Emirates Journal of Food and Agriculture. 2023. 35(2): 121-129
doi: 10.9755/ejfa.2023.v35.i2.3012
http://www.ejfa.me/

RESEARCH ARTICLE

# Stability and maturity indexes of organic fraction compost

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## ABSTRACT

Composting is an environmentally friendly way to turn wastes into useful product (compost). This study aimed to monitor various chemical, physical, and biological parameters over the course of the co-composting of three organic compounds. In this context, 55 kg (55%) of green waste (GW) were co-composted with 40 kg (40%) of poultry manure at 40 kg (40%) and 5 kg (5%) green waste biochar (GWB). The monitoring of this experiment continues until the final product is stable. According to several previous studies, it was generally agreed that it was better to employ a combination of multiple tests to be sure that the compost has really reached a state of maturity and stability. During this study, a series of tests were used to determine the maturity and stability of co-composting organic wastes for safe use. Tests used during this follow-up include the pile temperature, pile moisture, pH, total nitrogen, total carbon, C/N ratio, microbial activity ($CO_2$ emission), germination index, and a scanning electron microscopy. According to the results of tests carried out during this experiment, the compost had attained maturity on the 54$^{th}$ day from the beginning of the composting.

**Keywords:** co-composting; Green waste; Biochar; Poultry manure; Maturity; Stability

## INTRODUCTION

The rapid rise in local population, especially in developing countries, causes a higher increase in solid wastes which will constitute a major environmental dilemma for these countries (Mishra & Yadav, 2021; Chaher et al., 2021). In Tunisia, green waste represent 68% of the total solid waste, but only 5% is transformed into compost (Achiba et al., 2009; ANGED, 2021). Despite this small portion of composted waste, the Tunisian government tried to organize the composting process with Law number 96-41of June 1996 relating to waste control, its management, and its disposal. After that, the appearance of Circular number 15 of June 17, 2009, from the Ministers of Environment, Sustainable Development and Tourism, relating to the collection of green waste, food residues and their composting. In 2013, the development of a Tunisian standard on the specificities and quality of compost NT 10.44, proposed by the agency for the attention of the Technical Committee of the National Institute for Standardization and Industrial Property. As a result of these government incentives, composting has received growing attention as a biological process and an acceptable means of removing and using organic wastes as a soil amendment (Jara-Samaniego et al., 2017; Meyer-Kohlstock et al., 2015; Paredes et al., 2002). Recent research has demonstrated that the composting of diverse organic compounds can shorten the composting period and lead to a nutrient-balanced product (Chaher et al., 2021; Feng & Zhang, 2021). Recently, the use of biochar in compost has been of great interest since it affects compost's processes and qualities (Petric et al., 2012; Paredes et al., 2002; Das et al., 2011; Malinowski et al., 2019).

Biochar is derived through biomass pyrolysis. Biochar, as an organic soil amendment, can increase the availability of nutrients (Ajayi & Horn, 2016; Karbout et al., 2019), enhance the physical properties of the soil (Barnes et al., 2014; Mohawesh & Durner, 2019), and increase crop yields (Ali et al., 2017; J. Zhang et al., 2021). Most of these effects are associated with the valuable physical and chemical properties of biochar, in particular the high specific surface area (Mohawesh & Durner, 2019; J. Zhang et al., 2021). Likewise, Agyarko-Mintah et al. (2017); Malinowski et al. (2019); and Zhou et al. (2021) highlighted the role of biochar because of its favorable physical and chemical properties in improving the composting process. Hua et al. (2009) and López-Cano et al. (2016) showed that the co-composting of an amount between 3% and 5% of biochar with other organic wastes

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**Received:** 20 August 2022; **Accepted:** 30 January 2023

can activate the maturity of compost, decrease the smell, and activate the microbiological community. Also, recent studies by Malinowski et al. (2019) and Zhou et al. (2021) have confirmed that the use of biochar in the composting process at a percentage of 1.2% to 6 % can accelerate the degradation of organic compounds while preventing greenhouse gas emissions and nitrogen losses. However, Liu et al. (2017) and Zhou et al. (2021) don't recommend the use of higher doses of biochar because of its negative impacts, in particular on the microbial community.

Various chemical, physical, and biological tests must be carried out on a regular basis throughout the composting process in order to determine the compost's maturity and stability (Azim et al., 2018; Liu et al., 2017; López-Cano et al., 2016; Schulz et al., 2013; Zhou et al., 2021). In fact, maturity determines the extent to which the organic matter is transformed during the co-composting process and the phytotoxicity of the end product (Y. Yuan et al., 2012; Alvarenga et al., 2015; Cesaro et al., 2015; Luo et al., 2018; Villaseñor et al., 2011; Oviedo-Ocaña et al. 2015; Viaene et al., 2017;Luo et al., 2018). In order to assess the compost's ecotoxicity, Huguier et al. (2015) adopted a direct approach based on solid phase tests and an indirect approach based on liquid phase tests evaluating sample extracts.

The main purpose this study is to convert organic waste available in the Institute of Arid Regions into a stable, non-toxic product ready for use as an organic amendment in degraded soils. In addition, the valorization of these wastes through composting can reduce the amount of waste produced and thus limit the costs associated with their disposal. In this context, the intent is to produce a stable organic material by co-composting 55 kg of green waste, 40 kg of poultry effluent, and 5 kg of green waste biochar. The final composting product will serve as an organic amendment to rehabilitate degraded soils and fight desertification. A variety of chemical, physical, and biological tests are used throughout the composting process to make sure that the compost reaches the desired stable and mature state.

## MATERIALS AND EXPERIMENTAL PROCEDURES

### Composting process

The research was carried out at the Institute of Arid Regions (IRA) of Medenine -South East of Tunisia (Fig. 1) (UTM WGS 8- X: 652587- Y: 3707742**)**.

The experiment consisted of the co-composting of three organic wastes, namely poultry manure green waste, and green waste biochar. The green waste consisted of fresh leaves and thin branches are collected from the pruning of green spaces in the Institute (table 1). All green waste was shredded into small pieces (≤ 1cm particle size) with an electric grinder (Fig. 2). The ground material was manually homogenized and sun-dried in an open environment for 2 weeks, then sieved through a 0.5x0.5 cm square mesh. Wastes larger than 5 mm in diameter were pyrolyzed as recommended by Domene et al. (2015); Karbout et al. (2019); Lu et al. (2013); Han et al. (2016); Laghari et al. (2016); and Méndez et al. (2013) in a continuous flow oven at temperatures of 350°C for 3 hours. The biochar obtained is characterized by a pH of around 7.63, contains 81.2% of organic matter (OM), contains 0.608% of $NH_4^+$, and has concentration of extractable phosphorus (P) and exchangeable potassium ($K^+$) of respectively 2.976 $mg.kg^{-1}$ and 407.446 mg $kg^{-1}$. With a water content of 5.19 %, the cation exchange capacity (CEC) was approximately 54.6 meq/100g.

After manually mixing with the following proportions: 55 kg, 40 kg, and 5 kg (by weight of dry matter), respectively, for the three elements: green waste (particle size < 0.5 cm), poultry manure (particle size < 0.5 cm), and biochar (green waste particle size ≥0.5 cm), the mixture was moved to the composting basin (Fig. 3).

The carbon-to-nitrogen ratio (C: N) of the mixture was equal to 36.6 at the beginning of the experiment, which was considered to be the optimal starting ratio for a composting (Sanchez-Monedero et al., 2018; Nekliudov and Fedotov, 2008). The raw material was composted from October 21 to December 25, 2019 (65 days). The process was conducted in a cement basin with the dimensions of width: 1m; length:1m; height: 1.5 m with a perforated bottom. For the effective metabolic activity of microorganisms, the moisture content was attempted to reach 40 % (Agnew & Leonard, 2013), and the composted material was irrigated regularly to ensure humidity conservation of at least 60%. To avoid material compaction, the mixture was turned with a spading fork every 3 days for the first week, and then whenever the recorded temperatures exceeded 60°C. The temperature was controlled daily using a digital probe thermometer, which was placed in the center and at both ends of the pile at a depth of 30 cm. Temperature measurements were taken until the pile temperature approached the ambient temperature (within a range of ±5°C).

### Sampling and laboratory tests

On the basis of monitoring the composting process, a representative sample of 1 kg was collected at a depth of 30 cm from the center and at both extremities of the pile at the beginning of the experiment ($T_0$) and at days 7, 14, 21, and 28, in three replications. These samples were the subject of different tests in the laboratory to determine the compost's stability and maturity (Tiquia, 2005a).


**Fig 1.** Localization of the experimental area.

**Fig 2.** Grinding green waste into small pieces with an electric shredder.

**Fig 3.** Mixing of the three organic compartments at 55 kg of GW, 40 kg of PM and 5 kg of GWB.

Indeed, the moisture of the mixture was determined gravimetrically at 105°C. The total organic carbon was quantified by the Walkley-Black method (Brewer & Sullivan, 2001; Schulte & Gibson, 2011). The pH and the electrical conductivity were evaluated on aquatic solutions prepared at a 1/10 (v/w) ratio, respectively, with a pH meter (Thermo Electron Corporation, Orion Star) and

**Table 1: Composition of the green waste feedstocks**

| Green waste | Fresh weight (kg) | % of the total weight |
|---|---|---|
| Fig tree branches and leaves | 35.20 | 15 |
| Citrus branches and leaves | 28.15 | 12 |
| Leaves and thin branches of vines | 35.20 | 15 |
| Palm tree waste | 58.65 | 25 |
| Cypress | 30.50 | 13 |
| Ficus leaves and thin branches | 46.92 | 20 |
| Total (kg) | 234,62 | 100 |

a conductivity meter (Inolab Cond Level 1). Volatile solids were valued with loss on ignition at 550 °C for 4 hours. The total nitrogen was calculated according to the Kjeldahl method (Icontec, 1997). The C/N ratio of the mixture was evaluated during the composting. The compost temperature was measured daily by using a digital thermometer (Vee Gee Scientific-83210-12; range: -50 to 150°C). The respirometric index was evaluated via the measurement of $CO_2$ production from the samples. The germination index was quantified using pepper seed according to Zucconi et al. (1982), and it was calculated using the following equation (Guo et al., 2012):

$$GI = 100 * \frac{\text{seed germination of treatment}(\%) X \text{root lengh of treatment}}{\left(\text{seed germination of control}(\%) X \text{rootlength of controltreatment}\right)}$$

## Data analysis

The data were examined with SPSS software to monitor temperature, moisture, pH, total carbon, total nitrogen, C/N ratio, and $CO_2$ emission during the co-composting process. In addition, the data were presented for variance analysis (ANOVA), and the means were compared using the Turkey test ($P<0.05$) for the germination index.

## RESULTS AND DISCUSSION

### Variation of the pile temperature during the composting process

Composting is a natural procedure that takes place under the action of microbial activity to break down and stabilize the organic matter in waste (Hachicha et al., 2009). Temperature is an important factor that ensures and enhances the maturity of the compost. Also, an ideal temperature is required for the microbes to carry out the bioconversion of the organic compounds. As a result, the temperature was monitored daily during this study until the 65th day of treatment. As mentioned in Fig. 4, the composting process consists of three phases: a mesophilic stage followed by a thermophilic stage, and finally the cooling or maturation stage. The initial activation phase lasts 2 days and is marked by a sudden increase in temperature to reach 50.43°C (Fig. 4). This sudden rise may be explained by the mix of biochar to the raw organic waste materials, which can stimulate and accelerate the composting process with an abrupt rise in temperature at the beginning of the process (Khan et al., 2014; Zhang & Sun, 2014). Also, according to López-Cano et al. (2016) and Sanchez-Monedero et al. (2018), the presence of biochar in the pile increased compost pile aeration owing to its high porosity, favored the activation of the composting process, and boosted the temperature of the compost pile. The thermophilic phase started relatively quickly on the third day of the process, and the mesophilic microorganisms are progressively being replaced by thermophile bacteria, fungi, and actinomycetes with a gradual rise in temperature around 61.27°C on the fourth day. During this co-composting operation, the thermophilic phase lasted two weeks, and this is in accordance with the results of Liu et al. (2017), who mentioned that the co-composting of biochar with organic wastes accelerates and extends the high-temperature duration, which favors rapid mineralization during organic waste composting. In addition, Bernal et al. (2009) mentioned that the high $CO_2$ emission throughout the initial stage of co-composting (the thermophilic stage) is a reflection of the intensive microbial activity (Fig. 4). Finally, the temperature of the pile slowly decreases to enter the cooling stage, and the maturation stage is initiated at the ambient temperature (day 54) (Fig. 4), and a stabilized product is obtained (González et al., 2019). The results of pile temperature obtained in the current study are corroborated with results attained during previous research conducted by Sanchez-Monedero et al. (2018) and Zhou et al. (2021).

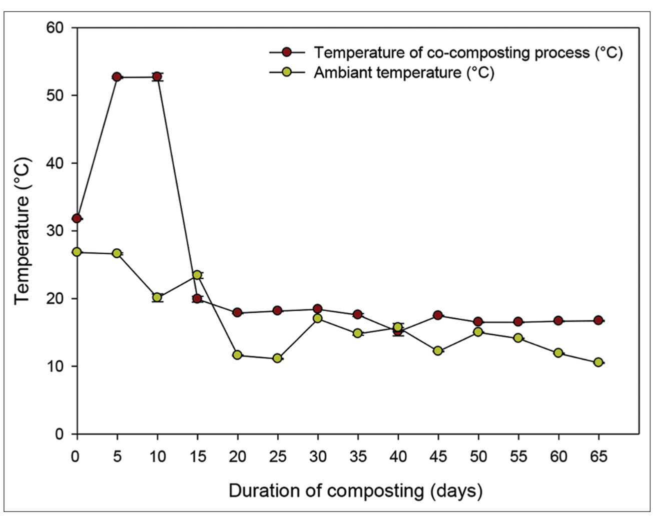


**Fig 4.** Temperature variation of co-composted materials in relation to the ambient temperature.

### Variation of the pile moisture during the composting process

The humidity content of the organic compounds is essential for proper microbial activity during composting. Indeed, humidity causes several biological, physical, and chemical effects during the operation of composting. Various recent researchers have suggested that preserving water content between 50 and 70% is perfect for high-quality compost (Mishra & Yadav, 2021). As a result, moisture content monitoring is required to ensure an adequate amount of water content and, thus, aerobic degradation of organic compounds throughout the composting process. Fig. 5 showed that the water content of the pile decreased continuously during the composting. The initial moisture content exceeded a value of 50%, which dropped to around 40% at the end of composting. The high reduction in moisture observed during the thermophilic phase (Fig. 5) is due to increased microorganism activity. The compost

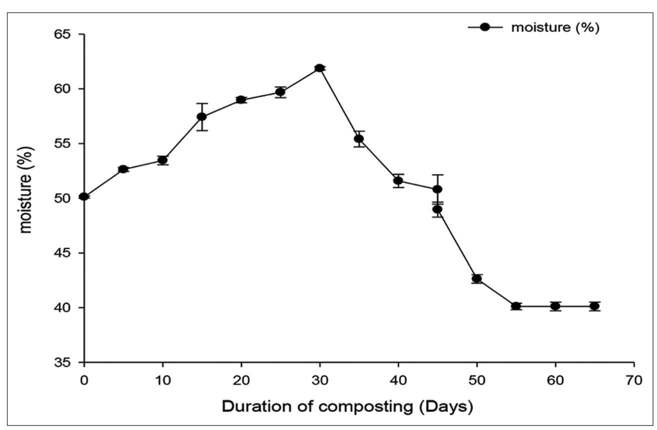


**Fig 5.** Variation of the pile moisture over time during the co-composting materials.

was irrigated when the moisture of the pile reached a minimum of 40% for the survival of microbes (Mishra & Yadav, 2021).

A decrease in moisture toward the end of composting is predicted as microbial activity diminishes and the compost reaches maturity. According to Barthod et al. (2018), a high moisture content favors anaerobic conditions, influences the oxygen uptake rate, limits the microbial activity, and thus decreases the degradation rate of the compost. Richard et al. (2013) claimed that the optimal water content for organic matter biodegradation has been estimated to be between 50 and 70%. On the contrary, Razmjoo et al. (2015) reported that a water content between 45 and 50% is suitable for the composting process. Misra et al. (2003) cited that the optimal moisture content of the pile should be within the range of 40% to 65%. In fact, microbial activity is limited when the moisture in the compost is less than 40%, and anaerobic degradation is favored when the moisture is greater than 65%.

### pH variation throughout the composting process

According to Fig. 6, the pH ranged between 5.4 and 8.91, which is sufficient for various microbes to work efficiently (Benito et al., 2005). The pH value became more neutral in the maturation phase and reached 7.5 (Gómez-Brandón et al., 2008). According to Mustin (1987), this pH decrease may be explained by the production of organic acids following the degradation of sugars, lipids, and other substances existing in the compost. Additionally, $CO_2$ production during aerobiological degradation contributes to environmental acidification (Mustin, 1987).

### Total carbon variation throughout the composting

Fig. 7 shows that the total organic carbon content diminished slightly during the thermophilic phase of composting. On the fifty-fifth day of the composting process, the carbon content dropped from 50.68% to 30.5%, indicating that the thermophilic phase had ended (Fig. 7). At the maturity stage, the total organic carbon content remains steady from the fifty-fifth day of the composting, which indicates that the compost has reached its stability stage. These results are consistent with those of Mishra and Yadav (2021).

### Variation in total nitrogen levels during composting

Fig. 8 shows that the total nitrogen augmented slightly from the tenth day of the composting process and reached a value of 1.8% at about the fifty-fourth day since the beginning of the experiment. This rise in the total azote percentage may be explained by the nature of the starting elements, especially the poultry manure, which is high in azote fermentables. In harmony with Mustin (1987), the increase in the percentage of total nitrogen is due to the breakdown of the proteins in the starting materials by the heat and action of the microorganisms. This increase is under the influence of the microbes and bacterial residues that have proliferated, particularly during the first stage of the experiment.

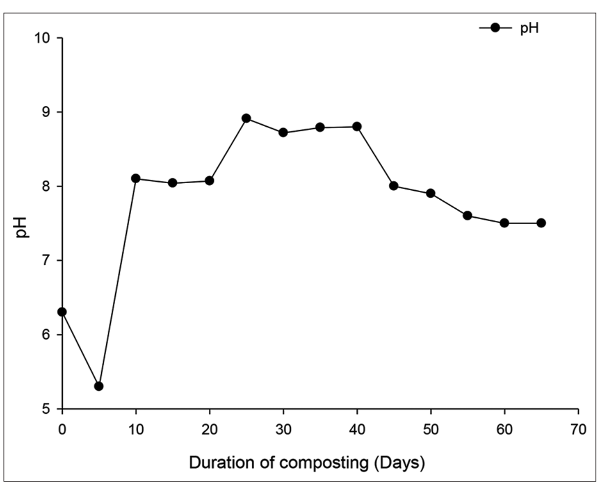


Fig 6. pH measurement over time in the compost.

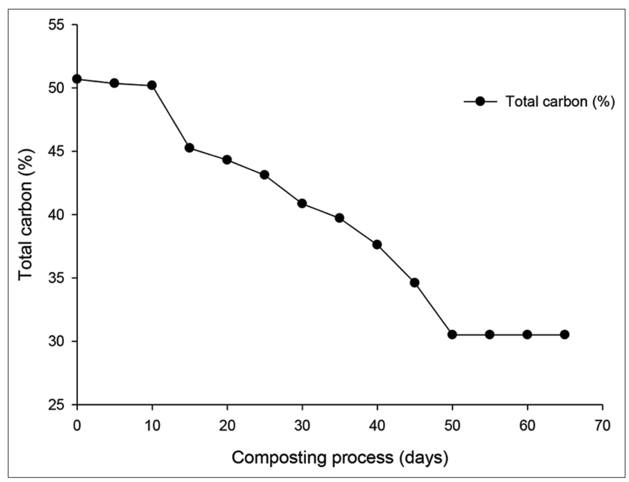


Fig 7. Variation in total carbon throughout the composting.

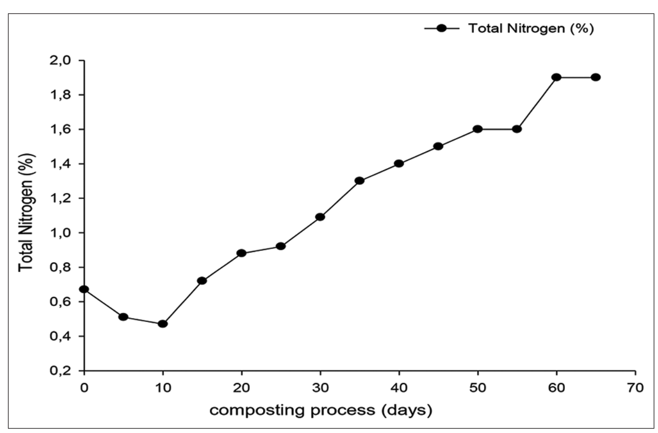


Fig 8. Total nitrogen variation throughout the composting.

### Variation of the C/N ratio of the compost

Nitrogen, carbon, and the C: N ratio are the major indices for the assessment of the stability of the compost (Elango et al., 2009; Yuan et al., 2015). In fact, for perfect composting, a C/N ratio of 25 to 30 is recommended (Feng & Zhang, 2021). The C/N variation in compost reflects compost stabilization (Khalil et al., 2008). Based on previous research, a final C/N below 25 indicates that compost reaches maturity (Alvarenga et al., 2015). Results in Fig. 9 indicate that the composting of 55 kg of green waste, 40 kg of poultry manure, and 5kg of green waste biochar was slightly higher in the beginning (36.6), then exhibited an apparent decrease with a value of 10.3 at the end of the experiment (Fig. 9). Wang et al. (2021) claimed that the smaller the C/N ratio, the better the quality of compost. Vuorinen and Saharinen, (1997) proposed that the compost had reached maturity when T was <0.6 ($T=(C/N)_{final}/(C/N)_{initial}$).

### Variation of the $CO_2$ emissions from the pile throughout the experiment

Results in Fig. 10 present the $CO_2$ emissions from the compost during the aerobic composting process. The first stage is distinguished by intense microbial activity, which began a few hours after the composting started and reached a maximum of 5600 mg.$CO_2$/kg compost on the third day. This peak was linced to an increase in the biodegradation of easily degradable compounds. According to Fig. 10, a slight decrease was detected in the emission of $CO_2$ due to the overturning of the pile on the third day of composting. Then, a second raise was reached after 14 days of composting. Subsequently, the emission of $CO_2$ decreased sharply and then stabilized around the 28th day, showing a slowing of biological activity, which indicates the compost's ripeness despite the turning over of the compounds. In conformity with previous research by Goyal et al. (2005) and Brewer & Sullivan (2001), we can confirm that our compost has reached its maturity degree. Goyal et al. (2005) mentioned a value of 500 mg $CO_2.100g^{-1}$ as an index of the compost's maturity, whereas Brewer & Sullivan (2001) presented a rate of 6 mg $CO_2.g^{-1}$ carbon (C). $day^{-1}$.

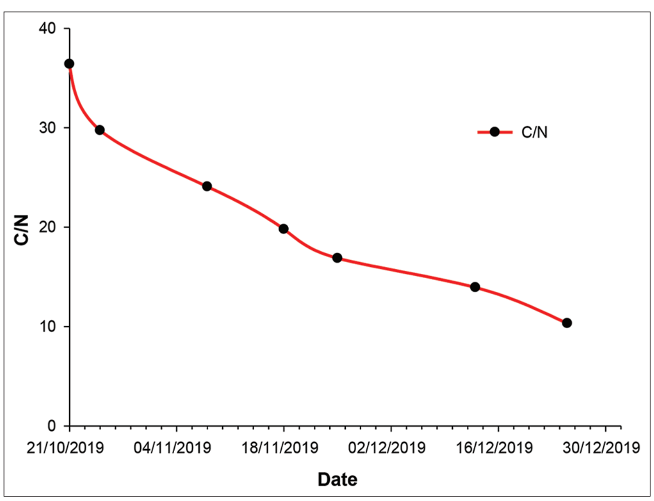


Fig 9. The C: N ratio variation during composting.

### Variation of the germination index of the compost

According to Bernal et al. (2009) and Komilis (2015), the germination index can be affected by the use of an immature compost because of the presence of phytotoxic substances. Fig. 11 and Table 2 show, respectively, the results of the germination index and medium-length root of Baklouti pepper seeds (a local variety in south Tunisia) in the extracts of different organic compounds and compared with the control (water). The results of the germination index (Fig. 11) indicated that seed germination exceeded 70% in the extracts of compost and biochar, and it was higher in the extracts of compost compared to biochar and the control. The results of Table 2 show that the highest medium length is recorded for seeds sprouted in the compost extract, followed by seeds sprouted in the

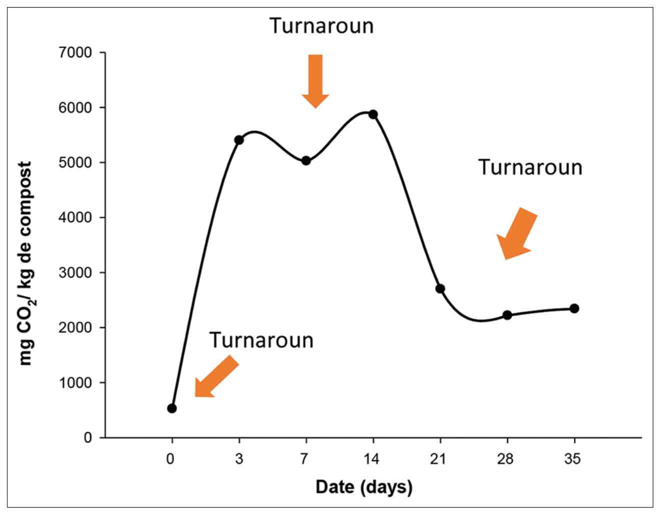


Fig 10. Variation of the $CO_2$ emissions from the pile during the co-composting materials.

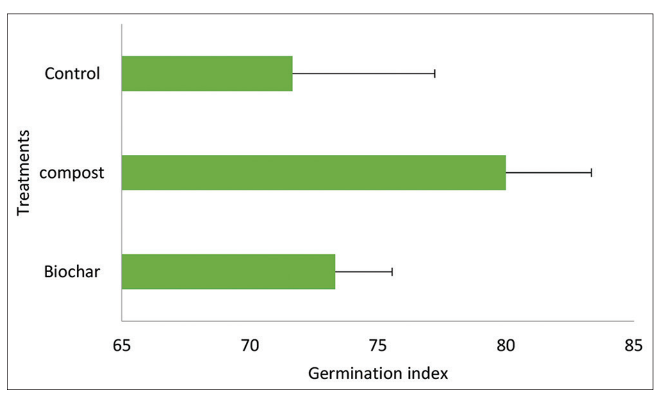


Fig 11. Germination index of Baklouti pepper seeds sprouted in different extracts of organic compounds.

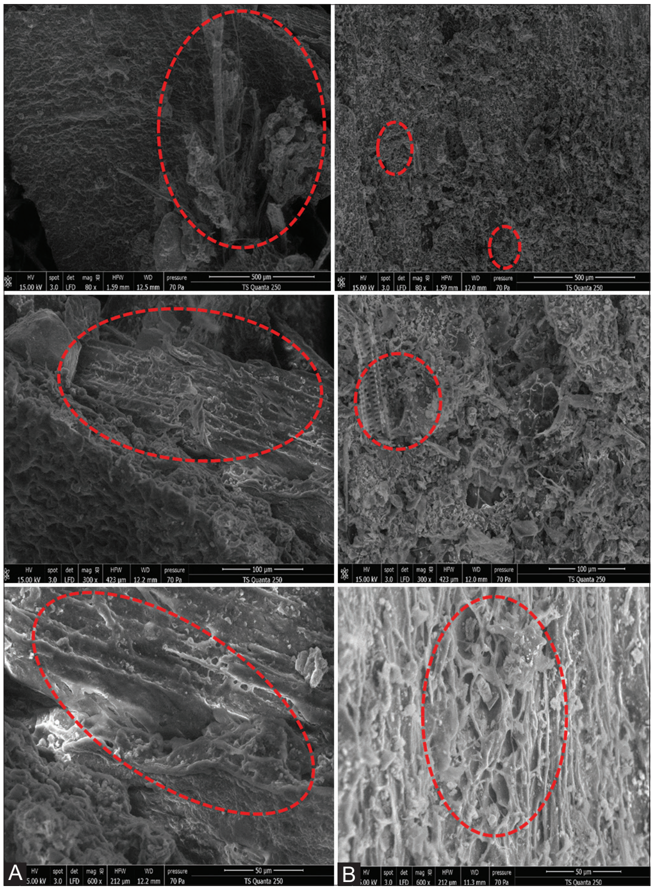


**Fig 12.** MEB Observation of different amendment: Compost (A) and Biochar (B).

**Table 2: Medium-length root of Baklouti pepper seeds sprouted in different extracts of compost and biochar**

| | Distilled watter (control) | Extracts of compost | Extracts of biochar |
|---|---|---|---|
| medium- length root | 0.94±0.16 | 0.97±0.21 | 0.95±0.16 |

extract biochar, and finally the seeds sprouted in the distilled water (control). The medium lengths are, respectively, 0.97 cm, 0.95 cm, and 0.94 cm for seeds sprouted in extracts of compost, biochar, and distilled water. According to Luo et al. (2018), our findings show that compost and biochar are not toxic and don't prevent the pepper seeds' germination. In accordance with Guo et al. (2012) and Jagadabhi et al. (2019), the seed's germination reflects both the maturity and the toxicity of the compost. Zucconi et al. (1981) suggested the employment of biological tests to check the toxicity of compost and assumed that the compost is deemed non-toxic when the seed germination value is greater than 50%. According to Tequila (2005b) and Rashad et al. (2010), the compost reaches maturity when the germination index is >80%.

### Scanning electron microscopy analysis

Scanning Electron Microscopy is a technique that produces high-resolution images by scanning the surface of samples with a focused beam of electrons. The physical characteristics of compost and biochar are conditioned by the chemical composition of the organic compounds. According to Fig. 12, the Scanning Electron Microscopy images illustrated that the mean pore size from the six SEM images of compost and biochar and particles ranged from 12.5 to 12.2mm (sd± 0.3mm) to 12.1 to 11.3 mm (sd±0.9 mm). The pores were highly elliptical, depending on their orientation and measurements, indicating that the original porous structure of the wood feedstock had become distorted during pyrolysis. Furthermore, the pore size distribution was greatly asymmetric, with 95% of pores being smaller than 212 μm (Fig. 12). Finally, the disparity in porosity observed in Fig. 12 depends on the processes of composting and biochar fabrication.

## CONCLUSION

This study examined different parameters for evaluating the compost's maturity and stability. The final compost's main physical, chemical, and biological properties assert that it has achieved stability and maturity. Results indicated that the compost temperature reached the ambient temperature on the $54^{th}$ day. Also, the pile moisture confirmed that the compost had reached the maturation phase. The C/N ratio reached 10.3 and $T = 0.28$ on the $54^{th}$ day, indicating that the compost had matured. The germination index test proved that the compost was nontoxic, reaches maturity (GI = 80%), and couldn't have negative effects on soil or plant health.

According to previous research on the use of biochar and the results obtained during this study, we can note that the incorporation of biochar (at low rates) to other organic residues (green waste and poultry manure, etc.) at the beginning of the composting process can speed up the operation by promoting the microbial communities and their activities. All these results require further research by testing other rates and types of biochar. More research is needed, however, on biochar as an organic amendment, biochar residence time, and the pyrolysis temperature of biochar.

### Authors contributions

Habib Lamourou: formal analysis, methodology, writing original draft. Nissaf Karbout: conceptualization, formal analysis. Zied Zriba: visualization. Inès Rahma Zoghlami: visualization. Mohamed Ouessar: supervision. Mohamed Moussa: validation, funding acquisition, supervision.

## REFERENCES

Nekliudov, A. D., G. N. Fedotov and A. N. Ivankin. 2008. Intensification of composting processes by aerobic microorganisms: A review.

Prikl. Biokhim. Mikrobiol. 44: 9-23.

Achiba, W. B., N. Gabteni, A. Lakhdar, G. D. Laing, M. Verloo, N. Jedidi and T. Gallali. 2009. Effects of 5-year application of municipal solid waste compost on the distribution and mobility of heavy metals in a Tunisian calcareous soil. Agric. Ecosyst. Environ. 130: 156-163.

Agnew, J. M. and J. J. Leonard. 2013. The physical properties of compost. Comp. Sci. Utiliz. 11: 238-264.

Agyarko-Mintah, E., A. Cowie, L. Van Zwieten, B. P. Singh, R. Smillie, S. Harden and F. Fornasier. 2017. Biochar lowers ammonia emission and improves nitrogen retention in poultry litter composting. Waste Manag. 61: 129-137.

Ajayi, A. E. and R. Horn. 2016. Comparing the potentials of clay and biochar in improving water retention and mechanical resilience of sandy soil. Int. Agrophy. 30: 391-399.

Ali, S., M. Rizwan, M. F. Qayyum, Y. S. Ok, M. Ibrahim, M. Riaz, M. S. Arif, F. Hafeez, M. I. Al-Wabel and A. N. Shahzad. 2017. Biochar soil amendment on alleviation of drought and salt stress in plants: A critical review. Environ. Sci. Pollut. Res. 24: 12700-12712.

Alvarenga, P., C. Mourinha, M. Farto, T. Santos, P. Palma, J. Sengo, M. C. Morais and C. Cunha-Queda. 2015. Sewage sludge, compost and other representative organic wastes as agricultural soil amendments: Benefits versus limiting factors. Waste Manag. 40: 44-52.

ANGED. 2021. ANGED : Agence Nationale de Gestion des Déchets. Available from: https://www.anged.nat.tn/index.php?option=com_content&view=article&id=146 [Last accessed on 2021 Nov 08].

Azim, K., B. Soudi, S. Boukhari, C. Perissol, S. Roussos and I. T. Alami. 2018. Composting parameters and compost quality: A literature review. Org. Agric. 8: 141-158.

Barnes, R. T., Gallagher, Masiello, Z. Liu and B. Dugan. 2014. Biochar-induced changes in soil hydraulic conductivity and dissolved nutrient fluxes constrained by laboratory experiments. PLoS One, 9: 108340.

Barthod, J., C. Rumpel and M. F. Dignac. 2018. Composting with additives to improve organic amendments. A review Composting with additives to improve organic amendments. A review. Agron. Sustain. Dev. 38: 17.

Benito, M., A. Masaguer, A. Moliner, N. Arrigo, R. M. Palma and D. Effron. 2005. Evaluation of maturity and stability of pruning waste compost and their effect on carbon and nitrogen mineralization in soil. Soil Sci. 170: 360-370.

Bernal, M. P.,J. A. Alburquerque and R. Moral. 2009. Composting of animal manures and chemical criteria for compost maturity assessment. A review. Bioresour. Technol. 100: 5444-5453.

Brewer, L. J. and D. M. Sullivan. 2001. Maturity and Stability Evaluation of Composted Yard Debris. Available from: https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/fb494d59n?locale=en

Cesaro, A., V. Belgiorno and M. Guida. 2015. Compost from organic solid waste: Quality assessment and European regulations for its sustainable use. Resour. Conserv. Recycl. 94: 72-79.

Chaher, N. E. H., M. Chakchouk, A. Nassour, M. Nelles and M. Hamdi. 2021. Potential of windrow food and green waste composting in Tunisia. Environ. Sci. Pollut. Res. 28: 46540-46552.

Das, M., H. S. Uppal, R. Singh, S. Beri, K. S. Mohan, V. C. Gupta and A. Adholeya. 2011. Co-composting of physic nut (*Jatropha curcas*) deoiled cake with rice straw and different animal dung. Bioresour. Technol. 102: 6541-6546.

Domene, X., A. Enders, K. Hanley and J. Lehmann. 2015. Ecotoxicological characterization of biochars: Role of feedstock and pyrolysis temperature. Sci. Total Environ. 512-513: 552-561.

Elango, D., N. Thinakaran, P. Panneerselvam and S. Sivanesan. 2009. Thermophilic composting of municipal solid waste. Appl. Energy. 86: 663-668.

Feng, X. and L. Zhang. 2021. Vermiculite and humic acid improve the quality of green waste compost as a growth medium for *Centaurea cyanus* L. Environ. Technol. Innov. 24: 101945.

Gómez-Brandón, M., C. Lazcano and J. Domínguez. 2008. The evaluation of stability and maturity during the composting of cattle manure. Chemosphere, 70: 436-444.

González, D., J. Colón, D. Gabrieland A. Sánchez. 2019. The effect of the composting time on the gaseous emissions and the compost stability in a full-scale sewage sludge composting plant. Sci. Total Environ. 654: 311-323.

Goyal, S., S. K. Dhull and K. K. Kapoor. 2005. Chemical and biological changes during composting of different organic wastes and assessment of compost maturity. Bioresour. Technol. 96: 1584-1591.

Guo, R., G. Li, T. Jiang, F. Schuchardt, T. Chen, Y. Zhao and Y. Shen. 2012. Effect of aeration rate, C/N ratio and moisture content on the stability and maturity of compost. Bioresour. Technol. 112: 171-178.

Hachicha, S., F. Sellami, J. Cegarra, R. Hachicha, N. Drira, K. Medhioub and E. Ammar. 2009. Biological activity during co-composting of sludge issued from the OMW evaporation ponds with poultry manure-physico-chemical characterization of the processed organic matter. J. Hazard. Mater. 162: 402-409.

Han, L., K. S. Ro, K. Sun, H. Sun, Z. Wang, J. A. Libra and B. Xing. 2016. New evidence for high sorption capacity of hydrochar for hydrophobic organic pollutants. Environ. Sci. Technol. 50: 13274-13282.

Hua, L., W. Wu, Y. Liu, M. B. McBride and Y. Chen. 2009. Reduction of nitrogen loss and Cu and Zn mobility during sludge composting with bamboo charcoal amendment. Environ. Sci. Pollut. Res. 16: 1-9.

Huguier, P., N. Manier, L. Chabot, P. Bauda and P. Pandard. 2015. Ecotoxicological assessment of organic wastes spread on land: Towards a proposal of a suitable test battery. Ecotoxicol. Environ. Saf. 113: 103-111.

Instituto Colombiano de Normas Técnicas y Certificación (Icontec). 1997. Norma Técnica Colombiana 370, Abonos o Fertilizantes-Determinación de Nitrógeno Total. ICONTEC, Bogotá, Colombia.

Jagadabhi, P. S., S. P. Wani, M. Kaushal, M. Patil, A. K. Vemula and A. Rathore. 2019. Physico-chemical, microbial and phytotoxicity evaluation of composts from sorghum, finger millet and soybean straws. Int. J. Recycl. Organ. Waste Agric. 8: 279-293.

Jara-Samaniego, J., M. D. Pérez-Murcia, M. A. Bustamante, A. Pérez-Espinosa, C. Paredes, M. López, D. B. López-Lluch, I. Gavilanes-Terán and R. Moral. 2017. Composting as sustainable strategy for municipal solid waste management in the Chimborazo Region, Ecuador: Suitability of the obtained composts for seedling production. J. Clean. Prod. 141: 1349-1358.

Karbout, N., N. Brahim, R. Bol, M. Moussa and H. Bousnina. 2019. Applying biochar from date palm waste residues to improve the organic matter, nutrient status and water retention in sandy oasis soils. J. Res. Environ. Earth Sci. 7: 203-209.

Khalil, A., M. Domeizel and P. Prudent. 2008. Monitoring of green waste composting process based on redox potential. Bioresou. Technol. 99: 6037-6045.

Khan, N., I. Clark, M. A. Sánchez-Monedero, S. Shea, S. Meier and N. Bolan. 2014. Maturity indices in co-composting of chicken manure and sawdust with biochar. Bioresour. Technol. 168: 245-251.

Komilis, D. P. 2015. Compost quality: Is research still needed to assess it or do we have enough knowledge? Waste Manag. 38: 1-2.

Laghari, M., R. Naidu, B. Xiao, Z. Hu, M. S. Mirjat, M. Hu, M. N. Kandhro, Z. Chen, D. Guo, Q. Jogi, Z. N. Abudi and S. Fazal. 2016. Recent developments in biochar as an effective tool for agricultural soil management: A review. J. Sci. Food Agric. 96: 4840-4849.

Liu, N., J. Zhou, L. Han, S. Ma, X. Sun and G. Huang. 2017. Role and multi-scale characterization of bamboo biochar during poultry manure aerobic composting. Bioresour. Technol. 241: 190-199.

López-Cano, I., A. Roig, M. L. Cayuela, J. A. Alburquerque and M. A. Sánchez-Monedero. 2016. Biochar improves N cycling during composting of olive mill wastes and sheep manure. Waste Manag. 49: 553-559.

Lu, H., W. Zhang, S. Wang, L. Zhuang, Y. Yang and R. Qiu. 2013. Characterization of sewage sludge-derived biochars from different feedstocks and pyrolysis temperatures. J. Anal. Appl. Pyrolysis. 102: 137-143.

Luo, Y., J. Liang, G. Zeng, M. Chen, D. Mo, G. Li and D. Zhang. 2018. Seed germination test for toxicity evaluation of compost: Its roles, problems and prospects. Waste Manag. 71: 109-114.

Malinowski, M., K. Wolny-Koładka and M. D. Vaverková. 2019. Effect of biochar addition on the OFMSW composting process under real conditions. Waste Manag. 84: 364-372.

Méndez, A., M. Terradillos and G. Gascó. 2013. Physicochemical and agronomic properties of biochar from sewage sludge pyrolysed at different temperatures. J. Anal. Appl. Pyrolysis. 102: 124-130.

Meyer-Kohlstock, D., T. Schmitz and E. Kraft. 2015. Organicwaste for compost and biochar in the EU: Mobilizing the potential. Resources. 4: 457-475.

Misra, R.V., R. N. Roy and H. Hiraoka. 2003. On-Farm Composting Methods. UN-FAO, Rome (Italy).

Mishra, S. K. and K. D. Yadav. 2021. Application of locally available microbial inoculant to accelerate green waste composting at a community level. Bioresour. Technol. Rep. 16: 100859.

Mohawesh, O. and W. Durner. 2019. Effects of bentonite, hydrogel and biochar amendments on soil hydraulic properties from saturation to oven dryness. Pedosphere. 29: 598-607.

Oviedo-Ocaña, E. R., P. Torres-Lozada, L. F. Marmolejo-Rebellon, L. V. Hoyos, S. Gonzales, R. Barrena, D. Komilis and A. Sanchez. 2015. Stability and maturity of biowaste composts derived by small municipalities: Correlation among physical, chemical and biological indices. Waste Manag. 44: 63-71.

Paredes, C., M. P. Bernal, J. Cegarra and A. Roig. 2002. Biodegradation of olive mill wastewater sludge by its co-composting with agricultural wastes. Bioresour. Technol. 85: 1-8.

Petric, I., A. Helić and E. A. Avdić. 2012. Evolution of process parameters and determination of kinetics for co-composting of organic fraction of municipal solid waste with poultry manure. Bioresour. Technol. 117: 107-116.

Rashad, F. M., W. D. Saleh and M. A. Moselhy. 2010. Bioconversion of rice straw and certain agro-industrial wastes to amendments for organic farming systems: 1. Composting, quality, stability and maturity indices. Bioresour. Technol. 101: 5952-5960.

Razmjoo, P., H. Pourzamani, H. Teiri, and Y. Hajizadeh. 2015. Determination of an empirical formula for organic composition of mature compost produced in Isfahan-Iran composting plant in 2013. Int. J. Environ. Health Eng. 4: 3.

Richard, T. L., H. V. M. (Bert) Hamelers, A. Veeken and T. Silva. 2013. Moisture Relationships in Composting Processes. Comp. Sci. Utiliz. 10: 286-302.

Sanchez-Monedero, M. A., M. L. Cayuela, A. Roig, K. Jindo, C. Mondini and N. Bolan. 2018. Role of biochar as an additive in organic waste composting. Bioresour. Technol. 247: 1155-1164.

Schulte, P. J. and A. C. Gibson. 2011. Hydraulic conductance and tracheid anatomy in six species of extant seed plants. Canad. J. Bot. 66: 1073-1079.

Schulz, H., G. Dunst and B. Glaser. 2013. Positive effects of composted biochar on plant growth and soil fertility Positive effects of composted biochar on plant growth and soil fertility. Agron. Sustain. Dev. 33: 817-827.

Tiquia, S. M. 2005a. Microbiological parameters as indicators of compost maturity. J. Appl. Microbiol. 99: 816-828.

Tiquia, S. M. 2005b. Microbiological parameters as indicators of compost maturity. J. Appl. Microbiol. 99: 816-828.

Viaene, J., V. Nelissen, B. Reubens, K. Willekens, F. Driehuis, S. De Neve and B. Vandecasteele. 2017. Improving the product stability and fertilizer value of cattle slurry solid fraction through co-composting or co-ensiling. Waste Manag. 61: 494-505.

Villaseñor, J., M. A. Pérez, F. J. Fernández and C. M. Puchalski. 2011. Monitoring respiration and biological stability during sludge composting with a modified dynamic respirometer. Bioresour Technol. 102: 6562-6568.

Vuorinen, A. H. and M. H. Saharinen. 1997. Evolution of microbiological and chemical parameters during manure and straw co-composting in a drum composting system. Agric. Ecosys. Environ. 66: 19-29.

Wang, C., J. Lv, J. Xie, J. Yu, J. Li, J. Zhang, C. Tang, T. Niu and B. E. Patience. 2021. Effect of slow-release fertilizer on soil fertility and growth and quality of wintering Chinese chives (*Allium tuberm* Rottler ex Spreng.) in greenhouses. Sci. Rep. 11: 8070.

Yuan, J., Q. Yang, Z. Zhang, G. Li, W. Luo and D. Zhang. 2015. Use of additive and pretreatment to control odors in municipal kitchen waste during aerobic composting. J. Environ. Sci. 37: 83-90.

Yuan, Y., Y. Tao, S. Zhou, T. Yuan, Q. Lu and J. He. 2012. Electron transfer capacity as a rapid and simple maturity index for compost. Bioresour. Technol. 116: 428-434.

Zhang, J., J. E. Amonette and M. Flury. 2021. Effect of biochar and biochar particle size on plant-available water of sand, silt loam, and clay soil. Soil Tillage Res. 212: 104992.

Zhang, L. and X. Sun. 2014. Changes in physical, chemical, and microbiological properties during the two-stage co-composting of green waste with spent mushroom compost and biochar. Bioresour. Technol. 171: 274-284.

Zhou, S., F. Kong, L. Lu, P. Wang and Z. Jiang. 2021. Biochar-an effective additive for improving quality and reducing ecological risk of compost: A global meta-analysis. Sci. Total Environ. 806: 151439.

Zucconi, F., A. Pear, M. Forte and M. D. Bertoldi. 1981. Evaluating toxicity of immature compost. Biocycle. 22: 54-57.