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ORIGINAL PAPER

Date Palm Wastes Co-composted Product: An Efficient Substrate for Tomato (*Solanum lycopercicum* L.) Seedling Production

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Abstract
Purpose The present study aimed to investigate the feasibility of using co composted date palm waste fibers as a growth medium for tomato (*Solanum lycopersicum* L.) plants production under greenhouse.
Methods Date palm waste fibers were co-composted with goat manure, and the resulting compost was characterized and evaluated for its effects on the tomato plants growth under greenhouse conditions. The tested substrates included a control composed of 100% soil, soil mixed with the produced compost or goat manure, experimented at two concentrations of 20 and 30% (v:v). For these substrates, small pieces of crushed palm waste fibers were added at a rate of 5% to test their efficiency as a biological structuring agent.
Results The results revealed that the compost displayed high levels of nutrients (N, P, K), a relatively low C/N ratio of 17, and a fertilizing value similar to that of goat manure, exhibiting its stability and lack of phytotoxic effect. Greenhouse experiment showed that co-composting of date palm waste fibers and goat manure induced positive effects on soil quality by increasing its organic matter content. The addition of crushed palm waste fibers increased seed germination percent for both manure and compost.
Conclusions Date palm waste composting constitutes the suitable substrate for tomato seed germination, aerial growth and root development. Consequently, the date palm waste fibers co composting could offer a viable, ecological and sustainable alternative to conventional fertilizers.

Keywords Compost · Date palm waste · Growing medium · Organic matter · Seedling production

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Introduction

During the last two decades, growing concerns have been expressed over the deteriorating quality and fertility of agricultural soils throughout the world. This degradation has been attributed to various natural and human-induced reasons, including erosion, nutrients depletion, organic matter (OM) exhaustion, and excessive application of chemical fertilizers [1]. The OM lack enhanced greenhouse cultures and increased seedling production costs, which lead to many agricultural crop problems and excessive use of chemical fertilizers and pesticides. However, farmers have always used materials with high cost such as peat [2] considered as non-renewable natural resource, and its extraction causes the destruction of high ecological value areas [3]. Indeed, to promote seedling growth, an appropriate growing medium is essential, providing plants nutrients needs and promoting root development [4]. The literature provides strong evidence that agricultural wastes offer a promising available raw material that can be transformed through composting, into low cost sources of high added-value such as compost as soil improvers or growing media components providing the nutrients needed for plant growth stimulation with low input costs [3–6].

The organic wastes composting has often been considered as an efficient and sustainable treatment producing stabilized resources for soil amendment and fertilization purposes [4]. This process offers an attractive organic amendment strategy for soil quality improvement [7]. Furthermore, this bio process presents promising opportunities for mitigating the serious environmental problems associated to waste disposal, especially the agro-industrial residues.

Recently, many studies have been developed on the composting of various agro food organic waste by-products, including olive residues [7, 8], grape marc [9], *Acacia* residues [10] and green residues [2].

The date palm tree (*Phoenix dactylifera* L.) is an important multi-purpose tree cultivated in various arid and semi-arid regions of the world, including the Middle East, North Africa and Arabian Peninsula. There are more than 100 million date palm trees around the world, with an average age of about 100 years [11]. Tunisia has about 4.5 million trees extending over an area of 32,000 ha and produces an average of 0.145 Mt of date yearly. Despite its important economic and socio-cultural values for people around the world, date palm production generates large amounts of agro-industrial by-products and residues, such as leaves and palm fiber, which present troublesome environmental and waste disposal problems. For instance, more than 0.2 Mt of leaves are produced every year [12]. These abundantly available waste products can be valorized into bio-stimulants or bio-fertilizers to reduce the problems associated with OM deficiency, without affecting plant production and productivity. In this way, the compost production from date palm residues would be of a great interest for countries suffering from poor or impoverished soils, including the soils of South Tunisia (OM $< 1\%$) and a medium growth for seedling production [13]. However, little work has been performed on date palm residues composting and the use of the produced compost under green house for seedling production [14, 15].

Therefore, considering the data scarcity on the date palm wastes valorization and the promising opportunities that compost from date palm waste might present for the seedling production development as an efficient soil amendment strategies, the present study aimed to investigate the feasibility of using composted date palm waste as a growth medium in tomato (*Solanum lycopersicum* L.) greenhouse plants production. Date palm residues were co-composted with goat manure, and the resulting compost was characterized and its effects evaluated on the growth of tomato plants under greenhouse conditions.

Materials and Methods

Raw Materials

In this study, compost was prepared by mixing goat manure with crushed date palm waste fibers (1: 3 v/v). Goat manure was collected from a local organic farm in Gabes (South of Tunisia), and date palm waste, from the Oasis of Cheneni (Gabes). The date palm waste fibers issued from the size process were first mechanically crushed to reach particles of 5-10 cm. These were swollen in water for 4 days, and then mixed with goat manure. The windrow of 7 tons was irrigated by well water characterized by neutral pH (7.08) and an electrical conductivity (EC) of 3.4 mS/cm. The physico-chemical characteristics of the defined raw materials and the produced compost are presented in Table 1. The obtained compost was then evaluated for its effects on the growth of *Rio grandi* tomato seeds under greenhouse conditions at a local nursery in Sfax (South Tunisia) (34°43′46″N and 10°41′86″East). The prepared compost was mixed with the greenhouse soil composed of 70% sand, 21% clay and 9% silt, and characterized by neutral pH (7.14 ± 0.26), low EC (0.25 ± 0.003 mS/cm), and OM content ($1.18 \pm 0.02\%$).

Composting Procedure

The composting procedure was carried out in the Oasis of Chenini, at the composting site of the Chenini Oasis Protection Association. Date palm residues were collected and dried in the sun to make easy the mechanical crushing. After being mechanically crushed, the date palm fibers were rehydrated in basin of 4 m $\times$ 4 m and 2 m depth for 4 days, this soaking improved their biodegradation during composting process. The raw materials were mixed at a proportion of 1/3 manure and 2/3 crushed-hydrated palm waste fibers (v:v). These wastes were co-composted in an open area, using a windrow of 1.3 m height, 10 m length and 1.5 m wide base. The ingredients were mixed by mechanical rotation allowing aeration. At the same time, the windrow was watered to keep a moisture range of around 50%. The windrow was turned once a week during the most active bio-oxidative phase, and once a month for the remaining composting period. The mature compost was ready after 6 months of adequate aeration and humidification.

Nursery Culture Method

A total of 9 different substrate compositions were tested and arranged in a random design. The 9 compositions used in this work are presented in Table 2. The tested compositions are made up of 4 substrates mixed at different rates. These included a control composed of 100% soil (S0) and 8 others compositions where the soil was mixed with goat manure at two concentrations 20 and 30% (v:v) as it was used for compost production (S1–S4) and the soil mixed with the produced compost at two concentrations 20 and 30% (v:v) (S5–S8). For the mentioned compositions,

Table 1 Physico-chemical characteristics of the raw materials and the produced compost

Parameters	Crushed palm	Goat manure	Compost
pH	6.07 ± 0.38	7.35 ± 0.25	7.00 ± 0.16
EC (mS/cm)	1.42 ± 0.07	7.13 ± 0.05	7.86 ± 0.08
Moisture (%)	16.86 ± 0.04	15.51 ± 0.53	17.52 ± 0.45
Dry matter (%)	83.14 ± 0.04	84.48 ± 0.53	82.48 ± 0.45
Organic matter (%)	91.23 ± 0.83	36.17 ± 0.82	50.40 ± 0.60
Total organic carbon (%)	53.11 ± 0.48	20.97 ± 0.47	29.26 ± 0.60
TKN (%)	0.81 ± 0.00	1.02 ± 0.00	1.63 ± 0.00
C/N	65.00 ± 0.48	20.55 ± 0.47	17.95 ± 0.60
Mineral matter (%)	8.77 ± 0.48	63.83 ± 0.82	49.60 ± 0.60
Lignin (%)	36.83	ND	ND
Cellulose (%)	36.96	ND	ND
P (g/kg)	0.69	11.85	10.24
K (g/kg)	68	24	88
Ca (g/kg)	1.55	1.84	ND
Mg (mg/kg)	167	192	227
Na (mg/kg)	89	75	127
Fe (mg/kg)	80	89	57
Mn (mg/kg)	2.11	2.07	1.85
Zn (mg/kg)	0.20	0.35	0.60
Cu (mg/kg)	0.09	0.12	0.78
Germination index (%)	ND	ND	81

EC electrical conductivity, *TKN* total Kjeldahl nitrogen, *ND* not determined

Table 2 Composition of the growing media

Substrate	Compost (%)	Manure (%)	Crushed palms (%)	Soil (%)
S0	0	0	0	100
S1	0	30	0	70
S2	0	20	0	80
S3	0	30	5	65
S4	0	20	5	75
S5	30	0	0	70
S6	20	0	0	80
S7	30	0	5	65
S8	20	0	5	75

crushed date palm waste fibers were manually chopped into small pieces and added at a rate of 5% to test their efficiency as a biological structuring agent (Table 2).

Three seedling plates, with 104 holes of 50 mL each, were investigated for tomato greenhouse cultivation using an early variety of *Rio Grande* seeds with a purity rate of 97% (Baddar Semences, Tunis, Tunisia). The plates were initially covered with black plastic and irrigated on a daily basis throughout the first week, and then 3 times a week after seed germination and plastic protection was removed. No additional fertilizer was used.

Physico-Chemical and Biological Analysis of Compost and Substrates

The initially processed substrates and produced compost were submitted to physico-chemical analysis using standard methods. Humidity content was determined by drying the samples at 105 °C for 24 h. The pH and EC values were measured in a solution consisting of 20 g of sample in 100 ml of distilled water (values represent means of three replications ± SD). OM and mineral contents were determined by dry matter and weight loss on ignition at 550 °C in a muffle furnace for 4 h [7]. Phosphorus content was determined by the colorimetric measurement of molybdovanadate phosphoric acid at 430 nm (NF V18-106, 1980). Total nitrogen was assessed based on the Kjeldahl method TKN. Macro and micro elements were first extracted by heating 2.0 g of the sample with a concentrated mixture of nitric and chlorhydric acids, and the hydrolysate was filtrated then analyzed by atomic absorption spectrophotometry (Hitachi Z-6100). Cation exchange capacity (CEC) was determined using ammonium acetate at pH 7 [13]. Cellulose content was determined according to the standard procedure (NF V03-040, 1977) and lignin content was estimated by acid hydrolysis [16].

Phytotoxicity was evaluated according to the method described by Hachicha et al. [7] and germination index (GI) was calculated using the following formula:

$$\text{GI}\ (\%) = [(\text{Seed germination} \times \text{Treated root length})/(\text{Seed germination} \times \text{Control root length})] \times 100$$

The physicochemical characterization of the experimented substrates is presented in Table 3.

Biometric Parameters

The produced compost effect on seed germination was investigated throughout the first 15 days of growth under greenhouse conditions. Biometric parameters were analyzed after one month, when tomato plants were ready to be transferred into the field.

The number of germinated tomato seeds and that of leaves were counted based on visual observation; the aerial seedling height (H) was measured with a ruler from the cotyledon to the maximum height of the shoot and the stem diameter (D) with a foot slides. After aerial parts measurement, the plants were harvested. The roots were washed and their lengths measured by a ruler.

The pH, EC and OM values of the different growth substrates were determined at the culture beginning and after the plant harvesting. The EC and pH values were measured on a mixture of the substrate sample/water (1:5), and OM was analyzed according to the Walkley–Black method [17].

Statistical Analysis

The data were submitted to variance analysis using IBM SPSS statistics version 19. The mean values of the treatments were compared using the Duncan's multiple range tests at 5% level of significance ($p < 0.05$). All the analyses were performed in triplicate.

Results

Physico-Chemical Characterization of the Produced Compost and the Experimented Substrates

The compost derived from date palm waste and goat manure co composting had a neutral pH and relatively high EC. It also exhibited a low C/N ratio and a high GI value (80%) (Table 1) reflecting its maturity and conformity to the compost quality standards described by Mustin [18].

The experimented substrates had neutral pH values within the required pH for plant growth. The S7 substrate including compost at 30% and palm waste at 5% was characterized by the highest EC and OM content. Furthermore, the crushed palm waste addition in the substrates decreased slightly the pH values and increased the substrates EC and OM content. Nitrogen content was more

Table 3 Initial physico-chemical properties of the growing media

Substrate	pH	EC (mS/cm)	Dry matter (%)	Organic matter (%)
S0	7.14	0.25	86.95	1.18
S1	7.55	3.08	96.78	4.62
S2	7.74	1.89	97.39	4.22
S3	7.09	3.08	97.16	5.37
S4	7.10	1.87	97.05	5.12
S5	7.33	2.59	95.11	4.2
S6	7.43	1.98	95.91	4.07
S7	6.90	3.58	83.45	5.34
S8	7.18	2.35	95.84	5.17

C compost, *M* goat manure, *P* crushed palm

S0 = S (100%); S1 = M (30%) + Soil (70%); S2 = M (20%) + Soil (80%); S3 = M (30%) + Soil (65%) + P (5%); S4 = M (20%) + Soil (75%) + P (5%); S5 = C (30%) + Soil (70%); S6 = C (20%) + Soil (80%); S7 = C (30%) + Soil (65%) + P (5%); S8 = C (20%) + Soil (75%) + P (5%)

important in substrates including the produced compost. In fact, in the experimented substrates, the manure and the compost addition to the soil improved by ten times nitrogen content (Table 3).

Substrate Composition Effects on Tomato Seedling Growth

Seedling Emergence

Figure 1a revealed that OM exerted significant and concentration-depended effects on tomato seed germination percent. Indeed, the prepared compost and the manure had different effects on seed germination. The comparison between the two used rates of manure and compost indicated that when mixed with 5% of crushed palm, manure at 20% presented the best seed germination followed by compost at 30%. Then, substrate with manure used at 30% or compost at 20% had similar effects on seed germination with 5% crushed palms (S3 and S8). As a result, the incorporation of crushed palms in the substrate composition significantly improved seed germination. Indeed, at a low manure concentration (20%) and in the presence of crushed palm (S4), the seed germination was 5 times higher than that without crushed palm (S2). Furthermore, the experiment results showed that the substrate involving the highest rate of compost (30%) and palm waste (S7), presented better seed germination percentage compared to the one including the highest rate of manure and palm waste (S3).

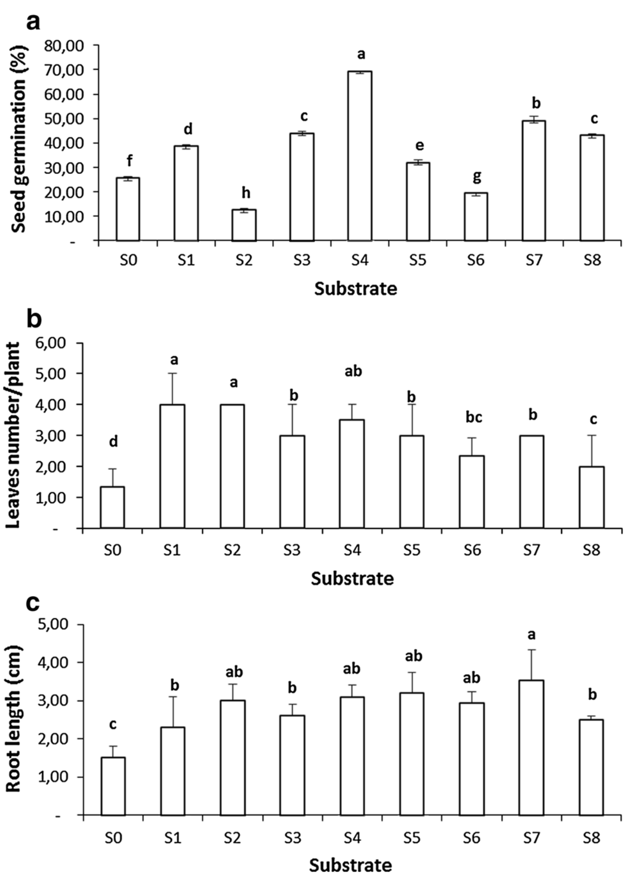

Fig. 1 Effect of the experimental treatments on tomato seeds germination (**a**), leaves number (**b**) and roots elongation (**c**) (n = 10; α = 0.05). *C* compost, *M* goat manure; *P* crushed palm; S0 = S (100%); S1 = M (30%) + Soil (70%); S2 = M (20%) + Soil (80%); S3 = M (30%) + Soil (65%) + P (5%); S4 = M (20%) + Soil (75%) + P (5%); S5 = C (30%) + Soil (70%); S6 = C (20%) + Soil (80%); S7 = C (30%) + Soil (65%) + P (5%); S8 = C (20%) + Soil (75%) + P (5%)

Aerial Parts Growth

The values recorded for tomato plants in terms of stem height and diameter growth on the different substrates are presented in Table 4. Results showed that soil mixed with compost or manure increased the tomato aerial parts growth, and for the different substrates used, stem height was important when compost was used at 30% (S5 and S7) and manure at 20% (S2 and S4). The recorded results for the seedling growth rates exhibited the best growth on manure at 20% but the best seedling rigorous state was exhibited on compost at 20% (S6 and S8). Moreover, when the produced compost was used at a rate of 30% (S5 and S7), the addition of crushed palm waste as structural agent (5%) (S7) improved the rigorous state of the young plants, defined by the H/D ratio. However, the combination of crushed palm waste with manure as a growing medium did

Table 4 Effects of the substrate composition on tomato stem growth (cm) after 30 days (n = 10; $p = 0.05$)

Substrates	Height (H)	Diameter (D)	H/D
S0	1.31 ± 0.25^{d}	0.10 ± 0.05^{b}	13.10
S1	2.30 ± 0.20^{b}	0.20 ± 0.03^{a}	11.50
S2	3.00 ± 0.30^{a}	0.25 ± 0.05^{a}	12.00
S3	1.55 ± 0.05^{d}	0.13 ± 0.03^{b}	12.40
S4	$1.60 \pm 0.10^{c,d}$	0.12 ± 0.02^{b}	13.33
S5	$2.10 \pm 0.10^{b,c}$	0.10 ± 0.00^{b}	21.00
S6	1.35 ± 0.35^{d}	0.13 ± 0.02^{b}	10.80
S7	$1.65 \pm 0.35^{c,d}$	0.14 ± 0.04^{b}	11.79
S8	1.50 ± 0.50^{d}	0.14 ± 0.01^{b}	11.11

C compost, *M* goat manure; *P* crushed palm

S0 = S (100%); S1 = M (30%) + Soil (70%); S2 = M (20%) + Soil (80%); S3 = M (30%) + Soil (65%) + P (5%); S4 = M (20%) + Soil (75%) + P (5%); S5 = C (30%) + Soil (70%); S6 = C (20%) + Soil (80%); S7 = C (30%) + Soil (65%) + P (5%); S8 = C (20%) + Soil (75%) + P (5%)

Values represent the means of three samples (± SE). *Different letters* (a–d) indicate significant differences ($p < 0.05$) between substrates treated separately not exert any significant effect on the plant height and diameter. Furthermore, H/D comparison revealed that at a rate 30% and without crushed palm, the seedling state was more vigorous in substrate with manure (S1), for the others experimented substrates i.e. S6, S7 and S8 H/D compost ratios were inferior to those including manure in their composition, respectively S2, S3 and S4. This fact may reflect the best seedling rigorous state, since the seedling with low H/D ratio would present more resistance to wind and frost.

Figure 1b showed that both compost and manure uses induced an increase in leaves number per plant compared to the control substrate (S0). On substrate including the manure (20 and 30%) leaves number was the most important and no significant difference was observed between manure experimented concentrations. Crushed palm waste addition affected leaves number production (S1/S3, S2/S4). However, when compost was used alone, the best leaves production was recorded for the highest organic amendment rate (30%). Student test between substrates including manure (S1, S2, S3, S4) and compost (S5, S6, S7, S8) respectively showed no significant difference ($p = 0.06$).

The present findings also revealed that different number of leaves per plant was achieved with date palm waste compost or manure, both used at a concentration of 30% (S1/S5) but no significant difference was observed ($p = 0.5$).

Roots Elongation

The results recorded for the effect of the produced compost and goat manure on tomato roots development are presented in Fig. 1c. Referring to the control (S0), both compost and goat manure induced roots development. However, at 30% rates (S1 and S5) the compost (S5) amendment exhibited the best root development with an increase of 53% while with manure, the increase was of 34% compared to S0. This could be attributed to the aeration rate and higher moisture content improvements ensured by the compost. In addition, and considering that root development needs of potassium, the physico-chemical analysis showed that the potassium rate in the compost was three times higher than that observed in the manure (Table 1). Furthermore, at 30% rate, the differences between compost and manure were significant and compost increased root development by 28% when used alone (S1 and S5) and by 26% when crushed palm was added to the substrate composition (S3 and S5).

The results also revealed that the crushed palm waste fiber addition to compost improved the root elongation by 9% (S5 and S7) but no positive effect was observed with manure when used at a rate of 30%. Furthermore, significant difference was observed between compost and manure used at 30% with crushed palm (S3 and S7), this way noted by a marked increase of 34% in root development. The crushed palm effect was evidenced also when added to manure at 20%. However, no significant difference was observed between S1 and S5, including the organic amendment.

Moreover, the results exhibited that significant tomato root elongation values were achieved in the presence of compost at a concentration of 30% compared to the values obtained at 20% compost (S5 and S6; S7 and S8). This result could be attributed to the root aeration enhancement in the presence of compost.

Overall, considering root development, the results suggested that the substrate S7 combining compost at 30% with a low concentration of crushed palm waste (5%) was the best growth substrate exhibiting the maximum root elongation.

Physico-Chemical Properties Evolution of the Experimented Substrates

pH

The soil amended with the different experimented organic matter (Fig. 2a) had significant effect on the initial soil pH. Indeed, after 45 days, the pH values increased by 0.4–0.8. This could be ascribed to the OM solubility and the organic acids released biodegradation.

Electrical Conductivity

Figure 2b showed that the compost and manure application significantly increased soil EC values from 0.25 to 1–3 mS/cm. These results show a significant difference between the initial and final EC of the different substrates including the produced compost or goat manure mixed with soil, with an increase of about 16% when comparing compost to manure both added with 5% of crushed palm waste. The substrate S7 was characterized by the highest initial EC value and a final low EC 3 folds lower than the initial one.

Organic Matter

The results presented in Fig. 2c showed that the addition of goat manure (S1 and S3) or the produced compost (S5 and S7) to soil increased the available OM levels during plant breeding. Moreover, the crushed palm addition increased OM levels of both goat manure and the produced compost.

Correlation Between the Experimented Analyzed Parameters

A correlation matrix was established to investigate the relationships between the experimented substrates composition and the biometric parameters of the tomato seedling

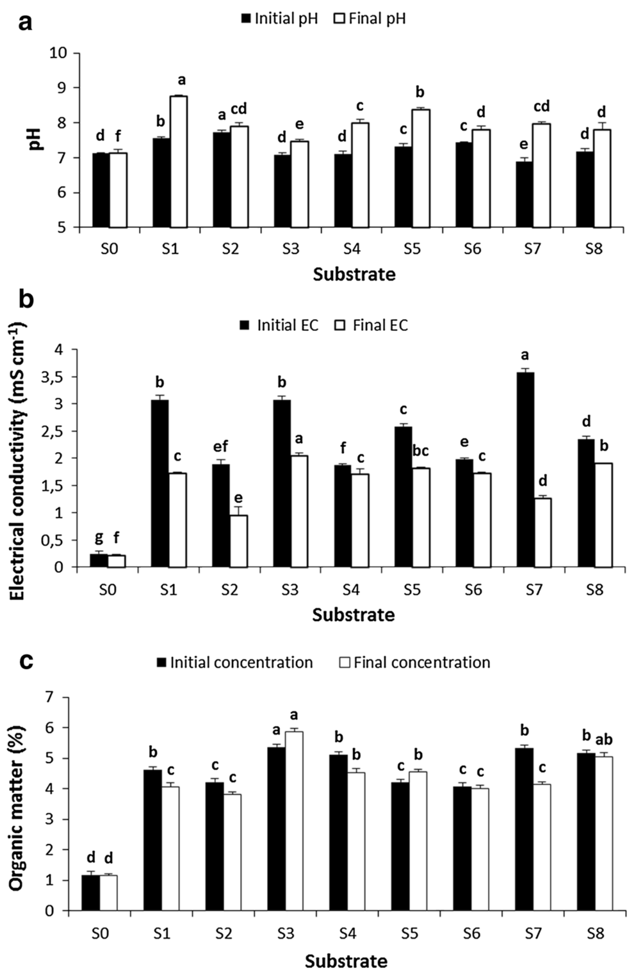

Fig. 2 Evolution of pH (**a**), electrical conductivity (**b**), and organic matter (**c**) expressed in percentage of DM of the experimented substrates during tomato greenhouse culture (n = 10; α = 0.05). *C* compost, *M* goat manure, *P* crushed palm; S0 = S (100%); S1 = M (30%) + Soil (70%); S2 = M (20%) + Soil (80%); S3 = M (30%) + Soil (65%) + P (5%); S4 = M (20%) + Soil (75%) + P (5%); S5 = C (30%) + Soil (70%); S6 = C (20%) + Soil (80%); S7 = C (30%) + Soil (65%) + P (5%); S8 = C (20%) + Soil (75%) + P (5%)

(Table 5). At the 0.05 level, this matrix exhibited strong correlation between soil's electrical conductivity and organic matter content as well as manure and compost rates, initial pH and seed germination. Finally, palm waste fibers were negatively correlated with initial pH and seed germination.

Discussion

The produced compost from palm waste and goat manure co-composting had a pH value within the range of 6.0–8.5 and an EC value lower than 3 mS/cm; these values are compatible with most plants growth needs [19]. The final C/N ratio value indicated the complete biodegradation and the stability of the substrate [20, 21]. Furthermore, according to the French organic conditioners standards, the studied compost could be described as vegetal compost with TKN and OM values inferior to 3 and 55%, respectively [22].

Greenhouse experiment was conducted on tomato (*Solanum lycopercicum* L.) seedling production. The differences observed in the seedling emergence rates brought by the substrates could be attributed to tomato nutrient needs. In fact, compost was previously reported to have a fine structure and large specific surface, thus providing strong absorbability and nutrient retention [23]. The produced compost was more suitable for tomato seed germination when used at 30% with crushed palm. Sellami [24] has also observed that tomato seed emergence rates were high when compost was incorporated at percentages equal to or less than 30% in the substrate. In the same context, Ali [25] reported that compost from date palm leaves and peat moss showed no significant difference in terms of their effects on seed germination.

The results revealed also significant difference between the substrate effects on seedling and tomato stem growth (Table 4). Seedling quality was assessed by length and diameter measurements. According to Haase [26], height/diameter is a sturdiness ratio. However, a high ratio indicates a relatively spindly seedling while a low ratio indicates a stouter seedling. Furthermore, seedlings with high ratios can be susceptible to damage resulting from handling, wind, drought and frost. The difference in seedling aerial growth could be ascribed to the substrate particle size considering the fact that the composting process is known to decrease particle size and increase water holding capacity [27]. More recently, Ghehsareh and Kalbasi [28] tested seven soil conditioners, including date palm waste, perlite and soil, in terms of their effects on cucumber cultivation and found that date palm waste induced the highest stem length rates.

In the present work, the produced compost seems to be the most efficient on tomato seedling, especially leaves number, when used at 30% in the substrate. A dissimilar result was reported by Ancuţa et al. [29] in a study using different types of composts for tomato seedlings production, where the maximum leaves number was observed when compost was used at a rate of 50% in the substrate.

In other studies dealing with compost and seedling, Chrysargyris et al. [30] found the highest leaves number per melon plant with substrate made of 15% municipal solid waste compost and 85% peat, under nursery conditions.

Likewise, El-Quesni et al. [31] tested the effects of some bio fertilizers and composts (peanut compost and nil compost) on *Jatropha curcas* L. growth, particularly in terms of improving leaf number per plant. They noted that

Table 5 Correlation matrix between the experimental substrate and the studied parameters

Parameters	C	M	P	Soil	Sger	H	D	H/D	LN	RL	pHi	pHf	ECi	ECf	OMi	OMf
C	1.000															
M	−0.667*	1.000														
P	0. 091	0.091	1.000													
Soil	−0.035	−0.035	0.529	1.000												
Sger	−0.137	0.201	0.792*	0.521	1.000											
H	−0.381	0.561	−0.417	0.032	−0.375	1.000										
D	−0.275	0.579	−0.253	−0.057	−0.370	0.831**	1.000									
H/D	−0.065	−0.160	−0.258	0.169	0.001	0.162	−0.412	1.000								
LN	−0.448	0.735*	−0.034	0.420	0.149	0.768*	0.679*	0.039	1.000							
RL	0.277	0.159	0.305	0.501	0.248	0.253	0.109	0.217	0.508	1.000						
pHi	−0.104	0.374	−0.744*	−0.388	−0.680*	0.755*	0.726*	−0.016	0.461	−0.070	1.000					
pHf	0.029	0.172	−0.202	0.423	0.158	0.529	0.359	0.258	0.704*	0.427	0.400	1.000				
ECi	0.155	−0.015	0.412	0.922*	0.347	0.190	0.200	−0.08	0.536	0.620	−0.140	0.579	1.000			
ECf	0.356	0.047	0.401	0.629	0.410	−0.066	−0.080	0.097	0.326	0.450	−0.041	0.474	0.685*	1.000		
OMi	0.203	0.275	0.645	0.749*	0.531	0.141	0.218	−0.132	0.558	0.701	−0.140	0.464	0.847**	0.812**	1.000	
OMf	0.224	0.211	0.566	0.714*	0.412	0.080	0.080	0.036	0.433	0.569*	−0.088	0.344	0.756*	0.920**	0.919**	1.000

C compost; *pHf* final pH, *ECf* final electrical conductivity, *OMf* final organic matter, *pHi* initial pH, *ECi* initial electrical conductivity, *OMi* initial organic matter, *LN* leaves number, *M* goat manure, *PH* plant height, *P* palm waste, *RL* root length; *Sger* seed germination; *soil* soil rate

* $P < 0.05$

** $P < 0.01$

when the two types of compost were used, the leaf number per plant was doubled.

In the present study, the recorded results in terms of seed germination percentages and leaf number indicated that the best rates could be achieved with manure and crushed palm waste at 20 and 5% rates then with compost and crushed palm waste at 30 and 5% respectively. However, for the root length, the main organ providing plant nutriment, the highest length was achieved on the produced compost based on palm waste and goat manure. Indeed, previous study showed that compost better ensured tomato root elongation rates and protected the plants from the root rot disease caused by *Fusarium oxysporum f.* sp and *Radicis lycopersici* [32]. In another study, Ribeiro et al. [33] reported that *Pinus pinea* L. cultivated on 100% compost had the most important root dry weight compared to the control and other substrate compositions based on compost and peat.

The slightly increase observed in the final substrate pH could be attributed to sulphide oxidation during the mineralization of OM labile forms, which might have changed the growth substrate redox potential state [34]. Indeed, relatively high pH values ranging between 7.0 and 8.5 are usually related to the presence of Ca and Na salts and are well tolerated by plants [35]. The telluric microorganisms' activity and the root respiration could have also contributed to the pH increase, which has previously been reported to lead to CO_2 build-up in the rhizosphere [36]. The present results also indicated that the pH increase was generally proportional to the palm waste compost rate applied, which could presumably be due to the carbon mineralization, the subsequent OH^- ions production by ligand exchange, and the basic cations introduction, such as K^+, Ca^{2+} and Mg^{2+} [37].

The EC values were noted to decrease during tomato seedling growth, reflecting the exhaustion of the nutrient medium and the depletion of mineral elements by the plants, with the emergence of leaching fractions resulting from irrigation. This decrease in EC values could presumably be related to the high EC values of the organic waste compounds, and is in agreement with the results previously reported by Kammoun and Medhioub [35] for tomato culture in anthropic soils. A similar effect was previously reported by Herrera et al. [38]. The present findings revealed that the substrate composition including 30% compost and 5% crushed palm was more suitable for tomato plants seedling by offering the required nutrients (organic matter and minerals) and the adequate growth conditions with the highest initial EC and the lowest EC values compared to the other substrates (Fig. 2b). This condition would be the best one for seedling emergence, leading to vigorous plants.

Furthermore, Herrera et al. [38] reported that high substrate EC values reduced water retention when municipal solid waste compost and other additives, such as old and white peat, were used as a growing media for tomato nursery cultivation. Likewise more recently, Ouni et al. [37] showed that date palm waste compost induced a high increase in the soil EC when applied at rates ranging from 50 to 150 t ha^{-1}, which could be ascribed to the high K^+ and Ca^{2+} content rates.

Actually, several studies have previously reported that compost addition improved soil quality. The decrease in OM content could be attributed to the soluble OM leaching and its assimilation by the telluric microorganisms during the first seedling development stages [39]. Furthermore, in their study on the compost effects on soil carbon content, Ouni et al. [37] showed that palm waste compost increased the carbon content in saline soil because of its high OM content. Accordingly, date palm waste could be considered as an efficient promising alternative for soil organic amendment and saline soil remediation, used both for compost preparation as well as a structuring agent for tomato seedling.

Conclusion

The present study aimed to investigate the feasibility of palm waste valorization through composting and the application effects of the produced compost as a growing medium for tomato seedling production under greenhouse nursery conditions. The results indicated that the produced compost based on palm waste and goat manure could be used as an efficient organic amendment for tomato seedling growth, since its use could reduce the application of manure and other chemical fertilizers. Indeed, the obtained compost from manure and crushed date palm waste improved the seed germination percentage and the plant root elongation rate when used as an additive to the different investigated substrate compositions. In the present work, the analysis of the different experimented substrates proved that the date-palm waste compost addition improved the soil quality by increasing its OM, as well as the tomato seedling potential. Considering the high availability and the low cost of date palm waste in several countries cultivating date palm trees, the composting of this agricultural by-product could offer a sustainable cost-effective and eco-friendly process to ensure the biological fertilization of OM deficient soils.

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