the Egyptian Economic Affairs Sector in 2018, the number of date palms was estimated at approximately 14.1 million fruitful date palm trees cultivated on about 47.2 ha, producing 1.56 million metric tons. Annually, date palm tree residue is estimated to be about 211.4 tons, with an average of 50 kg green waste $tree^{-1}$ **(Jouiad et al. 2015)**. In the past, disposal of such residue was carried out by burning it in an open field, which caused increased emissions of greenhouse gases (GHGs) such as carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4), which, in turn, negatively affected the environment **(Singh et al. 2016; Boateng et al. 2017; Wei et al. 2019)**. The presence of residual fronds is a serious problem for farmers in Egypt; thus, converting such residue to BCH and applying it as a low cost and environmentally friendly material for soil amendment is an optimal solution **(Yuan et al. 2019; Wu et al. 2019; Rehman et al. 2021; Malyan et al. 2021; Haider et al. 2022)**.

Several studies in the literature show that BCH has a multifunctional role in improving soil physico-chemical properties **(Chen et al. 2019; Khan et al. 2019; Diatta et al. 2020; Mohawesh et al. 2021)**. In a study by **Thomas and Gale (2015)**, they reported that the addition of BCH increased CEC, nutrient availability, and organic carbon (OC) content, consequently improving tree growth **(Sahin et al. 2017)**. Despite the extensive work on the impact of BCH on soil properties, the available information about its effects in mitigating abiotic stresses is still somewhat scarce. However, studies by **Akhtar et al. (2015a)** indicated that BCH is a good potential solution for salt-affected soil, because it significantly decreases salt stress, but its application increases salinity tolerance. Very recent studies mentioned that water potential, stomata conductance, and potassium (K) uptake increased in BCH-treated plants; moreover, BCH addition reduced Na^+ uptake and the Na^+/K^+ ratio in bean, potato, and quinoa plants and increased superoxide dismutase, peroxidase, and catalase activity **(Ibrahim et al. 2020; Parkash and Singh, 2020; Yang et al. 2020b)**. In the same context, **She et al. (2018) and Huang et al. (2019)** showed that BCH incorporated into saline soil improved the availability and uptake of nutrients by wheat, bean, and quinoa plants. Moreover, the incorporation of BCH into saline soil enhanced seedling germination **(Ibrahim et al. 2021)**. These enhancements were attributed to BCH increasing the leaf relative water content and water use efficiency in wheat and quinoa plants grown under saline soil conditions **(Kanwal et al. 2018; Nikpour-Rashidabad et al. 2019)**. On the other hand, some researchers noted that BCH does not behave the same way in different soil textures. **Kwapinski et al. (2010) and Sohi et al. (2010)** noted that mixing BCH into soil could hamper optimal plant growth due to the negative effect of BCH on the microbial activity of SOM **(Koabana 2010)**. Based on the above, the effect of applying BCH can be between positive or negative depending on several factors, including the source of feedstock biomass and the pyrolysis temperature (PYT). However, BCH can be produced from a wide range of feedstocks, such as fruit shells, plant residues (including leaves, stems, and branches), green manure, animal manure, sewage sludge, and industrial waste **(Amarasinghe et al. 2016; Wang et al. 2018)**. Furthermore, acidic BCH can be produced at low pyrolysis temperatures (PYTs), while alkaline BCH can be obtained at high PYTs **(Bista et al. 2019)**, and the soil texture and addition rate are considered. Therefore, our investigation included more than one purpose: (i) to determine the optimal way to recycle and dispose of date palm fronds without polluting the environment by converting them into BCH, and (ii) to take advantage of the possible BCH's benefits in improving saline-calcareous soil chemical properties and barley seedling germination parameters.

2. Materials and Methods

2.1. Study location, climate conditions, timing and plant material.

In two consecutive seasons (2020-2021 and 2021-2022), two pot experiments were installed at the Faculty of Agriculture and Natural Resources, Aswan University, Egypt (24° 05´ 20"N; 32° 53´ 59"E). The average monthly (October to February) weather data in the studied location in both seasons are given in **Table 1**.

2.2. Source, production, and characterization of BCH

Palm tree fronds (PTFs) as a feedstock biomass were collected from Edfu district, which is located about 120 km north of Aswan, Aswan Governorate, Egypt. The collected PTFs were transferred to the Laboratory of Soil Chemistry at the Faculty of Agriculture and Natural Resources, Aswan University, and stored under ambient conditions before carbonization. They were air-dried for 7 days, ground, and placed in a sealed ceramic crucible to burn in a muffle furnace (internal dimensions 250 × 250 × 250 mm, 3000 W, electronically controlled). Before the pyrolysis process, the muffle was flushed with nitrogen for 10 min. Three PYTs were 350, 500, and 700 °C (abbreviated as PYT_{350}, PYT_{500}, and PYT_{700}, respectively), for 4 h of burning at isothermal conditions in the absence of O according to several previous studies (Burrell et al. 2016; Berihun et al. 2017; Mor et al. 2019). After the pyrolysis process was complete, the BCH samples were sieved to small granules through a 2 mm sieve and stored in plastic bags.

Table 1. Average monthly climatic data for Aswan region in Egypt during the 2020-21 and 2021-22 seasons

Month	ADT (° C)	ANT (° C)	ARH (%)	AWS (ms^{-1})	AM-APC-A ($mm\ d^{-1}$)	AP ($mm\ d^{-1}$)
2020-2021 season						
November	32.81	10.37	35.50	2.82	2.53	0.00
December	25.77	4.76	46.69	2.87	2.85	0.00
January	25.23	2.90	50.75	3.20	2.89	0.00
February	28.19	2.88	42.50	3.21	2.67	0.02
2021-2022 season						
November	28.27	7.77	45.75	3.09	2.90	0.00
December	30.08	7.60	39.25	2.46	2.91	0.00
January	29.26	4.36	38.81	2.81	2.78	0.00
February	28.47	2.26	36.44	3.50	3.21	0.00

ADT, average day temperature; ANT, average night temperature; ARH, average relative humidity; AWS, average wind speed; AM-APC-A, Average of the measured pan Evaporation Class A; AP, average precipitation.

2.3. Treatments, experimental design, and layout.

In both seasons of the study, the BCH produced at PYT_{350}, PYT_{500}, and PYT_{700} were applied with three addition rates (i.e., 0.0, 28.0, and 56.0 $g.pot^{-1}$ abbreviated as BCH_0, BCH_{28}, and BCH_{56}, respectively). Plastic pots with a diameter of 23 cm and height 20 cm were filled with 7 kg of soil. This study was carried out in a randomized complete block design with three replications to test the effects of PYT × BCH treatments, which are detailed in **Table 2**.

Table 2. Description of treatments applied in this study

Treatment	Description
BCH_0	Un-amended soil (no-BCH addition)
$PYT_{350} \times BCH_{28}$	applying of PTF-derived BCH pyrolysis at 350 °C with rate at 28 g pot^{-1}
$PYT_{350} \times BCH_{56}$	applying of PTF-derived BCH pyrolysis at 350 °C with rate at 56 g pot^{-1}
$PYT_{500} \times BCH_{28}$	applying of PTF-derived BCH pyrolysis at 500 °C with rate at 28 g pot^{-1}
$PYT_{500} \times BCH_{56}$	applying of PTF-derived BCH pyrolysis at 500 °C with rate at 56 g pot^{-1}
$PYT_{700} \times BCH_{28}$	applying of PTF-derived BCH pyrolysis at 700 °C with rate at 28 g pot^{-1}
$PYT_{700} \times BCH_{56}$	applying of PTF-derived BCH pyrolysis at 700 °C with rate at 56 g pot^{-1}

PTF= palm tree fronds-derived biochar. BCH = biochar and PYT pyrolysis temperature.

2.4. Soil collections and determinations

Soil samples were taken from the surface layer at a depth of 0-30 cm in the Sahari district, which is located in the southern part of Aswan city (latitude 22° 30′ and 23° 30′ and longitude 30° 30′ and 32° 00′). The samples were collected over a period of 2 months, then transferred to the Soil Chemistry Analysis Laboratory (SCAL) at Aswan University, air-dried, sieved through a 2 mm sieve, and kept in plastic containers prior to soil chemical and physical analysis, as shown in **Table 3**. Soil particle distribution was determined by the hydrometer method, as described by **Gee and Bauder (1986)**. Soil reaction (pH) was measured in saturated soil paste using a pH meter (Jenway, UK) according to **Thomas (1996)**. ECe, a salinity indicator, was measured in saturated soil paste extract, as described by **Blume et al. (1982)**, using an EC meter (LF-191 Condukometer, Germany).

Using the Collins calcimeter method, the $CaCO_3$ content was determined as described by **Page et al. (1982)**. The SOM was determined by using the wet digestion method according to **Walkey and Black (1934)**, as described by **Nelson and Sommers (1982)**. Soluble cations (Na^+, K^+, Ca^{++}, and Mg^{++}) were extracted with 1 N NH_4AOC at pH 7.0 (*w/v*), left to sit overnight, and filtered with No. 42 Whatman paper. The resting and filtration of the extract were repeated until completed to a final volume of 100 mL with distilled water. Using flame photometry, K^+ and Na^+ were measured as described by **Jackson (1973)**, while Ca^{++} and Mg^{++} were measured with the titration method using EDTA. Soluble anions (CO_3^{--}, HCO_3^-, Cl^-, and SO_4^{--}) were measured by the titration method according to **McLean (1982)**. The cation exchange capacity (CEC) was measured according to the micro-Kjeldahl method as described by **McLean (1982)** by extracting 1 M NH_4AC (pH 7.0), then leaching the NH_4AC with 10% sodium chloride (NaCl) and measuring. Na^+ ions replaced the NH_4^+ ions, then the amount of NH_4^+ ions in the percolate was determined. The produced BC samples were analyzed for their ammoniacal nitrogen (NH_4^+-N) content.

Soil NH_4-N was determined using a 2 M KCl extract solution, and samples were examined by a spectrophotometer according to **Keeney and Nelson (1983)**. Soil P was calculated by spectrophotometric analysis, using $NaHCO_3$ solution (0.5 M) as an extractant **(Olsen, 1982)**. K concentration was measured on a flame photometer, with 1 N ammonium acetate solution used to run the samples **(Helmke et al. 1996)**. Micronutrients in the soil were determined by using the AB-DTPA extraction method **(Soltanpour and Schwab, 1977)**.

2.5. Characterization of palm tree fronds-derived biochar prepared and applied in this study

The characterization of PTF-derived BCH at different PYTs (350, 500, and 700 °C) was performed using several analytical techniques. Elemental analysis, including the C, O, P, K, Ca, Mg, Cl, and Si content of BCH, was conducted using energy dispersive X-ray (EDX) (Elementar Analysensysteme GmbH, Langenselbold, Germany). Scanning electron microscopy (SEM) was used to determine the morphology of BCH samples. Additionally, Fourier transform infrared spectroscopy (FT-IR) with a Bruker Vertex 80v was used to identify the chemical functional groups present in the BCH samples.

2.6. Germination parameters.

Germination percentage (GP) was determined by a formula presented by **Close and Wilson (2002)**: $GP\ (\%) = \frac{\text{Number of seeds germinated during time interval}}{\text{Total number of seeds sown}} \times 100$.

Seed vigor (SV) of the barley seedlings was measured by a formula presented by **Abdul and Andersson (1973)**: $SV = \frac{\text{Germination percentage} \times \text{mean seedling length}}{100}$.

Germination rate (GR) was determined by a formula presented by **Khan and Ungar (1984)**: GR (%) = $\frac{\text{First day of seed germination}}{\text{Total number of seeds sown}}$ × 100. Mean emergence time was calculated using the formula proposed by **Labouriau (1983).**

Table 3. Some soil chemical and physical properties

Soil property	2020-2021 season	2021-2022 season
Particle size distribution (%)		
Sand	80.45	81.40
Silt	11.30	10.50
Clay	8.25	8.10
Soil texture	Loamy sand	Loamy sand
pH (in soil paste)	8.15	8.13
ECe (dS m^{-1})	10.8	10.7
SOM (%)	1.63	1.70
$CaCO_3$ (%)	19.1	18.8
CEC ($cmol_c kg^{-1}$)	7.20	7.20
Soluble ions (mmol L^{-1})		
CO_3^{--}	----	----
HCO_3^-	12.8	13.7
Cl^-	63.4	65.3
SO_4^{--}	19.3	21.1
Ca^{++}	39.6	41.2
Mg^{++}	17.8	18.4
Na^+	12.4	14.3
K^+	25.7	26.2
Macronutrients (mg kg^{-1})		
Total N	7.01	7.05
Available P (extractable with $NaHCO_3$ pH=8.5)	3.57	3.58
Available K (extractable with NH_4OAC pH=7.0)	67.1	67.4
DTPA-extractable micronutriments (mg kg^{-1})		
Fe	9.7	10.2
Mn	14.5	16.3
Zn	0.15	0.14
Cu	0.48	0.38

SOM= Soil Organic Matter, CEC=Cation Exchange Capacity and DTPA= Diethylenetriaminepentaacetic acid

2.7. Statistical analysis

The analysis of variance (ANOVA) and Duncan's test were calculated using the InfoStat statistical package version 2011 (InfoStat Microsoft), according to Di Rienzo et al. (2011). The standard error (±SE) for each treatment was calculated. The Pearson correlation was performed to calculate the correlation coefficient between soil chemical properties and nutrients content.

3. Results and Discussion

3.1. Characterization of biochar samples

The results presented in **Table 4** show the chemical properties, elemental composition, and molecular ratios of the PTF-BCH samples under PYT_{350}, PYT_{500}, and PYT_{700} using energy dispersive EDX analysis. Our results indicate that the pH of all the biochar obtained was alkaline, in general. The BCH's pH increased with increasing pyrolysis temperature and can be coordinated in the following descending order: PYT_{700} (11.68) > PYT_{500} (9.76) > PYT_{350} (9.15). Like the BCH's pH, the CEC of the BCH samples increased with increasing pyrolysis temperature. As shown in **Table 4**, the highest (47.15 cmol kg^{-1}) and lowest (44.89 cmol kg^{-1}) CEC values were recorded for the BCH produced at PYT_{700} and PYT_{350}, respectively. In contrast, the BCH's electrical conductivity (EC) declined with increasing pyrolysis temperature. The EC of the BCH decreased when produced at PYT_{500} and PYT_{700} by approximately 27.18 and 34.19%, respectively, compared with PYT_{350}. Carbon (C) content is a major constituent of BCH. The results revealed that the C content increased with increasing pyrolysis temperature.

Table 4. Effect of different pyrolysis temperatures (PYTs) on elemental composition and atomic ratios of palm tree fronds-derived biochar samples

Parameters	**PYTs (°C)**		
	PYT_{350}	**PYT_{500}**	**PYT_{700}**
pH*	9.15	9.76	11.68
ECe (dS m^{-1})**	11.70	8.52	7.70
CEC (cmol kg^{-1})	44.89	45.72	47.15
Elemental composition (%, on basis oven-dry weight)			
Carbon ©	57.77	58.45	63.14
Oxygen (O)	15.40	10.10	7.30
Nitrogen (N)	2.20	2.80	4.20
Phosphorus (P)	0.106	0.113	0.164
Potassium (K)	2.24	1.98	0.82
Calcium (Ca)	0.65	2.24	2.81
Magnesium (Mg)	0.17	0.54	0.58
Silicon (Si)	0.69	0.34	0.49
Cloride (Cl)	1.04	1.20	0.62
Molar ratio			
O/C	0.1999	0.1296	0.0866
(O+N)/C	0.2272	0.1622	0.1323

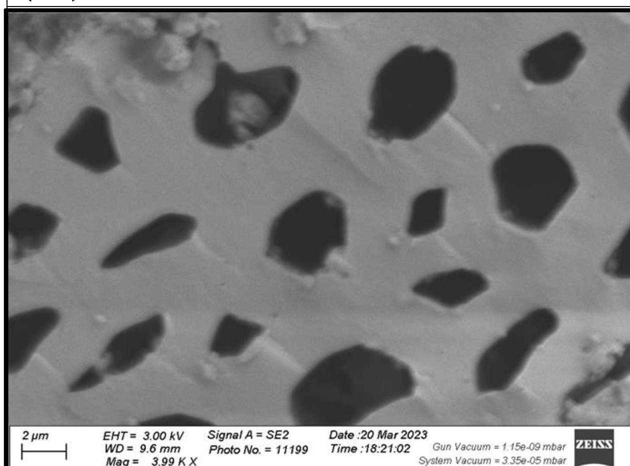
*Soil past and **soil paste extract. PYT_{350}, PYT_{500} and PYT_{700} represent pyrolysis temperature (PYT) of palm fronds at 350, 500 and 700 °C, respectively. CEC=cation Exchange Capacity; ECe=Electrical Conductivity

The PYTs were ranked in descending order as PYT_{700} (63.14) > PYT_{500} (58.45) > PYT_{350} (57.77). Similarly, the nitrogen (N) content in BCH was positively correlated with the pyrolysis temperature. As shown in **Table 4**, the N content increased by 90.91 and 50% in PYT_{700} and PYT_{500}, respectively, compared with PYT_{350}.

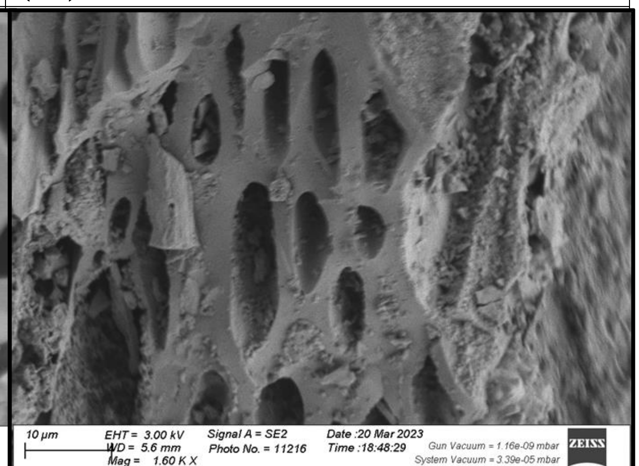
The O content in the BCH decreased with the increase in the PYT, and the studied PYT could be arranged in the order PYT_{350} (15.40) > PYT_{500} (10.10) > PYT_{700} (7.30). Negligible increases were observed in P content of the BCH samples, with 0.106, 0.113, and 0.164 in PYT_{350}, PYT_{500}, and PYT_{700}, respectively. In contrast, the K content was significantly increased with the increasing PYT.

In addition, there were adequate quantities of calcium (Ca), magnesium (Mg), chloride (Cl), and silicon (Si) in the prepared BCH. As shown in **Table 4**, the molecular ratios of elements, which determine polarity (O/C) and (O+N/C), were appreciably influenced by the PYT and the BCH samples were significantly affected by the PYT, as shown in **Table 5**. The PT was ranked in descending order as PYT_{350} > PYT_{500} > PYT_{700}, with values of 0.1999 > 0.1296 > 0.0866 for O/C and 0.1323 > 0.1622 > 0.2272 for (O+N)/C.

(1A)



(1B)



(1C)

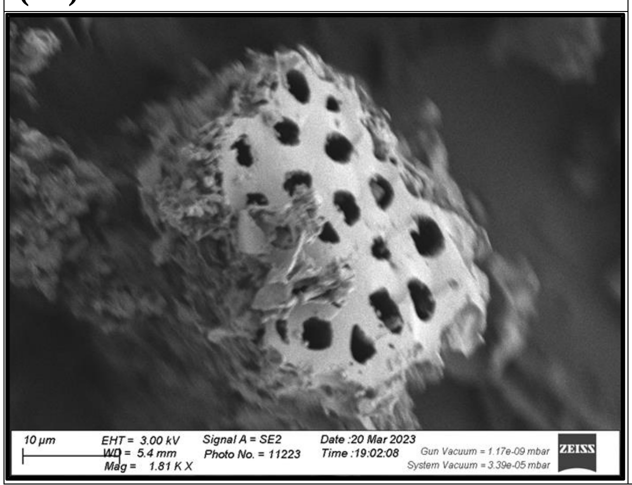


Figure 1. Scanning electron microscopy of date tree fronds-derived biochar (PTF-BCH) obtained through pyrolysis temperature at 350 **(1A)**, 500 **(1B)** and 700 °C **(1C)**, respectively.

Figure 1. Shows the morphology of the BCH obtained from palm tree fronds (PTF-BCH) at PYT_{350} **(1A)**, PYT_{500} **(1B)**, and PYT_{700} **(1C)** by scanning electron microscopy. Visual inspection of the images (at different magnifications) revealed differences in irregular porous surfaces. Pores were observed in all the BCH samples, with higher numbers and greater distribution in PYT_{500}

and PYT_{700} compared to PYT_{350}. In contrast, there was a greater volume of pores in PYT_{350} than in PYT_{500} and PYT_{700}.

3.2. Soil Chemical properties

As shown in **Table 3**, the experimental soil was characterized as moderately alkaline (pH 8.15 vs. 8.13) loamy sandy soil with a high content of salt (ECe = 10.8 vs. 10.7 $dS.m^{-1}$) and calcium carbonate ($CaCO_3$ = 19.1 vs. 18.8%) in the 2020-21 and 2021-22 seasons. The results given in **Table 4** indicate the impact of the BCHs produced from PTF at PYT350, PYT_{500}, and PYT_{700} with two addition rates 28 and 56 g pot^{-1} compared with the un-amended soil (BCH_0) on some soil chemical properties, such as soil pH, $CaCO_3$ content, organic matter content (OMC), and CEC. Our results clearly showed that the soil incorporated with BCH heated at 350 °C with a rate of 28 g pot^{-1} ($PYT_{350} \times BCH_{28}$) gave the lowest soil pH values (8.13 vs. 8.14) in both seasons, respectively.

3. 3. Soil nutrient's content

The data pertaining to the impact of the studied BCH derived from palm tree fronds at different PYT with different rates on soil macronutrient contents are explored in **Table 5.** Our results indicate that $PYT_{700} \times BCH_{56}$ had the highest impact on the available soil macronutrient content in both seasons, except available phosphorus content (APC) in the first season. In detail, this treatment recorded the highest values of ammoniacal nitrogen NH_4^+-N (14.02 vs. 14.11 mg kg^{-1}) and available potassium content (AKC) (118.00 vs. 272.67 mg kg^{-1}) in both growing seasons, as well as APC (8.96 mg kg^{-1}) in the second season. The lowest NH_4^+ (6.64 vs. 6.50) and AKC (5.31 vs. 6.41) in both seasons and the AKC (105.33 $mg.kg^{-1}$) in the first season were obtained in BCH_0, respectively. Meanwhile, the $PYT_{350} \times BCH_{56}$ was the least influential on the AKC in the second season recording 209.33 mg kg^{-1}.

Based on the highest and lowest values, the amount of increase was 111.15 vs. 117.08% for NH_4^+-N, 15.25 vs. 39.78% for AvP, and 12.03 vs. 30.26% for AvK in both seasons, respectively. The results produced from the analysis of variance indicated a significant (at $p \leq 0.01$) influence of NH_4^+-N in the 2020-21 and 2021-22 seasons and AKC in the second season, as well as a significant (at $p \leq 0.05$) influence of APC in the 2021-22 season, but there was a non-significant influence of APC and AKC in the 2020-21 season.

According to the results presented in **Table 5**, our pot study indicated that $PYT_{700} \times BCH_{28}$ treatment led to a marked enhancement in soil fertility by increasing the AFeC and AZnC producing 3.90 vs. 3.88 mg kg^{-1} and 1.42 vs. 1.40 mg kg^{-1} in the 2020-21 and 2021-22 seasons, respectively. Meanwhile, the $PYT_{700} \times BCH_{56}$ was the most influential on the AMnC recording 1.80 and 1.90 mg kg^{-1}. Oppositely, the minimum of AFeC (2.80 vs. 3.00 mg kg^{-1}), AMnC (1.45 vs. 1.50 mg kg^{-1}), and (1.15 vs. 1.20 mg kg^{-1}) were obtained in soils treated with $PYT_{700} \times BCH_{28}$, $PYT_{500} \times BCH_{28}$, and $PYT_{500} \times BCH_{56}$ in both seasons, respectively. The increasing percentages amounted to 39.29 vs. 29.33% for AFeC, 24.13 vs. 26.67% for AMnC, and 23.48 vs. 16.67% for AZnC in the first and second seasons, respectively. Despite the observed enhancements, the statistical analysis indicated that the treatment had a nonsignificant influence on the AZnC in both seasons and the AMnC in the first season. Meanwhile, it showed a significant (at $p \leq 0.05$) impact on the AFeC and AMnC in the second season and a significant (at $p \leq 0.01$) impact on the AFeC in the first season.

Table 4. Influence of the different rates of the palm tree fronds-derived biochar derived at different pyrolysis temperatures on some chemical properties of saline–calcareous soil (ECe=10.8 vs. 10.7 dS.m^{-1}, $CaCO_3$=19.1 vs. 18.8% and soil pH = 8.15 vs. 8.13) in the 2020-21 and 2021-22 seasons, respectively

Treatment	Soil pH	CEC (cmol kg^{-1})	$CaCO_3$ (%)	OMC (%)
2020-21 season				
BCH_0	8.15±0.01c	7.23±0.14d	18.77±0.06a	1.40±0.17b
PYT_{350} × BCH_{28}	8.13±0.02c	7.27±0.07d	19.06±0.06a	1.30±0.07b
PYT_{350} × BCH_{56}	8.15±0.01c	7.28±0.07d	18.77±0.10a	1.40±0.14b
PYT_{500} × BCH_{28}	8.22±0.01b	11.05±0.13c	15.43±0.06b	1.70±0.07a
PYT_{500} × BCH_{56}	8.24±0.01b	11.18±0.22c	13.48±0.07c	1.77±0.05a
PYT_{700} × BCH_{28}	8.37±0.01a	12.43±0.13b	11.52±0.03d	1.83±0.06a
PYT_{700} × BCH_{56}	8.36±0.02a	13.00±0.07a	10.51±0.06e	1.90±0.02a
$LSD_{0.05}$	**	**	**	**
2021-22 season				
BCH_0	8.15±0.01c	7.44±0.07d	19.06±0.07a	1.50±0.07c
PYT_{350} × BCH_{28}	8.14±0.01c	7.26±0.07d	19.06±0.06a	1.53±0.19c
PYT_{350} × BCH_{56}	8.15±0.01c	7.31±0.13d	18.91±0.03a	1.67±0.12b
PYT_{500} × BCH_{28}	8.26±0.01b	11.14±0.07c	15.58±0.03b	1.77±0.10b
PYT_{500} × BCH_{56}	8.24±0.01b	11.28±0.19c	13.84±0.03c	1.77±0.07b
PYT_{700} × BCH_{28}	8.36±0.02a	12.34±0.19b	11.67±0.03d	1.90±0.03a
PYT_{700} × BCH_{56}	8.36±0.02a	12.98±0.13a	10.43±0.01e	1.93±0.02a
$LSD_{0.05}$	**	**	**	**

Means followed by different letters in each column indicate significant differences ($p \leq 0.05$). Soil pH=soil reactivity; $CaCO_3$=calcium carbonate; OMC= organic matter content; CEC=cation exchange capacity. PYT_{350}, PYT_{500}, and PYT_{700} represent pyrolysis temperatures of 350, 500, and 700 °C, respectively. BCH_0, BCH_{28}, and BCH_{56} represent biochar applied at 0, 28, and 56 g pot^{-1}, respectively. * and ** indicate to significant and highly significant, respectively and ns= no significant.

3. 4. Barley seedling's leaf nutrient contents.

The data listed in **Table 6** indicate the effect of palm-tree fronds-derived BCH at different PYTs on the barley leaf nutrient contents including LNC, LPC, and LKC. As shown in **Table 6**, the PYT_{700} × BCH_1 treatment had the highest impact on the LNC (3.62%) in the 2021-22 season and the LPC (0.43%) in the 2020-21 season. In addition, the highest LPC (0.24%) in the second season and LKC (2.07 vs. 2.36%) were produced in barley seedlings treated with PYT_{700} × BCH_{56}.

Furthermore, the PYT_{350} × BCH_{28} was the most influential on the LNC in the first season, recording 3.38%. In contrast, the barley seedling grown in BHC_0 had the lowest effect on the LKC (1.61 vs. 1.84%) in both seasons and on the LPC (0.20%) in the second season. It can be observed from **Table 7** that the increasing rates of the highest and lowest values were 60.95 vs. 70.86 for LNC, 19.44 vs. 20.00 for LPC, and 28.57 vs. 28.26 for LKC in both growing seasons, respectively. The results obtained from the ANOVA indicated highly significant differences for the LNC and LKC, but non-significant differences were presented for the LPC in both seasons.

Table 5. Influence of the palm-fronds-derived biochar derived at different pyrolysis temperatures at different rates on the soil micronutrient contents of saline–calcareous soil (ECe=10.8 vs. 10.7 dS.m^{-1}, $CaCO_3$=19.1 vs. 18.8% and soil pH = 8.15 vs. 8.13) in the 2020-21 and 2021-22 seasons, respectively

Treatment	NH_4^+-N	APC	AKC	AFeC	AMnC	AZnC
	(mg kg^{-1})					
2020-21 season						
BCH_0	6.64±0.73c	5.31±0.46a	105.33±4.67a	2.80±0.17cd	1.70±0.12ab	1.30±0.06ab
PYT_{350} × BCH_{28}	6.65±0.17c	5.51±0.34a	110.00±6.00a	2.70±0.12d	1.65±0.09ab	1.25±0.09ab
PYT_{350} × BCH_{56}	6.67±0.73c	5.56±0.42a	108.67±7.42a	3.15±0.26b-d	1.60±0.09ab	1.35±0.06a
PYT_{500} × BCH_{28}	9.34±1.17b	5,36±0.14a	114.67±6.77a	3.10±0.17b-d	1.45±0.03b	1.25±0.03ab
PYT_{500} × BCH_{56}	9.34±2.34b	5.41±0.08a	118.67±4.06a	3.45±0.14ab	1.55±0.09ab	1.15±0.14b
PYT_{700} × BCH_{28}	12.84±1.16ab	6.12±0.11a	110.00±7.57a	3.90±0.12a	1.50±0.06ab	1.42±0.06a
PYT_{700} × BCH_{56}	14.02±0.67a	6.05±0.24a	118.00±4.16a	3.40±0.23a-c	1.80±0.09a	1.35±0.06a
$LSD_{0.05}$	**	ns	ns	**	ns	ns
2021-22 season						
BCH_0	6.50±0.60c	6.41±0.22c	220.67±7.69b	3.00±0.29b	1.78±0.01ab	1.28±0.01a
PYT_{350} × BCH_{28}	6.51±0.12c	7.00±0.39bc	218.67±12.77b	3.03±0.07b	1.55±0.03bc	1.21±0.06a
PYT_{350} × BCH_{56}	6.53±0.12c	7.10±0.46bc	209.33±2.91b	3.23±0.22b	1.55±0.09bc	1.33±0.07a
PYT_{500} × BCH_{28}	9.34±0.60b	7.74±0.33a-c	258.00±5.29a	3.18±0.22b	1.50±0.06c	1.25±0.03a
PYT_{500} × BCH_{56}	8.17±0.73b	7.76±0.77a-c	256.00±9.02a	3.40±0.12ab	1.60±0.12bc	1.20±0.12a
PYT_{700} × BCH_{28}	12.80±1.64a	8.02±0.36ab	276.00±3.71a	3.88±0.01a	1.55±0.09bc	1.40±0.06a
PYT_{700} × BCH_{56}	14.11±2.19a	8.96±0.47a	272.67±7.69a	3.43±0.25ab	1.90±0.01a	1.33±0.07a
$LSD_{0.05}$	**	*	**	*	*	ns

Means followed by different letters in each column indicate significant differences ($p \leq 0.05$). Soil pH=soil reactivity; $CaCO_3$=calcium carbonate; OMC=soil organic matter; CEC=cation exchange capacity. PYT_{350}, PYT_{500}, and PYT_{700} represent pyrolysis temperatures of 350, 500, and 700 °C, respectively. BCH_0, BCH_{28}, and BCH_{56} represent biochar applied at 0.0, 28.0, and 56.0 g pot^{-1}, respectively. * and ** indicate to significant and highly significant, respectively and ns= no significant. NH4+-N indicate the ammoniacal nitrogen; APC; AKC; AFeC, AMnC, and AZnC indicate the available phosphorus, potassium, iron, manganese and zinc contents, respectively.

The results pertaining to the effect of treatments on LFeC, LMnC, and LZnC are presented in **Table 6**. The overall trend showed that PYT_{700} × BCH_{56} had the highest LFeC (59.90 vs. 60.60 mg kg^{-1}) and LZnC (28.35 vs. 29.50 mg kg^{-1}). Moreover, the PYT_{700} × BCH_{28} recorded the highest LMnC (53.43 vs. 50.95 mg kg^{-1}) in the 2020-21 and 2021-22 seasons, respectively. Regarding the lowest values, our results indicated that the BHC_0 and PYT_{350} × BCH_{56} treatments had the least effect on the LMnC and LZnC in the first and second seasons, respectively. Based on the maximum and minimum values, the increasing percentages were 28.82 vs. 35.72% for LFeC, 24.90 vs. 16.46% for LMnC, and 7.67 vs. 11.53% for LZnC in both seasons, respectively.

Table 6. Influence of the palm-fronds-derived biochar derived at different pyrolysis temperatures at different rates on the soil micronutrient contents of saline–calcareous soil (ECe=10.8 vs. 10.7 $dS.m^{-1}$, $CaCO_3$=19.1 vs. 18.8%, and soil pH = 8.15 vs. 8.13) in the 2020-21 and 2021-22 seasons, respectively

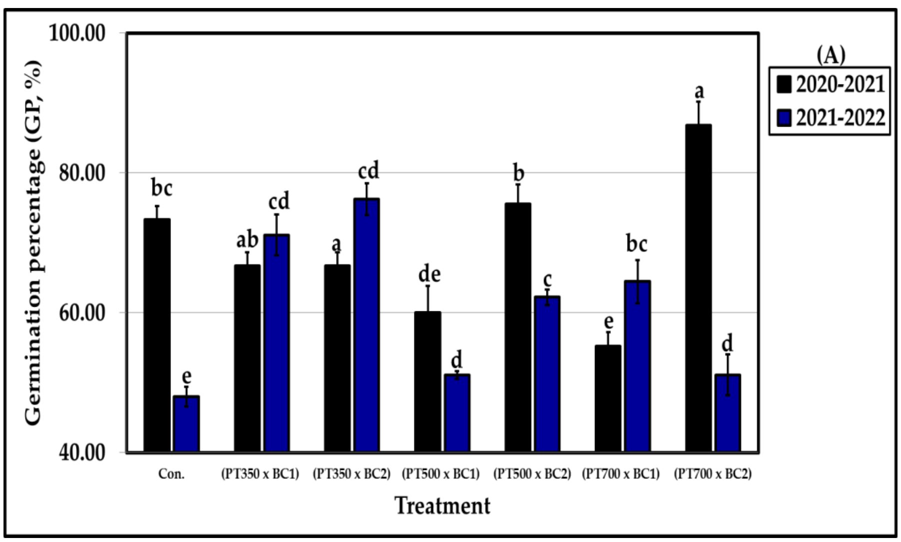
Treatment	LNC	LPC	LKC	LFeC	LMnC	LZnC
	(%)			(mg kg^{-1})		
			2020-21 season			
BCH_0	2.80±0.11b	0.38±0.11ab	1.61±0.16c	48.63±0.11cd	42.78±0.10d	26.33±0.10bc
PYT_{350} × BCH_{28}	1.85±0.14a	0.36±0.15b	1.66±0.17c	46.50±0.12d	45.35±0.11cd	25.28±0.11c
PYT_{350} × BCH_{56}	1.89±0.12c	0.37±0.11ab	1.61±0.10c	52.00±0.10bc	44.53±0.10d	26.38±0.12bc
PYT_{500} × BCH_{28}	2.07±0.10a	0.37±0.12ab	1.85±0.10b	57.55±0.18a	48.95±0.11bc	28.28±0.12a
PYT_{500} × BCH_{56}	2.07±0.11c	0.41±0.14ab	1.89±0.12b	56.70±0.17ab	51.48±0.11ab	28.13±0.10ab
PYT_{700} × BCH_{28}	2.80±0.12b	0.43±0.14a	2.05±0.11a	59.10±0.13a	53.43±0.12a	27.90±0.11ab
PYT_{700} × BCH_{56}	3.15±0.12a	0.39±0.23ab	2.07±0.12a	59.90±0.10a	53.20±0.14ab	28.35±0.12a
$LSD_{0.05}$	**	ns	**	**	**	**
			2021-22 season			
BCH_0	3.38±0.11a	0.20±0.10a	1.84±0.11c	44.65±0.12e	44.35±0.15b	28.35±0.12ab
PYT_{350} × BCH_{28}	2.57±0.13b	0.23±0.19a	1.97±0.13bc	48.20±0.15d	46.10±0.17ab	27.45±0.14bc
PYT_{350} × BCH_{56}	2.92±0.14b	0.22±0.17a	1.96±0.12bc	47.70±0.34d	43.75±0.11b	26.45±0.12c
PYT_{500} × BCH_{28}	3.50±0.10a	0.23±0.11a	2.08±0.11b	57.70±0.13c	48.50±0.12ab	28.05±0.18ab
PYT_{500} × BCH_{56}	2.68±0.11b	0.21±0.10a	2.10±0.10b	59.60±0.12b	46.95±0.12ab	28.65±0.17ab
PYT_{700} × BCH_{28}	3.62±0.11a	0.21±0.12a	2.31±0.10a	60.40±0.11a	50.95±0.12a	29.47±0.13a
PYT_{700} × BCH_{56}	3.38±0.10a	0.24±0.11a	2.36±0.10a	60.60±0.10a	49.20±0.11ab	29.50±0.10a
$LSD_{0.05}$	**	ns	**	**	ns	**

Means followed by different letters in each column indicate significant differences ($p \leq 0.05$). Soil pH=soil reactivity; $CaCO_3$=calcium carbonate; OMC=soil organic matter; CEC=cation exchange capacity. PYT_{350}, PYT_{500}, and PYT_{700} represent pyrolysis temperatures of 350, 500, and 700 °C, respectively. BCH_0, BCH_{28}, and BCH_{56} represent biochar applied at 0, 28, and 56 g pot^{-1}, respectively. * and ** indicate to significant and highly significant, respectively and ns= no significant.

Statistically, highly significant differences were found between the treatments for all the studied microelements except for the LMnC in the first season.

3. 4. Barley germination parameters

The results obtained from the statistical analysis showed significant differences among all the studied germination parameters in both growing seasons, except for SV in the first season. However, non-significant effects were obtained for the SV in the second season. As graphically illustrated in **(Figures 2, A-C)**, the amended soil in $PYT_{350} \times BCH_{56}$ had the best values due to its improved influence on the GP, and mean emergency time (MET) in the first growing season compared with the BCH_0-treated soil, which gave the lowest values (50.20) for GP, and (0.26) for MGT, respectively. On the other hand, it was found that results regarding the second season were not dissimilar. In detail, the highest values of GP and MGT were produced using the application of $PYT_{700} \times BCH_{56}$ recording 75.57 and 0.42, respectively. Meanwhile, $PYT_{500} \times BCH_{56}$ was the superior treatment for SV, recording the highest value (20.20 vs. 31.29). As shown in **Figure 2A and C**, the increasing percentages of the highest and lowest values reached 57.15 vs. 90.55 for GP, 84.31 vs. 212.90 for SV, and 61.54 vs. 90.91% for MGT in the 2020-21 and 2021-22 seasons, respectively.



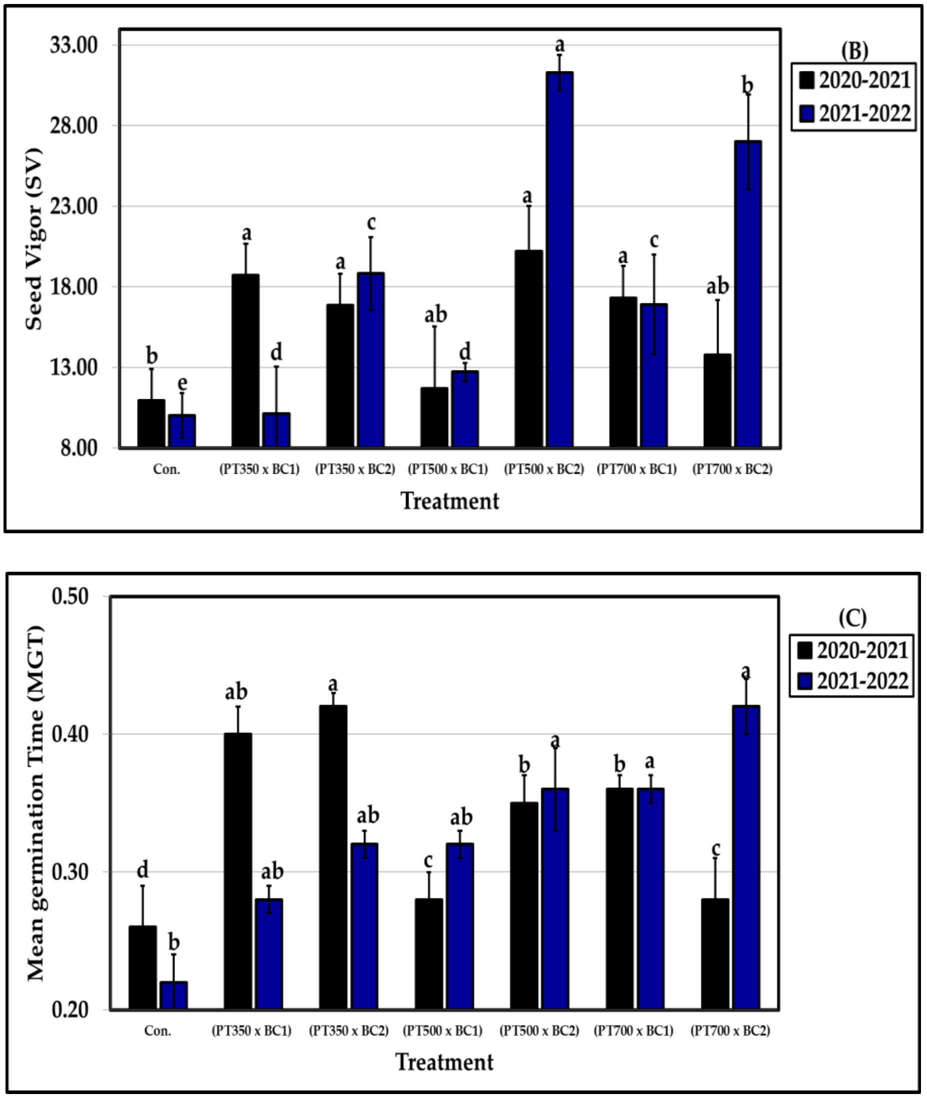


Figure 3. Impact of different pyrolysis temperatures (PYTs) applied to produce palm tree fronds-derived biochar on **(A)** germination percentage (GP), **(B)** seed vigor (SV) and **(C)** mean emergence time (MET) of barley seedlings grown in sandy loam clay soil with undesirable characteristics (ECe=10.8 vs. 10.7 $dS.m^{-1}$, $CaCO_3$=19.1 vs. 18.8% and soil pH = 8.15 vs. 8.13) in 2020-21 and 2021-22 seasons, respectively.

3. 5. The heat map correlation coefficient.

The data shown graphically in **Figure 3** indicate the correlation coefficient between the soil chemical properties as a result of applying BCH generated under three PYTs at different addition rates. A highly negative correlation was found between the pH and $CaCO_3$ content (r = -0.935** and -0.945**) in both seasons. Meanwhile, the soil pH showed a strong positive correlation with the SOM (r = 0.845** and 0.836**) and the CEC (r = 0.928** and 0.938**) in the first and second seasons.

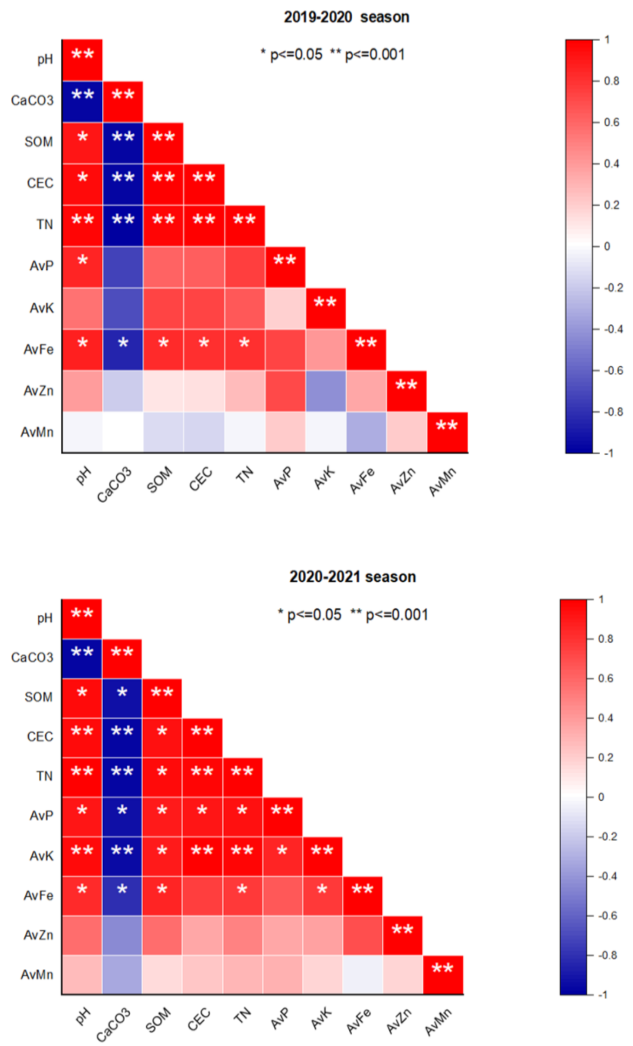


Figure 3. The heat map Pearson's correlation coefficients between soil chemical properties and available nutrients content in 2020-21 and 2021-22 seasons.

Concerning the correlation coefficient for available macro- and micronutrients as affected by other soil chemical properties, our results indicate that the soil pH had a highly significant positive impact on the NH_4^+-N (*r* = 0.876** and 0.927**) and the AFeC (*r* = 0.709** and 0.588**) in both seasons and a profound effect on the APC (*r* = 0.668**) in the second season. In addition, CEC had a strong positive correlation with OMC (*r* = 0.920** and 0.854**) and NH_4^+-N (*r* = 0.871** and 0.937**) and a strong negative correlation with the $CaCO_3$ content (*r* = -0.974** and -0.970**) in the two growing seasons, respectively. Similar results were obtained regarding the relationship between the available nutrient contents and leaf nutrient contents. Highly significant positive correlations were found between the NH_4^+-N and AFeC (*r* = 0.594**) in the first season and the NH_4^+-N and APC (*r* = 0.655**) in the second season. In the present study, a significant negative correlation ($p \leq 0.01$) was observed between the NH_4^+-N and $CaCO_3$ content (*r* = -0.866** and -0.950**) and a highly positive correlation between NH_4^+-N and OMC (*r* = 0.765** and 0.812**) in both seasons. Furthermore, there was a highly significantly correlation between the APC and soil pH (*r* = 0.668**), OMC (*r* = 0.573**), CEC (*r* = 0.707**),

NH_4^+-N (*r* = 0.655**), and AKC (*r* = 0.650**) in the second season. Meanwhile, the APC was negatively correlated ($p \leq 0.01$) with the $CaCO_3$ content (*r* = -0.687**) in the 2021-22 season.

As is long known, date palm trees are among the oldest cultivated plants in Egypt, producing huge amounts of waste including fronds, offshoots, and date pits. According to **Jouiad et al. (2015)**, such trees generate about 50 kg of waste annually. Until recently, the waste has been disposed of by burning in open fields, resulting in increased emission of GHGs, including CO_2, N_2O, and NH_4, which negatively affects the environment. In the past two decades, the conversion of plant- and animal-based waste into a carbon-rich substance known as BCH has received a great amount of attention based on its unique features **(Tian et al. 2020)**. Although numerous studies have examined its effect on different soil properties, most of them did not deal with its behavior in soils with undesirable characteristics. Generally speaking, the influence (positive or negative) on soil properties is associated with factors such as feedstock biomass type, PYT, heating rate, soil type, and BCH addition rates **(Arif et al. 2017; Gluszek et al. 2017 and El-Naggar et al. 2018)**.

The general trend of our results indicates that C is a major constituent that increases with increasing PYT. This may due to the high carbonization and thermochemical decomposition of feedstock biomasses at high PYTs **(Singh et al. 2017)**. On the contrary, the decreased O and hydrogen (H) content with higher PYT could be due to the removal of moisture, hydrocarbons, and gases, such as H_2, CO_2, and CO **(Chun et al. 2004)**. These results are supported by some recent studies **(Frikha et al. 2021; Huang et al. 2021; Ghorbani et al. 2022; Tu et al. 2022)**. Another possible explanation is that high PYT could cause cracking of weak bonds in prepared BCH **(Sun et al. 2014)**. The mineral analysis revealed that both feedstock (FS) and PYT appreciably affected the P, Ca, and Mg content (which increased). The positive relationship between PYT and Ca content could be ascribed to the presence of insoluble $CaCO_3$ and its calcination into soluble calcium oxide **(Usman et al. 2015)**. Furthermore, Mg is present in magnesium oxide and insoluble periclase **(Lehmann and Joseph, 2015)**. Several studies indicated that the content of these elements in BCH is significantly influenced by the type of biomass used to produce it. It can be seen that P content is positively affected by high pyrolysis temperature (HPYT). For example, **Xiao et al. (2018) and Li et al. (2020)** reported that available P increased with increasing PYT. However, the Ca content in crop residue derived BCH ranged between 0.20 and 1.57% **(Prakongkep et al. 2015; Abujabhah et al. 2016; Arif et al. 2016)** and Mg content ranged between 0.001 and 3.78% **(Wrobel-Tobiszewska et al. 2015; Yu et al. 2017; Zhao et al. 2018)**. On the other hand, K content is negatively influenced by the feedstock. In addition, there are adequate amounts of Si and Cl due to the presence of metallic oxides in BCH samples **(Singh et al. 2017)**. The large variation of K content was also associated with the feedstock type, which is likely due to the concentration effect **(Xiao et al. 2018)**. Our results indicate that both feedstock biomass and PYT played pivotal roles in determining the elemental composition and properties of BCH. These results are in agreement with previous reports of **Joseph and Taylor (2014), Yargicglu et al. (2015), Laghari et al. (2016), and Yuan et al. (2017)**. The SEM is another technique used to determine the morphology of BCH samples as shown in **Figure 1A and C**, all BCH samples had a smooth surface, and the pores were more visible.

Our pot experiment clearly indicated that PYT significantly affected soil chemical properties regardless of the BCH addition rate, depending on the influence of PYT on BCH chemical and physical properties. As shown in **Table 6**, PYT_{350} was found to have the most influence on soil pH (which decreased) compared to PYT_{500} and PYT_{700}. These results could be attributed to the increase in basic oxides and carbonates produced during the pyrolytic process **(Alazzaz et al. 2020)**. These results are in line with previous studies of **Cardelli et al. (2017), Yao et al. (2017) and Tang et al. (2019)**, who reported that soil pH increased with increasing PYT. In this respect, **Singh et al. (2020)** noted that functional groups, such as carboxyl, formyl, and hydroxyl groups, could be removed under high PYTs, along with increased inorganic element concentrations and basic oxides. In other words, the high pH of the BCH samples could be attributed to the presence of alkali, and alkali metals are not volatilized during the pyrolysis process **(Yang et al. 2018)**. On the other hand, PYT_{700} had the most impact on other soil properties: EC and $CaCO_3$ (which decreased) and SOM and CEC (which increased). The appreciable decreases in EC were explained by the inverse relationship between EC and PYT. However, EC decreased with increasing PYT, as shown in **Table 4**. Meanwhile, the slight increase in SOM content could be due to increased C content of BCH produced with higher heating temperature; C is a basic element in the BCH structure (varying between 40 and 75%) and is not easily broken down by microorganisms **(Tan et al. 2015)**. In addition, there was a marked increase in CEC. The high PYT increases the surface area and porosity of palm tree fronds, in turn increasing the concentrations of minerals such as K, P, Ca, and Mg on the adsorbent surface, which increases CEC **(Sun et al. 2014)**. These results align with those of **Lehmann and Joseph (2015)**. In other words, the functional groups, including carboxyl, hydroxyl, and amino groups, have a profound influence on increasing the adsorption of minerals **(Zbair et al. 2019)**.

Concerning the effect of PYT on available soil macronutrients (N, P, and K) and micronutrients (Fe, Mn, and Zn), the results revealed that the total nitrogen (TN) content of BCH increased with increasing PYT, and pyrolysis treatments were ranked in descending order as PYT_{700} (4.20%) > PYT_{500} (2.80%) > PYT_{350} (2.20%). These findings may be attributed to the residence time of pyrolysis; in addition, the N-containing component of BCH can be present on the surface or inside the pores as nitrates, ammonium salts, or heterocyclic compounds **(Grierson et al. 2011)**. These results agree with those of **Chang et al. (2015)**, who found that N content in *Chlorella*-based algal waste BCH increased from 10.23 to 14.12% when the time pyrolysis time at 500 °C was increased from 20 to 60 min. A similar trend was reported by **Zhu et al. (2016)**, who noted that inorganic N forms such as NH_4-N and NO_3-N increased when biomass was heated at 800 °C, whereas the same forms decreased when it was heated 4 d at 300 °C. As with N content, the increased P content with increasing PYT could be due to the "concentration impact" as a result of decreased BCH yield with increasing temperature. These findings agree with those of **Xiao et al. (2018)**, who found that P content increased by 1.91, 2.15, and 2.96% when PYT was increased fro 250 to 350, or 550 °C, respectively, for production of BCH from chicken manure. In general, P content varies between 0.005 and 5.9% depending on the type of feedstock. For instance, studies have reported P content of 5.9% in BCH derived from swine solids **(Cantrell et al, 2012),** 2.96% in BCH produced from chicken manure **(Xiao et al. 2018),** and 2.57% in BCH produced from poultry manure **(Brantley et al. 2016).** A comparable pattern was obtained for K content, which depended on biomass type and PYT. High K content was explained by to the concentration impact. For example, the K content in BCH produced from poultry manure increased from 3.88 to 5.88% when the heating temperature was increased from 400 to 600 °C **(Subedi et al. 2016). Vaughn et al. (2018)** reported K values of 3.89, 3.98, 4.06, 4.02, 8.12, and 9.83 for biosolid-derived BCH at 300, 400, 500, 700, and 900 °C, respectively.

The results regarding the influence of BCH addition rate on soil chemical properties show that incorporating BCH at any application rate improved all chemical properties of the studied soil. It was found that BCH_2 was the best treatment for all studied properties, except soil pH in the first season, which was influenced by BCH_1 **(Table 7)**. The slight enhancement in soil pH could be attributed to oxidation and the generation of acidic materials in BCH during pyrolysis **(Zhang et al. 2019)**. In their study, **Lee et al. (2013)** noted that the pH of BCH depends on three factors: organic functional groups, carbonate content, and inorganic alkali content. Similar results were reported by **Cheng et al. (2018)**, who supposed that the slight decrease in soil pH could be attributed to organic acids obtained during the pyrolysis of palm tree fronds affecting the pH of the final BCH. Furthermore, the pH of BCH was positively correlated with pyrolysis temperature. Our results show that the slight increase in soil pH was related to increased PYT and BCH addition rate. The BCH is alkaline in its nature, and the alkalinity rises with increased heating temperature during pyrolysis, as shown in **Table 4**. This could be attributed to some acidic functional groups being removed at higher PYTs, subsequently increasing basic oxides and inorganic elements **(Shakya and Agawal 2018; Singh et al. 2020)**. These findings agree with those of **Hossain et al. (2022)**, who reported pH levels of BCH ranging from 6.52-12.64. In other words, the high pH of BCH could be due to the presence of alkali, and alkali metals are not volatilized during the pyrolysis process **(Yang et al. 2018)**. This view was opposed by **Li et al. (2017)**, who reported that at high PYT, the concentrations of these functional groups decreased. In this regard, **Igalavithana et al. (2018)** reported that the EC of most BCH is higher than that of other agricultural amendments due to its high content of soluble salts such as NO_3^-, K^+, and Ca^{2+} which might increase the EC of agricultural soils. The CEC is one of the most influential properties affecting soil fertility because of the high adsorptive capacity of positive ions and mineral nutrients in the soil **(Sohi et al. 2010)**, although CEC in most soils is a natural and inherent property, and accordingly it does not change. However, our results show that the soil CEC increased with higher BCH addition rates due to the presence of negative charges on the surface of BCH due to the presence of strong of carboxyl and phenolic functional groups **(Tian et al. 2017 and Palansooriya et al. 2019)**. Comparable results were reported by **Gao et al. (2017), Pandit et al. (2018), and Karimi et al. (2020)**, who documented that BCH application increased soil CEC.

As previously mentioned in the literature, BCH is a nutrient source for crop plants, and the nutrient content in BCH mainly depends on the feedstock biomass and pyrolysis conditions **(El-Naggar et al. 2019a)**. For instance, the N content of BCH can vary between 0.24 and 6.8% based on the biomass type. Studies have reported N content of 6.8% in BCH derived from sewage sludge **(Gonzaga et al. 2019)**, 5.85% in BCH from poultry litter **(Macdonald et al. 2014)**, and 4.9% in BCH from grass waste **(Enders et al. 2012)**. Contrary to our results, N content in BCH was reported to decline with increased PYT due to the conversion of amino acids into pyridine-N and pyrrolic-N **(Leng et al. 2020)**. Moreover, a loss of NH_4^+-N as NH_3 gas through the pyrolysis process has also been reported **(El-Naggar et al. 2019a)**.

4. Conclusions

The current investigation explored the impact of the palm tree fronds-derived biochar prepared at three different pyrolytic temperatures on saline-calcareous soil chemical properties and barley germination parameters. The results clearly indicate that 56 g biochar plot^{-1} produced at 700 °C was the most influential treatment for most parameters of the studied defective soil, such as $CaCO_3$ content, soil organic matter, and cation exchange capacity. Moreover, it had a profound effect on improving the availability of macro- and micronutrients, except for the available potassium content in the first season. The 28 g biochar plot^{-1} produced at 350 °C treatment was found to have the highest impact on the soil pH. In addition, biochar-amended soil, regardless of the application rate, showed the best soil pH compared with the un-biochar-amended soil. Regarding the potential positive effect on the barley seedling germination parameters grown under the experimental saline-calcareous soil, the results pointed out that the highest germination percentage and mean emergence time were obtained applying 56 g biochar plot^{-1} produced at 350 °C and 56 g biochar plot^{-1} produced at 700 °C in the first and second seasons, respectively. In addition, the treatment of 56 g biochar plot^{-1} produced at 500 °C was the most impactful for the seed vigor in both seasons. Ultimately, research is still needed to elucidate the effect of biochar over the long term under field conditions.

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