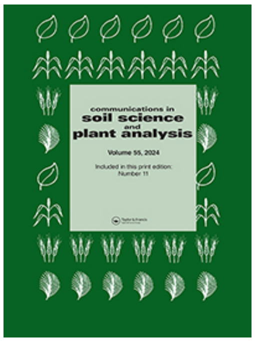

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Assessment of Phytotoxicity and Efficiency of Date Palm Waste Compost on Barley Seeds Germination and Seedlings Growth

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ABSTRACT

The valorization of date palm wastes as bioresources has received little attention. In this context, the feasibility of date palm waste valorization through composting and the application effects on barley plants production under control condition was investigated. The principal requirements for compost to be safely used are stability and maturity that refer, respectively, to the microbial biomass activity's level, germination tests, and plant growth bioassays or phytotoxicity. Indeed, the phytotoxicity of composted date palm waste used for seed germination and seedling growth bioassays was researched. The finished compost values of the C/N ratio were 15.36 and 18.58%, 1.21%, 0.54%, and 0.95% for total organic carbon, N, P, and K contents, respectively. The concentration of heavy metals and microelements were lower and met the requirement established by national standards. Moreover, the end product was free from harmful pathogens like *Salmonella*, *Escherichia coli*, total coliforms, and fecal coliform bacteria. Application of compost extract (especially 25%, 50%, and 75%) did not affect barley seed germination, stimulated hypocotyl and radicle growth and is characterized by a GI exceeding 90%, demonstrating its stability and lack of phytotoxic effect. Moreover, compost promotes plant growth, improved physiological parameters, photosynthetic pigments, and plant biomass. According to the results, the prepared compost especially at the dose T3 (soil amended with 30 t/ha) increased the nutrients availability and uptake which may be the reason for an increase in photosynthetic activity, chlorophyll synthesis, and dry matter accumulation. Composting may well represent an acceptable solution for disposing of date palm waste and be of great interest to sustainable agriculture in Tunisia oasis ecosystems.

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Barley; compost; date palm waste; phytotoxicity; sheep manure

Introduction

Agriculture plays an important role in the Tunisian economy. However, under low input agriculture systems the sector has faced several challenges, including lack of adequate nutrient supply and poor soil structure, which has led to low crop productivity (Brahim et al. 2021). Tunisian oases are situated in the dry lands of Tunisia covering a total area of 40,803 ha, but they are the

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most important agricultural and socio-economic locations of the desert region and the main source of employment and income for most people in Southern Tunisia (Hachicha and Ben Aissa 2014). Oases ecosystems in Tunisia support a wide range of agriculture along with dates creating a microclimate suitable for the cultivation of fruit trees, cereal crops, and vegetables (Guebsia et al. 2019; Tengberg 2012). Generally, in these complex ecosystems crop production is constrained by low soil fertility and low nutrient reserves. According to Mlih et al. (2019) soil in Tunisian oases suffers from low organic matter levels and high levels of salinity. Several studies reported that soil fertility could be restored by recycling organic matter (OM) and plant nutrients through appropriate farming practices (Garcia et al. 2017; Krause and Rotter 2018). For decades, farmers have traditionally used cow, sheep, or goat manure in order to alleviate oasis soil degradation. However, its influence varies from soil to soil, crop to crop, environmental variables, type of animal manure used and its management. Moreover, according to Guebsia et al. (2019) and Mlih et al. (2019) this practice is still traditional and usually done without sufficient study, depending on the availability of manure and the precise financial situation of the farmer at the time of application. Thus, in oases, composting as an eco-friendly approach has become an ideal solution for the recovery of organic wastes and the reduction of the dissemination of several pests, weeds and diseases, decomposing toxic substances, killing weed seeds and pathogens, improving handling of the manure, and increasing soil fertility. Indeed, composting and biodegradation are effective ways to deal with organic waste in order to lower or eliminate possible negative effects that raw materials may have on soil properties and organisms (Lim, Lee, and Wu 2016). Application of compost as organic fertilizer that is produced from animal by-products and crop residues is considered the best sustainable management application for conventional and organic farming which promotes soil improvement and agricultural productivity. An increasing use of compost and its extracts is due to their notable positive effects on soil properties and fertility, water use and crop productivity (Adugna 2016), improvement of nutrient utilization efficiency (Arif et al. 2018), and alleviation of biotic and abiotic stresses on plant and soil (Abd El-Mageed et al. 2019; Said et al. 2017). Compost application improved the yield and biomass of the mung bean and soybean (Hayat et al. 2012) and significantly enhanced the yield of bread wheat and barley (Kitila, Jalde, and Workina 2016). In addition, compost extract showed beneficial effects on biomass yield and seed germination in maize, mung bean, cauliflower, muskmelon, tomato, and barley (Radhouani et al. 2015; Sifatullah et al. 2011) and increased yield performance of pepper in a greenhouse organic farming system (Zaccardelli et al. 2018). Compost tea was revealed as a potential alternative to the application of synthetic fungicides due to its effect against tomato soilborne pathogens (*Rhizoctonia solani* and *Fusarium oxysporum*) and for tomato plant promotion in crop production (Morales-Corts, Pérez-Sánchez, and Gómez-Sánchez 2018).

Date palm is the dominant crop system for farmers in southern Tunisia. Production of compost based on date palm waste may be useful as an alternative to protect the environment from palm waste and to improve the soil fertility in this condition (Guebsia et al. 2019). The use of quality compost can have an important positive impact on soil fertility and plant growth and health (Pandit et al. 2020). Therefore, the maturity and stability of the compost are crucial parameters for its safe application (Jagadabhi et al. 2019). Various physicochemical and microbial analyzes are used to assess the maturity of such compost. However, phytotoxicity could be effectively determined using the seed germination bioassay (Jagadabhi et al. 2019; Kebrom et al. 2019; Radhouani et al. 2015).

In Tunisia, there are more than 4.5 million date palm trees (Abid et al. 2020) producing important waste quantities essentially palm leaf waste (20 kg/tree yearly) (Abid and Ammar 2022). The quantity of date palm waste produced annually in the oasis system is around 90,000 tonnes. These huge quantities of waste hamper the movement of farmers in the oasis. In the best of cases, this waste is burned which can harm the environment. However, little attention has been paid to the application of date palm waste compost as organic amendment for the promotion of sustainable oasis farming. The objective of this study was to evaluate the maturity and phytotoxicity of local date palm waste compost using physicochemical and microbial analyzes as well as barley seed germination and plant growth bioassays.

Material and methods

Compost preparation

Compost preparation was conducted at a composting station of NGmOASOC (Association for Saving Oasis of Chenini, Gabes, Tunisia). The global coordinates are 33°53'01.8''N; 10°04'01.7''E). The date palm leaves and sheep manure used for this experiment were collected from local farmers (Oases of Chenini). These were characterized in terms of their total nitrogen content using the Kjeldahl method (Kjeldahl 1883), and total carbon content via combustion at 550°C (Jensen et al. 2018). The moisture content was determined according to MaciasCorral et al. (2019). Date palm waste compost was prepared followed the Turned Windrow method, and the aerobic composting technique was adopted (El Janati et al. 2022). The complete date palm leaves were mechanically ground to produce date palm leaves mulch particle size (0.5 inches) using a Vermeer grinder machine. Then, ground material was transferred to steeping basins containing fresh cow manure and soaked in water for 7 days in order to accelerate microbial activities that lead to fast decomposition during composting. Thus, standard compost piles with a volume of 6 m^3 (Length 2.5 × Width 1.5 × Height 1.5) were prepared by mixing and alternating ground product (bulking material) with sheep manure in a ratio of 2:1 by dry weight. Alternating was done with two layers of plant material and two layers of manure. During this experiment, the mixture was aerated manually during the active stage (72 days) and once a week during the curing stage (60 days). The humidity was maintained at around 60%, and a temperature measurement was performed daily. These conditions are recommended in order to guarantee optimal microbial activity (Benabderrahim et al. 2018). Based on the temperature variation, the composting process has four phases, respectively: Mesophilic (≈35°C), thermophilic (55–65°C), cooling, and maturation or curing phase. During our experiment, the composting process lasted for about four months (132 days). At the final stage, the measured temperature remained stable and close to ambient temperatures.

Sampling

The composting process was monitored over 18 weeks. The sampling consisted of randomly selecting 12 points across the body of the studied pile by extracting 1 L subsamples each which were mixed thoroughly and composited. From each composite sample, a portion of 0.5 L was used to conduct microbiological analysis. The described samples were packed in hermetically sealed plastic bags and were immediately sent to the laboratory to avoid nutrient loss or continued microbial activity. It should be noted that, for the rest of the experiment, the physicochemical and microbiological analysis were conducted for the finished product (mature compost).

Physicochemical analyses

The total nitrogen content was determined in triplicate according to Kjeldahl (1883). To calculate the C/N ratio, organic carbon was determined according to the methodology of Jensen et al. (2018). Moisture content was determined according to MaciasCorral et al. (2019) by oven-drying a 100 ml sample at 65°C until constant weight was attained. Electrical conductivity (EC) and pH were measured using the Orion Star™ A215 pH/Conductivity meter (Thermo Scientific Orion, MA, USA).

Microbiological analyses

For microbial enumeration, compost aliquots (5 g) were used to determine the number of cultivatable microorganisms. All samples were analyzed in triplicate. Samples were plated onto 10-fold-diluted tryptic soy agar (Bio-Rad, France). Plates were incubated at 25°C for 3 days after spreading of 100 μl of appropriate dilution (Al-Lahham, El Assi, and Fayyad 2003; Ranjard et al. 1997). Only plates with between 30 and 300 colonies per plate were examined. For fungi enumeration, the appropriate compost dilution was spread on Malt extract Agar. The number of developed colonies was recorded after 7 days of incubation at room temperature. Compost microbes' enumeration was an expression of the number of colony forming units (CFU) per gram of dry watered compost. Soil pathogenic bacteria were purified through repeated subculture method using nutrient agar as media. When a plate yielded only one type of colony, the organisms were considered to be pure. The purification of the isolates was also confirmed by microscopic observation. Different morphological (periphery, color, and appearance of the colonies, etc.), and biochemical characteristics (mobility, H_2S production, catalase production, etc.) accompanied by colony characteristics on different selective medium were observed for the identification of bacterial isolates.

Germination bioassay

After the composting process, the phytotoxicity of the date palm waste compost was evaluated using the seed germination bioassay under laboratory conditions. Cultivated barley (*Hordeum vulgare* L.) cv. Sahli, a local spring six-row cultivar was used in this test. The seeds were supplied by the Technical Centre of Organic Agriculture (TCOA, Tunisia). The aerated compost extract was prepared by mixing compost and distilled water at 1:10 (w/v) ratio on a rotary shaker for 4 h at room temperature. The mixture was centrifuged at 3,000 rpm for 30 min at room temperature and then filtered through a 0.8 µm filter. Seeds were surface-sterilized in sodium hypochlorite (1%) for 10 min and immediately washed several times with distilled water before use. Twenty seeds were placed to germinate in square Petri dishes (10 × 10 × 2 cm) containing a sterile Whatman™ filter paper, saturated with distilled water (control) or compost extract solutions (25, 50, 75, and 100%) at 25°C in the dark. After 5 days, the number of germinated seeds, length of hypocotyl, and radicle of each germinated seed were documented. In each treatment, five replicates were used. The seeds were considered germinated when the primary root reached 2 mm (Kebrom et al. 2019). Germination percentage (GP), relative seed germination (RSG), germination index (GI), and relative root growth (RRG) were determined (Tam and Tiquia 1994):

$$\text{Germination percentage}(\%) = (\text{Number of seeds germinated}/\text{Total number of seeds}) \times 100$$

$$\text{Relative seed germination}(\%) = (\text{Number of seeds germinated in the extract}/\text{Number of seeds germinated in the control}) \times 100$$

$$\text{Relative root growth}(\%) = (\text{Mean root elongation in the extract}/\text{Mean root elongation in the control}) \times 100$$

$$\text{Germination index}(\text{GI}) = (\%\ \text{Seed germination})\ \text{x}\ (\%\ \text{Root elongation})/(100\%)$$

Seedling vigor index (SVI) was calculated according to the following formula (Abdul Baki and Anderson 1970):

$$\text{Seedling vigour index}(\text{SVI}) = (\text{Mean root length}(\text{mm}) + \text{Mean shoot length}(\text{mm})) \times \text{Germination percentage}(\%)$$

A second experiment was conducted in order to evaluate the effect of priming on seed germination. Barley seeds were soaked for 6, 12, 18, and 24 h in solution containing different concentrations (0: distilled water, 25, 50, 75, and 100%) of compost extract. Then seeds were placed to germinate in square Petri dishes (10 × 10 × 2 cm) at 25°C in the dark, containing a sterile Whatman™ filter paper in a 5 × 4 factorial design with five replications. Seed germination rates were assessed after 3 days, corresponding to the first days of seedling emergence.

Growing assay

This experiment was conducted at the Experimental Station of the Biotechnology Centre at Borj Cedria (35 Km South-east of Tunis) in a glasshouse under controlled conditions (temperature of 23 ± 2°C, relative humidity 65–70%, light 270 µmol of photons $m^{-2}{\cdot}s^{-1}$ photosynthetic active radiations and a 14/10 h day/night photoperiod). Plastic pots with capacity of 5 L were used to raise the seedlings. The experiment was laid out in a completely randomized design (CRD) with four replicates and six treatments which consisted of five levels of compost (32, 64, 96, 128, and 160 g pot^{-1}) and control (soil without compost). The compost levels used in the growth bioassay were equal to the application of 10 (T1), 20 (T2), 30 (T3), 40 (T4), and 50 t ha^{-1} (T5). The main characteristics of the experimental soil used in this research are shown in Table 1. In each treatment, 10 pots were used. Fifteen seeds per pot were sown at a depth of 0.5 to 1 cm, and pots were irrigated based on the needs of the plants. From the 1st day observations were taken regularly, and germinated seeds were counted daily to calculate the germination percentage for each of the treatments. Two months after sowing (booting stage), different physiological and growth parameters were recorded.

Stomatal conductance (gs), net photosynthesis (A), transpiration (E), and intercellular CO_2 concentration (Ci) were determined in flag leaves of five plants chosen randomly from each treatment. Measurements were performed on intact plants between 10:00 and 12:00 a.m. using a Portable Photosynthesis System Li-6400 (LI-COR, Lincoln, USA).

Chlorophyll pigments including Chlorophyll a (Chla), b (Chlb) and total chlorophyll (Chlt) and total carotenoids (Cart) contents were determined according to Arnon (1949). Briefly, leaf samples (0.1 g) were macerated with cold acetone (80% v/v). After centrifugation at 10,000 rpm for 15 min, the supernatant of each sample was measured spectrophotometrically at 663, 645, and 480 nm and translated into pigment contents using the following equations:

$$\mathrm{Chla} = 12.70(\mathrm{A}_{663}) - 2.69(\mathrm{A}_{645})$$

$$\mathrm{Chlb} = 22.90(\mathrm{A}_{645}) - 4.68(\mathrm{A}_{663})$$

$$\mathrm{Chlt} = 20.20(\mathrm{A}_{645}) + 8.02(\mathrm{A}_{663})$$

$$\mathrm{Cart} = \mathrm{A}_{480} + 11.40(\mathrm{A}_{663}) - 63.80(\mathrm{A}_{645})$$

Table 1. Some characteristics of the soil used in the experiment.

Parameters	Value
Clay (%)	5.50
Silt (%)	8.30
Sand (%)	84.40
Soil texture	Sandy
pH	7.50
EC (dS m^{-1})	4.02
Organic matter (%)	0.905
Total organic carbon (%)	0.525
Total N (g kg^{-1} soil)	0.28
Available P (mg kg^{-1} soil)	4.92
Exchange K (mg kg^{-1} soil)	292
Total coliforms (MPN g DW^{-1} soil)	24×10^2
Faecal coliforms (MPN g DW^{-1} soil)	<0.3
Escherichia coli (MPN g DW^{-1} soil)	<0.3
Faecal Streptococci (MPN g DW^{-1} soil)	39×10^2

Measurements were taken of plant height and samples of fresh shoots and roots of 10 randomly selected plants from each treatment were harvested and weighed. Then samples were dried at 65°C for 72 h to determine the dry weights, and the dry matter accumulation was calculated as follows:

$$\text{Dry matter accumulation}(\%)=(\text{Dry weight}/\text{Fresh weight})\text{x}100$$

Mineral analysis

The mineral uptake in barley leaves was assessed by determining N, P, and K content. Representative samples from ground leaves (0.1 g) were digested using a mixture of nitric and perchloric acids (4:1) at 100°C until complete evaporation. Then, 5 ml of nitric acid solution (0.5%) was added to the samples, and the mixture was filtered using Whatman filter paper (Zaier et al. 2010). The total nitrogen content was determined using the Kjeldahl method (Kjeldahl 1883). K content was determined using a flame photometer (Corning 400 uk). P was determined using the colorimetric method with a spectrophotometer (Pradhan and Pokhrel 2013).

Statistical analysis

Data were subjected to statistical analysis using Statistical Package for Social Sciences (SPSS 16.0) software (SPSS Inc., Chicago, Illinois, USA) (Karamurugan and Govindarajan 2022). Differences between treatments were made using one-way analysis of variance (ANOVA) and means were separated by Tukey's post-hoc test ($p \leq .05$).

Results

Physicochemical and microbial analysis of experimental date palm waste compost

Physicochemical and microbial properties of the prepared date palm waste compost and compost extract are shown in Tables 2 and 3. The total nitrogen content of the prepared compost was 1.21% which is relatively similar to most commercial fertilizers like the Netherlands, Belgium, and Italy compost quality standard (>0.7%) and the range reported by Swiss agriculture (1.05–1.13%). The C:N ratio is 15.36, which is quite acceptable, suggesting that the compost was mature. The percentage of organic carbon is responsible for improvement of the soil structure. The experimental compost extract had a neutral pH value (Table 3) within the required pH for plant growth and within the range suitable for compost tea preparation. However, EC was generally higher in compost extract which may be related to the increase of free ions and ammonia during the mineral solubilization of organic matter. Altogether, pH, EC values, and nutritive mineral concentrations were within the range suitable for aerated compost extract preparation (Morales-Corts, Pérez-Sánchez, and Gómez-Sánchez 2018).

Date palm waste compost contains metallic trace elements (MTEs) at variable concentrations. Indeed, Zn, Cu, Mn, Ni, and Fe are essential in small amounts for plant growth and development, while in higher amounts they may seriously affect plant growth, yield, and quality. On the other hand, other heavy metals like Cd, Pd, and Cr are of concern primarily because of their potential to harm soil organisms and humans who may eat contaminated plants or soil. The concentrations of Zn, Fe, Mn, Cu, Cd, Pb, Cr, and Ni in the prepared compost were 70.10, 70, 130, 11.60, 020, 4.15, 11.50, and 5.88 (mg kg–1 DW compost), respectively, and considerably lower at the critical level and below the permissible limits of AFNOR NFU 44–051 (2006).

Characteristics of compost extract are presented in Table 3. Indeed, the compost extract had pH 7.80, EC 8.69 dS m^{-1}, 900 mg L^{-1} organic carbon, 130 mg L^{-1} N, 33.40 mg L^{-1} P, 795 mg L^{-1} K, 1.53 g L^{-1} Ca, and 224 mg L^{-1} Mg.

Both studied compost and its corresponding extract were tested for the presence of harmful pathogens, such as *Salmonella*, *Streptococci*, *Coliform*, *Shigella*, and *E. coli*, and the most probable

Table 2. Chemical properties, metal composition, and harmful bacteria of experimental date palm waste compost.

Parameters	Value
Total organic carbon (%)	18.58
Total N (%)	1.21
C/N	15.36
P (%)	0.54
K (%)	0.95
Ca (%)	8.18
Mg (%)	1.05
Na (%)	0.42
Alkalinity (% CaCO3)	11.50
Zn (mg kg^{-1} DW compost)	70.10
Fe (g kg^{-1} DW compost)	70
Mn (mg kg^{-1} DW compost)	130
Cu (mg kg^{-1} DW compost)	11.60
Cd (mg kg^{-1} DW compost)	0.20
Pb (mg kg^{-1} DW compost)	4.15
Cr (mg kg^{-1} DW compost)	11.50
Ni (mg kg^{-1} DW compost)	5.88
Total coliforms (MPN g DW^{-1} compost)	143.33 ± 5.77
Faecal coliforms (MPN g DW^{-1} compost)	120 ± 17.32
Escherichia coli (MPN g DW^{-1} compost)	114 ± 23.79
Faecal Streptococci (MPN g DW^{-1} compost)	114.33 ± 23.8
Salmonella spp. (MPN g DW^{-1} compost)	<0.3
Shigella spp. (MPN g DW^{-1} compost)	<0.3

Table 3. Characteristics of date palm waste compost extract used in this experiment.

Parameters	Value
pH	7.80
EC (dS m^{-1})	8.69
Organic carbon (mg L^{-1})	900
N (mg L^{-1})	130
P (mg L^{-1})	33.40
K (mg L^{-1})	795
Ca (g L^{-1})	1.53
Mg (mg L^{-1})	224
Potassium permanganate oxidizable carbon (POX-C. mg L^{-1})	2600
Faecal coliforms (MPN 100 ml^{-1})	670 ± 51.96
Escherichia coli (MPN 100 ml^{-1})	416 ± 23.09
Salmonella spp. (MPN 100 ml^{-1})	<0.3
Shigella spp. (MPN 100 ml^{-1})	<0.3

number (MPN) was used to determine the fecal contamination of the compost. Our findings showed that locally produced date palm waste compost and its corresponding extract had a low-level coliform contamination. Moreover, compost and its extract showed the presence of a low level of *E. coli* with an average of 114 ± 23.79 (MPN g DW^{-1} compost) and 416 ± 23.09 (MPN 100 ml^{-1}), respectively, whereas no *Salmonella* and *Shigella* were detected.

Effect of compost extract on seed germination and growth

The germination response of compost extract-imbibed seeds was clearly concentration-dependent (Figure 1(a)). At high extract concentration (100%), barley seeds were the least sensitive to any negative effects from the compost extract. The final germination percentage (GP) was 85.57% while at 0%, 25%, 50%, and 75% presented a GP higher than 90% (94.80%, 94.03%, 90.10%, and 93.85, respectively). Furthermore, no differences ($p > .05$) were found between relative seed germination (RSG) obtained at 0%, 25% (99.16%), and 75% (96.40). However, at the 50% and 100% concentration, the RSG was lower ($p < .05$) than other concentrations (Figure 1(b)). The germination index (GI) at

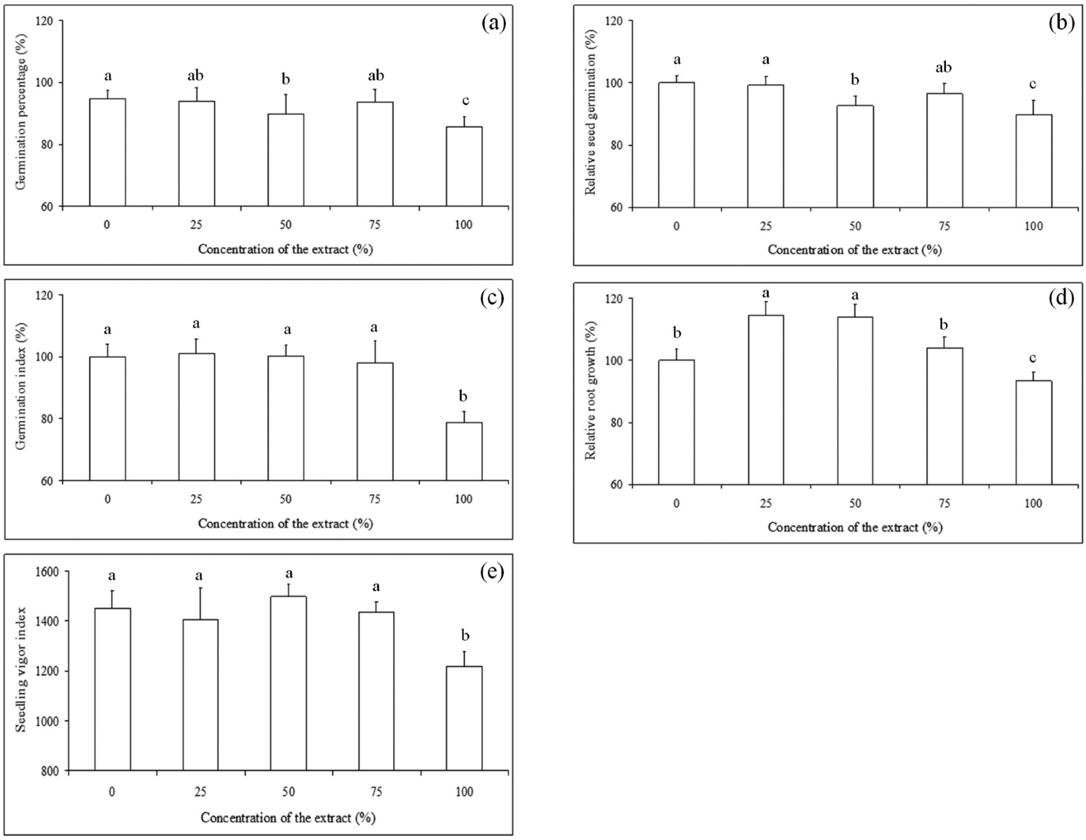

Figure 1. Effect of different concentrations of compost extract on germination percentage (a), relative seed germination (b), germination index (c), relative root growth (d) and seedling vigor index (e). Means (± SE) designated by the different letters on the bars indicate significant differences ($p < .05$) based on multiple comparisons (Tukey's HSD test) in ANOVA.

high extract concentration (100%) was about 78%, indicating mild phytotoxic effect. However, 25%, 50%, and 75% dilution appear to be free of phytotoxic effects (Figure 1(c)). In fact, at 25%, 50%, and 75% dilution, the GI was 101, 100, and 98%, respectively of the control. In addition to GI, we analyzed relative root growth (RRG) to see the effect of compost aqueous extracts specifically on seed germination and root growth of barley. The RRG in 25%, 50%, 75%, and 100% aqueous extracts was 115, 114, 104, and 93%, respectively, suggesting that RRG was improved in 25%, 50%, and 75% date palm compost aqueous extracts but significantly reduced in 100% aqueous extract (Figure 1(d)).

Hypocotyl length followed a similar trend and ultimately these impacts were significantly attributed in case of seedling vigor index (SVI). It ranged from 1219 to 1497 and the lowest vigor index was found in case of high extract concentration (100%), while the concentration of 0%, 25%, 50%, and 75% gave the highest vigor index (Figure 1(e)).

Effect of date palm compost and its aerated extract on barley plant growth

The photosynthetic performance of compost-exposed barley plants was evaluated *in vivo* by leaf gas exchange and chlorophyll fluorescence measurements (Table 4). The results showed highly significant differences between barley plants in response to the different treatments (control, T1, T2, T3, T4, and T5). T1 and T4 did not significantly affect photosynthetic parameters compared to the control. Interestingly, T2 and T3 significantly increased all leaf gas exchange values, having the strongest positive effect on Ci, Pn, E, and gs. However, the increase of compost dose (T5) significantly decreases

Table 4. Effect of different treatments on intercellular CO_2 concentration (Ci), photosynthetic rate (Pn), transpiration rate (E), stomatal conductance (gs), chlorophyll a (Chla), chlorophyll b (Chlb), total chlorophyll (Chlt), and carotenoids content. Shoot length (SL), root length (RL), shoot (SDW), root dry weight (RDW), and dry matter accumulation (DMA) at the tillering stage.

Parameters	Control	T1	T2	T3	T4	T5
Ci (µmol CO_2 mol^{-1})	300.50 ± 4.94^{b}	284 ± 4.24^{c}	316 ± 4.12^{a}	313 ± 2.82^{a}	299 ± 5.65^{b}	289.50 ± 3.53^{bc}
Pn (µmol CO_2 m^{-2} s^{-1})	6.26 ± 0.02^{c}	6.56 ± 0.19^{c}	11.32 ± 0.25^{a}	11.40 ± 0.10^{a}	7.12 ± 0.12^{b}	5.01 ± 0.22^{d}
E (mmol H_2O m^{-2} s^{-1})	0.53 ± 0.00^{b}	0.52 ± 0.04^{b}	0.90 ± 0.03^{a}	0.94 ± 0.02^{a}	0.53 ± 0.02^{b}	0.55 ± 0.02^{b}
gs (µmol H_2O m^{-2} s^{-1})	41 ± 1.41^{c}	44 ± 1.39^{b}	69.50 ± 0.70^{a}	70 ± 0.00^{a}	39 ± 1.37^{c}	40 ± 0.02^{c}
Chla (mg g^{-1} FW)	9.92 ± 0.70^{d}	11.71 ± 0.70^{bc}	11.25 ± 0.88^{c}	12.41 ± 0.39^{ab}	13.15 ± 0.73^{a}	12.95 ± 0.29^{a}
Chlb (mg g^{-1} FW)	2.73 ± 0.15^{c}	3.17 ± 0.05^{b}	3.61 ± 0.09^{a}	3.20 ± 0.15^{b}	3.30 ± 0.06^{b}	2.81 ± 0.11^{c}
Chlt (mg g^{-1} FW)	12.95 ± 0.74^{b}	15.16 ± 0.62^{a}	15.12 ± 0.80^{a}	15.48 ± 0.34^{a}	16.08 ± 0.39^{a}	15.67 ± 0.44^{a}
Carotenoids (mg g^{-1} FW)	2.17 ± 0.16^{ab}	2.07 ± 0.03^{b}	2.27 ± 0.15^{ab}	2.40 ± 0.19^{a}	1.48 ± 0.16^{c}	1.42 ± 0.23^{c}
SL (cm)	38.51 ± 0.90^{c}	40.23 ± 1.31^{bc}	40.93 ± 2.11^{b}	44.48 ± 0.76^{a}	39.38 ± 2.17^{bc}	34.48 ± 1.61^{d}
RL (cm)	20.01 ± 1.84^{b}	22.56 ± 2.10^{a}	18.72 ± 1.13^{b}	20.74 ± 1.84^{ab}	19.00 ± 1.76^{b}	18.94 ± 1.85^{b}
SDW (mg $plant^{-1}$)	133.51 ± 5.12^{c}	151.63 ± 8.30^{b}	202.21 ± 4.97^{a}	207.06 ± 7.48^{a}	205.58 ± 4.58^{a}	208.40 ± 7.79^{a}
RDW (mg $plant^{-1}$)	78.65 ± 5.04^{e}	92.62 ± 6.93^{d}	115.00 ± 5.75^{c}	121.56 ± 5.98^{bc}	126.91 ± 7.22^{ab}	132.60 ± 5.22^{a}
DMA (%)	19.81 ± 0.06^{d}	21.07 ± 0.65^{bc}	20.75 ± 0.19^{c}	22.85 ± 0.31^{a}	21.75 ± 0.04^{b}	21.58 ± 0.14^{bc}

All values are means of 10 replicates (±SE). Different letters indicate significant difference at $p < .05$ based on multiple comparisons (Tukey's HSD test) in ANOVA.

the Pn value. Indeed, the value of Pn at the highest dose (T5) averaged 79% of those of control plants. However, the values of Pn, E, and gs at T2 and T3 dose averaged 179–182%, 169–178%, and 169–171%, respectively of those of control plants. The contents of chlorophyll a, b, and total were significantly increased by compost treatments relative to untreated plants (Table 4). The increase in Chlt was 17%, 16%, 19%, 24%, and 21% in T1, T2, T3, T4, and T5, respectively. At the same treatment, T3 increased the carotenoid content by 10% compared to control treatment, while T4 and T5 showed decrease in the values of carotenoid content at 32% and 35%, respectively. Minimum values were recorded in root dry (RDW) and shoot dry weight (SDW) under control conditions, but compost treatment caused a significant increase in these growth attributes under all levels of compost doses, especially with T5 treatment, when the values of SDW and RDW increased by 56% and 68%, respectively (Table 4). The dry matter accumulation (DMA) of barley in response to compost application is also shown on Table 4. T3 had the highest DMA (22.85%). The control had the least DMA (19.81%) which was significantly lower than other treatments. The DMA was 21.75% in T4, which was not significantly different from T1, T2, and T5.

Effect of date palm compost application on nitrogen, phosphorus, and potassium accumulation in barley leaves

The content of mineral nutrients (N, P, and K) of barley leaves are presented in Table 5. Palm date compost application dose significantly affected N, P, and K uptake in barley. In general, the application of T1, T2, T3, T4, and T5 significantly increased N uptake by 14%, 19%, 26%, 30%, and 33%, respectively above the control. The application of T1 and T2 slightly increased the P uptake by 6% and 11%, respectively as compared to the control, whereas T3, T4, and T5 slightly decreased P uptake by 13%, 8%, and 19%, respectively below the control. Also, the date palm compost improved K uptake in barley leaves under all treatments by 17%, 15%, 16%, 24%, and 30% above the control in T1, T2, T3, T4, and T5, respectively.

Table 5. Effect of application dose of date palm waste compost on N, P, and K uptake in barley leaves.

Parameters	Control	T1	T2	T3	T4	T5
N (%)	3.15 ± 0.07^{d}	3.58 ± 0.08^{c}	3.74 ± 0.09^{c}	3.98 ± 0.05^{b}	4.10 ± 0.04^{ab}	4.18 ± 0.05^{a}
P (%)	0.71 ± 0.04^{ab}	0.76 ± 0.07^{a}	0.79 ± 0.05^{a}	0.62 ± 0.05^{ab}	0.65 ± 0.08^{ab}	0.57 ± 0.04^{b}
K (%)	3.88 ± 0.12^{d}	4.52 ± 0.14^{bc}	4.47 ± 0.08^{c}	4.52 ± 0.09^{bc}	4.81 ± 0.12^{ab}	5.02 ± 0.14^{a}

Data are means (±SE) of three biological replicates. Different letters denote significant differences (Tukey's HSD, $p < .05$).

Discussion

The compost derived from date palm waste had a relatively low C/N ratio, reflecting its maturity and conformity to the compost quality standards described by Abid et al. (2018) with fertilizing elements (N, P, K, Ca, and Mg) and lack of phytotoxic effect due to the low pathogenic bacteria contamination which can be used as fertilizers, probably without the risk of heavy metal contamination.

The C/N ratio of the prepared compost (15.36) is slightly lower than that determined by Abid et al. (2018) which is obtained from co-composted date palm waste fibers (17.95). These results are in keeping with the results obtained by Rosen et al. (1993) who found that the C/N ratio ranging from 15 to 20 corresponds to a mature compost and is ideal for ready-to-use compost which can significantly improve soil fertility. According to Vazquez and Soto (2017), a C/N ratio (10–15) likely indicated stable compost and it is a general indicator of advanced process of composting and a good retention of the nitrogen content favoring the conservation of nitrogen as nutrient. The prepared compost contains 18.58% total organic carbon that is lower than that found by Abid et al. (2020) and, in agreement with the finding of Ben Mbarek et al. (2019), reported that the mean of total organic carbon of compost produced from date palm waste was 18.59%. This result was supported by the study by Getahun et al. (2012) who stated that the total organic carbon reduced to 17% from about 44% at maturity phase due to the evolution of carbon dioxide. The mean of total N of the studied compost was 1.21%. These results were in keeping with those obtained by Benabderrahim et al. (2018), Abid et al. (2018) and Ben Mbarek et al. (2019) who found that the total N rate in date palm waste compost ranged from 1.2to 1.63%. Interestingly, the prepared compost has relatively high P (0.54%) and K (0.95%) concentrations, suggesting important indicators of compost quality. The obtained result was in keeping with the finding of Ben Mbarek et al. (2019), Benabderrahim et al. (2018) and Abid et al. (2018), who found that the P and K of compost produced from date palm waste ranged between 0.37% and 1.02% and 0.42% and 1.08%, respectively. According to Morales et al. (2016), the decomposition of organic matter gradually releases the available plant P, which determines the agronomic potential of plant production, while K improves the efficiency of water use by plants and improves crop growth. Furthermore, the studied compost also has high values of exchangeable bases like Ca (8.18%), Mg (1.05%), and Na (0.42%), making soil nutrients more available to plants.

The relatively higher content of $CaCO_3$ (11.50%) measured in the studied compost could lead to an increase in Ca content in the soil by $CaCO_3$ dissolution, becoming another source of Ca^{2+} (Morales et al. 2016).

Reasonable amounts of harmful pathogens are still present in the studied compost at maturity and meet the standard limit. Moreover, the heavy metal contents were below the acceptable limits, suggesting the efficiency of the composting treatment.

According to Pant et al. (2012), the type of compost had a significant effect on some characteristics like pH and EC of compost extract and its effect on plants may be predicted based on compost quality. The final pH value is recommended for the compost extract utilization. The EC of the compost extract was high, indicating a high concentration of dissolved salts such as ammonia and other nutrient ions released during the rapid mineralization of organic matter. These minerals are important for plant growth and development.

The studied aerated compost extract effect on seed germination of barley was presented in Figure 1. The results showed that the use of non-diluted extract (100%) markedly decreased GP, RSG, GI, RRG, and SVI compared to the control (distilled water). However, all these values increased or were not affected when applied with 25%, 50%, and 75% dilution and exhibited the best results considering all of the experimented parameters. Similarly, previous studies reported that GI and GP declined significantly for tomato and muskmelon with the solution of pure date palm compost extract (Radhouani et al. 2021). This finding can be attributed to the more effective suppression of seed germination and radical elongation of barley seeds by the compost extract and its sensitivity to higher electrical conductivity (EC). Indeed, the decrease in the compost extract concentration leads to a decrease in its EC that improves seed germination. In general, the use of 25%, 50%, and 75% of compost extract did not harm seed germination. At these concentrations, the percentages of seed germination were greater than 90% for barley and a final GI value of about 100% which may reflect mature compost and no phytotoxicity. In contrast, immature and unstable composts cause phytotoxicity which can affect root growth and seed germination and thus result in lower GI. This may be due to the presence of inhibiting substrates as main components in composted plant materials like phenolic, alkaloids, and ketones, as well as other flavonoid compounds, organic acids, ammonia, and lignin when compost is used at high concentrations (Kebrom et al. 2019). According to Barral and Paradelo (2011), compost with GI greater than 80% is considered as not phytotoxic, while a GI below 80% indicates potential phytotoxicity of compost to crops. Furthermore, a high GI (greater than 100%) indicates the presence of stimulator chemical compounds in the compost aqueous extracts (Moldes et al. 2007). In the present study, when the barley seeds were incubated with 25%; 50% and 75% aqueous extracts of date palm compost, the GI was about 100%, suggesting that the balance between growth stimulants and inhibitors in these aqueous extracts may determine seed germination and seedling growth and development. Abid et al. (2020) reported the effect of date palm compost extract on cress seeds (*Lepidium sativum* L.) germination and mentioned that the obtained compost was free of any phytotoxic effect with a high GI value (88%), reflecting its maturity and stability.

Several authors reported that organic amendments enhance plant photosynthetic activities and hence more dry matter is produced (Sulok et al. 2021). Rekaby et al. (2020) found that application of organic manure like compost increased the growth, dry matter accumulation, yield, and quality of the barley plant.

The application of T2 and T3 significantly increased the photosynthetic parameters (Ci, Pn, E, and gs) and concentration of Chla, Chlb, Chlt, and total carotenoids. However, in general application of T1, T4, and T5 exhibited no significant differences in the values of gas exchange parameters but showed a further increase in the concentrations of Chla, Chlb, Chlt, and total carotenoids when compared with the control treatment. These results are in line with that reported by Abdel-Ati and Eisa (2015). These authors suggested a positive effect of compost application on soil properties and thus plant nutrition and consequently on plant growth as proved by the chlorophyll content. The chlorophyll content and photosynthesis activity of forage maize (*Zea mays* L.) were significantly enhanced by the application of compost (Sandoval et al. 2017) which could be explained by the richness of compost in nutriments such as Mg playing a significant role in chlorophyll production and protein synthesis. Furthermore, a positive effect of compost treatment on fresh and dry weight barley plant has been reported in this study. The improved growth parameters due to the application of date palm waste compost may be attributed to the availability of nutrients which lead to increasing dry matter accumulation in the barley plant. A similar data was reported by Rekaby et al. (2020) who determined that dry matter accumulation in barley plants increased with compost treatment.

The application of different treatments increased the plant growth parameters, and the treatments can be arranged in descending order T2/T3 > T4 > T1 > T5. This indicates that date palm waste compost application should be conditioned by a well-defined dose to act positively on organic matter decomposition and mineralization of nutrients. The greater accumulation of dry matter in T3 compared to other treatments may be due to the availability of elements, such as N, P, K, Mg, and Zn in compost, absorbed and allocated as dry matter in the barley plant (Rekaby et al. 2020). Benabderrahim et al. (2018) and Abid et al. (2018) confirmed that date palm waste compost has positive effects on soil characteristics by improving soil organic matter and significantly increased both micronutrients and macronutrients in soil required for optimum plant growth. Rekaby et al. (2020) reported similar results for the effect of some organic amendments including compost on N, P, and K uptake by barley plants.

Conclusions

In conclusion, co-composting date palm waste and sheep manure in a ratio of 2:1 (w/w) could be an effective and environmentally friendly approach in terms of date palm waste management allowing improved biological fertilization of South Tunisia organic matter deficient soils by their content in micro and macronutrients. The obtained compost was free of any phytotoxic effect, with a low C/N ratio (15.36) and a high GI value (>90%) reflecting its stability. Indeed, the application of compost extract did not affect seed germination and stimulated hypocotyl and radical growth, as well as seedling vigor index (SVI). Seed germination and seedling parameters were maximum at 25%, 50%, and 75% of compost extract compared to other treatments. Furthermore, the use of soil amendment promotes barley plant growth and resulted in increases in plant biomass. According to the results, the dose corresponding to 30 t/ha (T3) is appropriate to achieve the greatest improvement in barley plant growth. However, further studies are necessary on the application of obtained compost and its extract under field conditions in order to reduce the use of fertilizers and develop organic and sustainable oasis agriculture.

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