VALORIZATION OF LIGNOCELLULOSIC MATERIAL FROM DATE PALM WASTE (*Phoenix dactylefera* L.) ELHMIRA CULTIVAR BY COMPOSTING AS ORGANIC FERTILIZER

Abdelaziz ARROUSSI[1,2], Ahmed TAHRI[3], Slimane KALLOUM[1], Nassima ABDELLI[1], Nacira BOUZIANE[1]

The date palm constitutes the main crop of agriculture in the Saharan regions and offers a wide range of agricultural by-products, while the increase of date palm by-products production leads to accumulation of waste with harmful effects on environment. The main objective of this study is to valorize the lignocellulosic material of date palm waste (Phoenix dactylefera L.*) of petiole, dry palms, spathe, and flower stalk used as organic fertilizers by composting and biological treatment. The composts characterization study showed that the petiole substrate has an equal content of 536.4 mg / L of potassium, while the spathe substrate has equal content of 478.17 ppm, with regard to the phosphorus content. Hence, the cultivation test mentioned that the flower stalk exhibited a considerable bean plant biomass compared to other composts.*

Keywords: Date palm waste, Elhmira cultivar, lignocellulosic material, compost, organic fertilizer

1. Introduction

The management of organic waste represents a concern and a strategic orientation for all countries, in particular for Maghreb Arab countries after their commitment in national, Mediterranean and international environmental policies. These guidelines aim to encourage industrial development processes and clean production of agricultural and food. Therefore, waste is considered as one of the biggest scourges threatening the environment [1, 2].

Selective sorting now allows us to recycle plastics, glass, paper and cardboard. The rest still fill our trash bags. If you have a garden, branches, lawn mowing, dead leaves undoubtedly encumber you regularly, and getting rid of them is a real chore. However, there is a simple, ecological, economical and

[1] Laboratoire Energie, Environnement et Systèmes d'information Université Africane- Ahmed Draya- d'Adradr, Algérie.
[2] Laboratoire des ressources naturelles sahariennes, Université Africane- Ahmed Draya- d'Adradr, Algérie.
[3] Unité de Recherche en Energie Renouvelable en Milieu Saharien, URERMs, Centre de Dévelepment des Energies Renovlables, CDER, Adrar, Algeria

beneficial solution for us and for nature: composting [3]. The problem posed by the accumulations of date palm by-products on agricultural perimeters in Algerian oases, especially in *Adrar willaya*, which exports a very large quantity of this waste, and this comes down to the very large number of date palms (*Phoenix dactylifera* L.) planted (approximately 2,288,687 vines over an area of 16,405 hectares in intensive agriculture and 1,463,400 vines over 1.1469 hectares in extensive agriculture) in the 2014-2015 agricultural campaign. The date palm (*Phoenix dactylifera* L.) is the main component of the oasis agro-system. About 18 million date palms are cultivated in Algeria with a total area estimated at 169,380 hectares. In this culture of large quantity of date palms a lot of waste are produced, which can be responsible for the phytosanitary problems of oases, while efforts have been made to eliminate waste and reduce their impact on the environment [4].

On the other hand, agricultural intensification is increased in modern approaches with degradation of soils attributed to organic matter content. One of the most complex challenges is that crop residues are not returned to the soil, particularly during drought years when residues are exported from plots for livestock feed [5]. Our study consists in using the different vegetative organs of the date palm (*Phoenix dactilefera* L.) as compost. Four types of composts were made from the waste of the date palm, they are petiole, dry palm, spathe and flower stalk. Monitoring the composting process over 12 weeks from November to February by analyzing physico-chemical parameters (hydrogen potential; electrical conductivity; organic matter; total organic carbon; phosphorus; potassium) at the level of Ahmed Draya Adrar university laboratory and a renewable energy research unit laboratory in the Saharan environment. A test to sow the cow bean plant was started in the four compost separately in order to determine the maturation of these substrates. The study consists of following the growth of the plant biomass of the chosen plant.

2. Material and methods

Collection site of date palm by-products

The collection of by-products used on the petiole, dry palm, spathe, and floral stalk were carried out from a private garden in the province of Adrar located in the southern region of Algeria. The characteristics of garden are as follows:

- The total area: 1600 m2;
- The number of date palm: 50 feet;
- The age of the date palm: 25 years;
- Cultivars: Hemira

Experimental Site

The composting process was carried out in the greenhouse of Ahmad draya at Aurar university. The choose of greenhouse as an experimental site is to protect the composts against the winds and to ensure an optimal temperature.

Preparation of composts

The composting process was carried out based on different fermentable materials such as petiole, dry palm, spathe, and floral stalk. Fig. 1

Fig 1: Different fermentable materials.

The substrates were crushed using a grinder and sieved through a 2-millimeter screen in order to reduce the size and facilitate the fermentation process. The oxygenation of substrate is affected by the average particle. The different crushed substrates are then soaked in plastic buckets for five days. The water was poured gradually until each saturation of substrates. The quantity of water absorbed was related to the increase of volume of substrate during soaking operation. The purpose of this operation is to ensure humidity and facilitate fermentation process. [6] The composting operation was carried out in 08 plastic silos perforated on all four sides to ensure ventilation of substrate. The silos are lined with plastic bags to prevent rapid drying of substrate, loss of compost, and keep the humidity in optimum conditions necessary for composting. Then, an equivalent amount of Alfalfa was added in each silo to accelerate the composting process and increase the C/N ratio. Alfalfa plant is recognized by its high nitrogen content. [7]

3. Method of analysis of physico-chemical parameters

Temperature

Temperature evolution of the different composts was monitored throughout the composting period. With each measurement of compost temperature, we measured at the same time the ambient temperature in the greenhouse and also the ambient temperature outside the greenhouse. The temperature measurements were recorded using (HANA; model HI 95502) electronic thermometer.

pH measurement

The pH was measured in a suspension of organic material using a glass electrode on an aqueous extract of total organic material (2g / 20 mL), the water-biomass mixture was stirred beforehand for three hours, left to stand one hour before the pH measurement.

Electrical conductivity

Electrical conductivity provided information on the presence of soluble ions and salinity in the substrate. This measurement was carried out with 2 g of compost taken up in 20 ml of distilled water, the solution obtained is stirred for 15 minutes and left to settle for 20 minutes. The electrical conductivity of the supernatant was measured using a conductometer.

Humidity

The humidity level was determined on a sample of 100 g after drying in an oven at 105 ° C for 48 hours and then determining the dry matter content.

The evaporation of water up to constant weight was influenced by the drying conditions, which depend on air exhaust system, humidity of air, and quality of preservation in desiccator. The constant weight was obtained between two successive measurements. The humidity level was determined according to the following relationship:

$$\text{Humidity level } (\%) = 100 \times (Fw - Dw)/ Fw$$

Fw = fresh weight.
Dw = dry weight.

Organic matter

The level of organic matter was determined after calcining the samples in an oven for six hours at 600 ° C. After calcination, the combustion of organic matter was complete, which facilitates the determination of its content by simple difference between the weight before and after calcination. The organic matter was the loss of mass by combustion and calculated according to the following formula :

$$OM(\%) = 100 \times (Dw - Cw)/Dw$$

Dw: Weight of dry sample.
Cw: Weight of sample after calcination.

The percentage of total organic carbon was determined from the percentage of organic matter by applying the following relation:

$$OM(\%) = TOC\ (\%) \times 1.8$$

TOC : total organic carbon.

Assimilable phosphorus dosage

The assimilable phosphorus dosage was determined by the Joret-Hebert method.[8]

• ***Extraction***

A test portion of 4 g of soil passed through a 500 µm sieve and introduced into a 250 mL stirring flask. Then,100 mL of a 0.2 N ammonium oxalate solution of pH 6.5 to 7 was added under stirring for 2 hours then filtered. The filtrate solution was collected in 100 mL Erlenmeyer flask.

• ***Colorimetry:***

1.5 mL of extraction solution, 2 mL of sulfomolybdic reagent, and 6.5 mL of ascorbic acid were added in pyrex test tube then homogenized and placed in a water bath for 10 to 12 minutes, then cooled in open air then passed through a colorimeter at 580 nm. The reduction of phosphomolybdic acid was obtained by keeping the tubes in a boiling water bath for 10 min. After cooling, the solutions were colorimetered. Therefore, the reduction of phosphomolybdic required a minimum time of 5 minutes at 100 °C and 12 minutes at 80 °C. In addition, the intensity of the blue color of phosphomolybdic acid reduced did not change after prolonging the time of heating.

Calculations:

$$P_2O_5 \ en \ ppm = X.\frac{U}{v} \cdot \frac{V}{P} = X.\frac{1000}{6}$$

• X = concentration read on the graph in mg / l P_2O_5;
• U = 10 ml colorimeter volume;
• v = volume of test solution of 1.5 ml;
• V = volume of extraction solution of 100 ml;
• P = weight of soil extraction solution of 4g.

Determination of potassium

The determination of potassium dosage were performed via percolation by the method of Mathieu and Pieltain. [9]

Self-heating test

The self-heating test was carried out in a calorimeter of 50 g of wet organic material. The temperature was measured every six hours for three days. The maximum temperature reached after three days, noted Tmax, was monitored for each sample during the various turns. [10]

Study of sowing parameters

Germination test

In order to assess the viability of seeds, a germination test was performed on a sample composed of ten beans of cow bean (vignaunguiculata) in a petri dish covered with filter paper soaked in distilled water. The test was carried out in a dark oven, the temperature was set at 25 °C for 72 hours. [11] Based on the total number of grains used, Ni the percentage of germinating seeds was calculated according to the following equation:

$$Tg\% = Ni \times 100 / Nt$$

where *Tg:* germination rate.

Culture test

To assess the effectiveness of composts obtained from each substrate, 30 pots were filled with each compost and 30 pots of soil were used as control. Cow bean was used as a crop. The growth of cow bean was controlled by measuring the height of plants and number of compound leaves (leaf composition). [12]

Estimation of tolerance index

The tolerance index was the ratio of growth in enriched soil to growth in controlled soil [13], in this study, the tolerance index represented the ratio between the dry weight of plants cultivated in different composts and the dry weight of plants cultivated in soil.

4. Results and discussion

Evolution of temperatures:

The first stepwas characterized by an increase of temperature parameter according to the nature of substrate during the first five days. The temperatures degrees were 26.56 °C, 28.28 °C, 32.28 °C, and 32.31 °C for petiole, dry palm, and spathe respectively. The increase recorded was related to the mesophilic phase of compost which was the first phase in the decomposition of organic matter by microorganisms. Moreover, a marked increase in the temperatures of the four composts was recorded between the sixth and twelfth days. Also, a sign of waiting was recorded for the thermophilic phase where temperatures reached maximum values on the twelfth day. The temperatures recorded were 56 °C, 56.5 °C, 51.5 °C, and 52 °C for petiole, dry palm, spathe, and flower stalk, respectively. This increase was explained by the biodegradation of organic matter by microorganisms which was an exothermic reaction.[14] And it can also be explained by the intensive microbial activity in the compost. The same observation was cited by Habchi et al. [15]

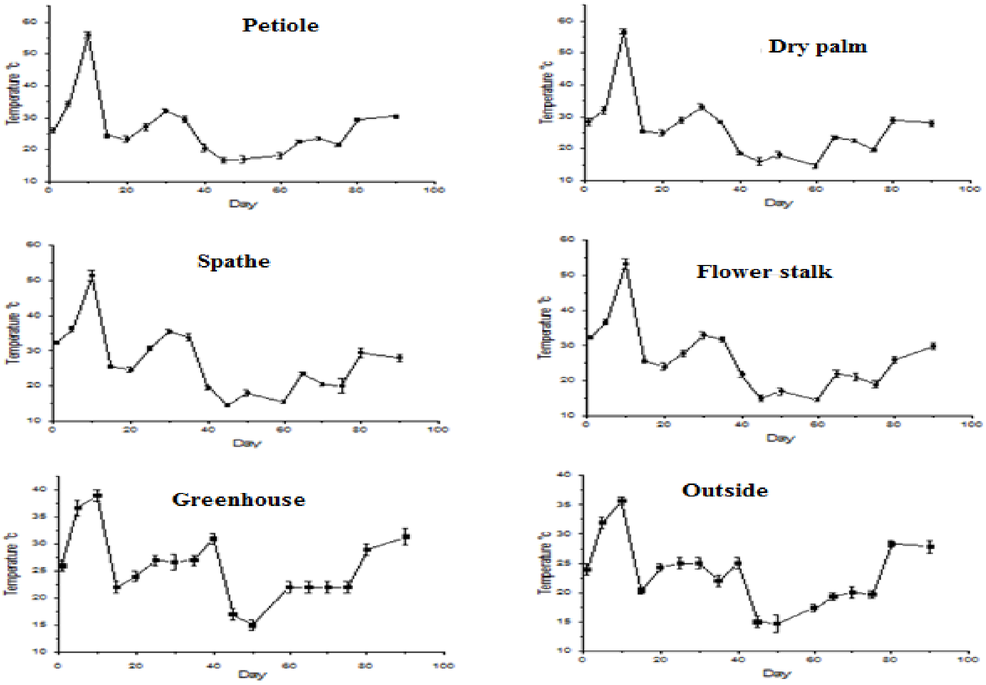

Fig 2: Temperature evolution as a function of time.

A second five-day period from the thirteenth day to the eighteenth day has been noticed. During this period, the temperatures decreased to 21.5 °C, 21.5 °C, 20.95 °C, and18.9 °C, for petiole, dry palm, spathe, and floral stem, respectively. The temperature of composts dropped regularly to reach room temperatures. This drop in temperature was due to the depletion of medium of metabolizable organic compounds and resistance against degradation (lignin, cellulose, etc.) persist. The short period of thermal decrease might be due to changes in climatic conditions; After the eighteenth day, the temperatures of composts varied simultaneously with that of ambient environment.

Evolution of pH

According of evolution curves of pH of substrates, the pH values of media varied during composting process. The pH values were acidic between 4.64 and 5.45 for various substrates and then gradually increased close to neutrality of 6.24 and 6.92 after 90 days of composting. This increase can be explained by the ammonification process and ammoniacal production of amines degradation of proteins, nitrogenous, and bases attributed to the release of bases of organic waste. The pH values decreased to 4.30 during the first twenty days of composting with exception of petiole. This decrease was due to the production of organic acids (Humus), and degradation of products of simple molecules (carbohydrates and lipids) in the medium. [16]

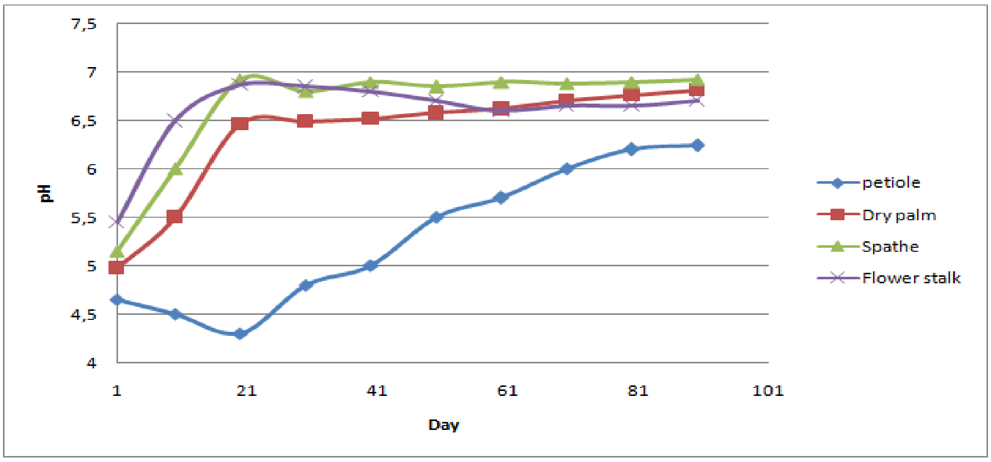

Fig 3: Evolution of pH as a function of time.

This reaction causes an acidification of environment produced by humification[17]. These acids were then degraded and lead to alkalinization of compost which increased the pH values up to 6.24.[18]

Characterization of composts

Table1.

Characteristics of the composts

Analysis performed	Unit	Petiole		Dry palm		Spathe		Flower stalke	
		Initial	Final	Initial	Final	Initial	Final	Initial	Final
Humidity	%	7,69	76,45	5,43	64,43	5,99	76,2	5	78,2
Electrical conductivity	$mS.cm^{-1}$	6,4	7,68	5,8	4,3	5,8	6,26	7,7	4,35
Organic matter	%	91,26	86,95	86,56	84,42	93,84	89,16	90,71	89,51
Total organic carbon	%	52,93	50,43	50,2	48,96	54,43	51,71	52,61	51,91
Assimilable phosphorus dosage	p.p.m.	35,83	54,16	64,13	82,49	275,82	478,17	140,66	107,67
Potassium	$mg.L^{-1}$	181,84	536,4	108,54	286,84	44,47	285,44	49,42	295,84

The results showed that the humidity levels ranged between 64.13 and 78.2%. It was ensured that this parameter was adequate for a good survival of microorganisms ranged between 50 and 70% [19]. The petiole and spathe substrates were very rich in salts in term of electrical conductivity. On the other hand, dry palm and floral stalk the variation in electrical conductivity which can be due to the origin of substrate sampling site and parts of by - products of date palm such as petiole, dry palm, spathe, and floral stalk. The levels of bio-available phosphorus reached the values of 54.16, 82.49, 478.17, and 107.67 ppm for petiole, dry palm, spathe, and floral scape, respectively. Thus, the spathe compost has the highest value compared to other substrates.

Self-heating test

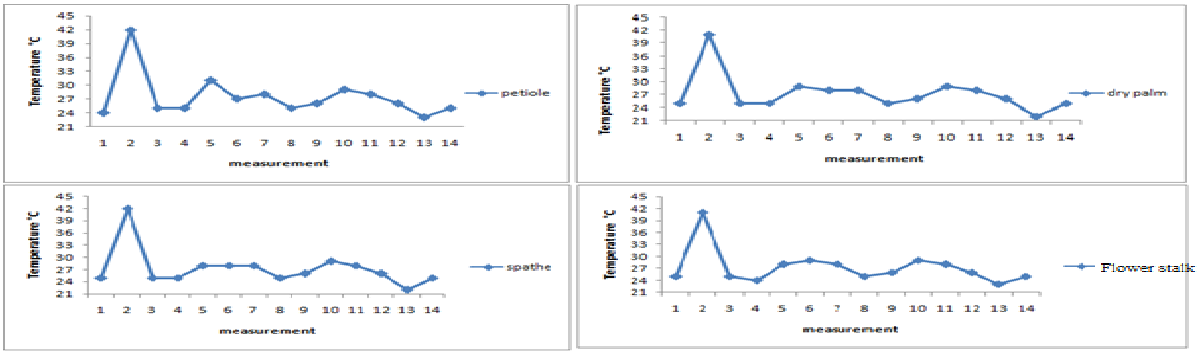

Fig 4: Temperature evolution during self-heating test.

Maximum values of temperatures were recorded on the second measurement after 6 hours during three days of self-heating experimentation. For petiole and spathe substrates, the temperature peaked at 42 °C; however, dry palm and flower stalk substrates peaked at 41 °C. Therefore, the temperature did not exceed 50 °C for all substrates, mentioning the fresh properties of four composts with a third degree of maturation [20]. The biomass self-heating measurement is a good indicator of bacterial activity, in fact the increase in bacterial activity leads to an increase in temperature. Stopping the self-heating of the de-structured biomass beyond this period indicates stabilized of organic matter. [21]

The germination test

The germination test revealed a germination rate of 90%, therefore, the seeds of the cow bean considered a good seed.

Evolution of plant vitality over time

The study of vegetative vitality for the 30 pots of composts from the 1st day of semi until the 43 days of the vegetative cycle revealed that the rate of plant vitality of compost reached its maximum on the 15th day after the semi with a percentages of 86.66%, 96.66%, 100%, and 76.66% for petiole, dry palm, floral stalk, and soil control, respectively, while the spathe reached its maximum on the 17th day with 63.33%.

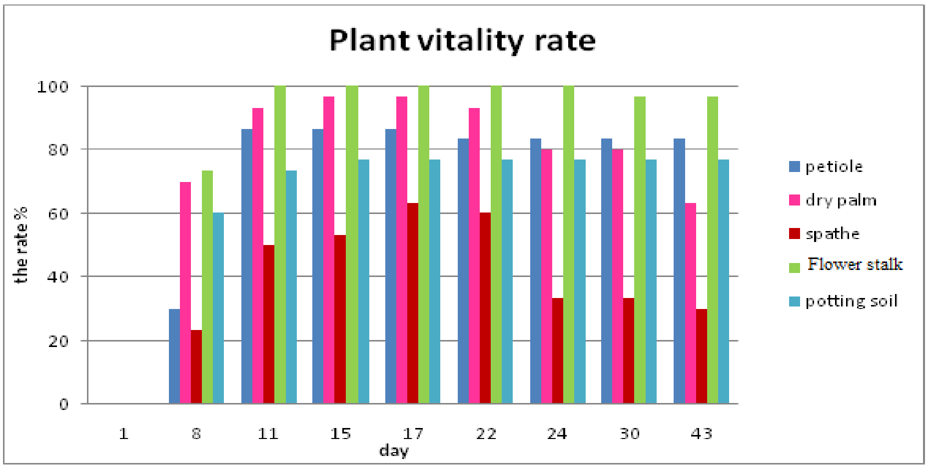

Fig 5: Rate evolution of cow bean plants.

At the end of monitoring, the rates decreased with the exception of soil. This decrease was probably explained by the physico-chemical and biological properties of substrates.[22] The difference in vegetative vitality between different composts is explained by the difference in composition of each compost. Where the compost Flower Stalk that gave the best yield is the richest in organic matter compared to the others. [23] This difference is also explained by the fact that its humidity level is the highest, which is 78%.

Evolution of plant height:

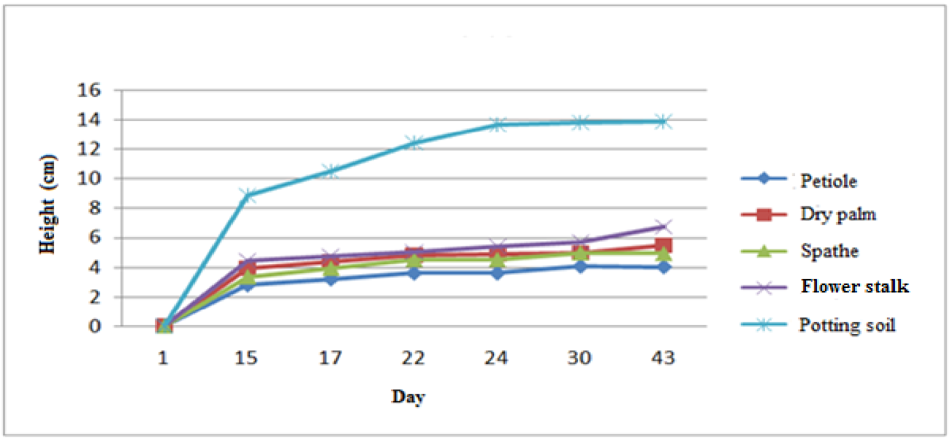

Fig 6: Evolution of stem growth.

The reference plant is implanted in a container that contains the soil and the results are presented under the name (potting soil).

Based on the curve of stem growth of cowpea bean versus sowing time, the control plants in the potting mix grow rapidly compared to other plants. After

43 days the growths reached the following average values of 13.84, 6.72, 5.49, 4.92, and 4 cm for compost, floral stalk, dry palm, spathe, and petiole, respectively. Hence, a considerable difference was recorded between the control plants and the other test plants.[24] The test plants of growth accelerated from sowing to the day 15 between 2 and 6 cm. After this age, a slowdown in growth was recoded.

Evolution of number of compound leaves

The average number of compound leaves for each substrate was counted.

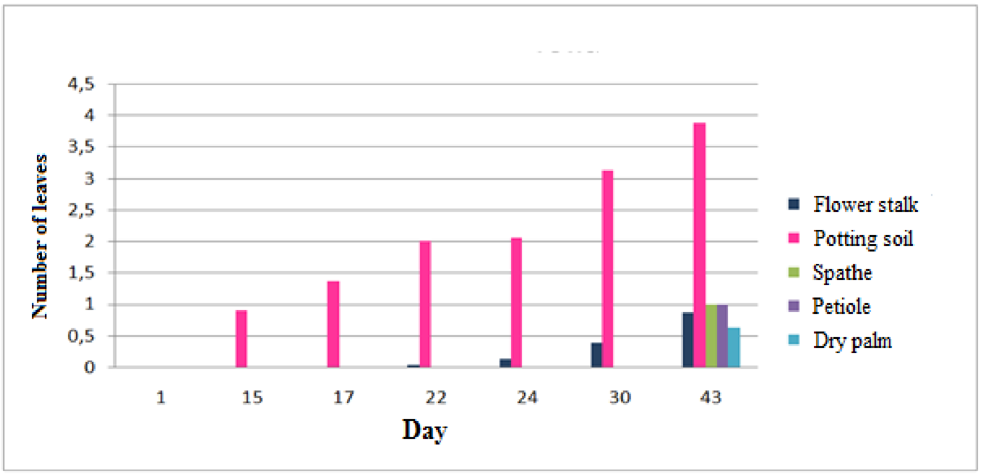

Fig 7: Foliar evolution.

The plants in the control substrate (potting soil) have the highest number of leaves. Then, a slowing down was recorded from the 22nd and 24th day. After that, a restart was observed after the twenty fourth day. A foliage was started on the 22nd days for plants treated with flower stalk. On the 43rd day, the average number of leaves was 3.86, 0.86, 0.63, 1, and 1 for leaves of potting soil, flower stalk, dry palm, petiole, and sheet for spathe, respectively. This difference can be explained by the elements necessary for plants development are more easily assimilated for the potting soil compared to other composts. [25]

Tolerance index

Fig. 8 exhibited that the tolerance index did not exceed the value of 1 for the 4 substrates, indicating the remarkable influence of potting soil compared to other substrates. The difference in the tolerance index can be attributed by that the composition of the potting soil is more favorable for the growth of the plants compared to the other composts.

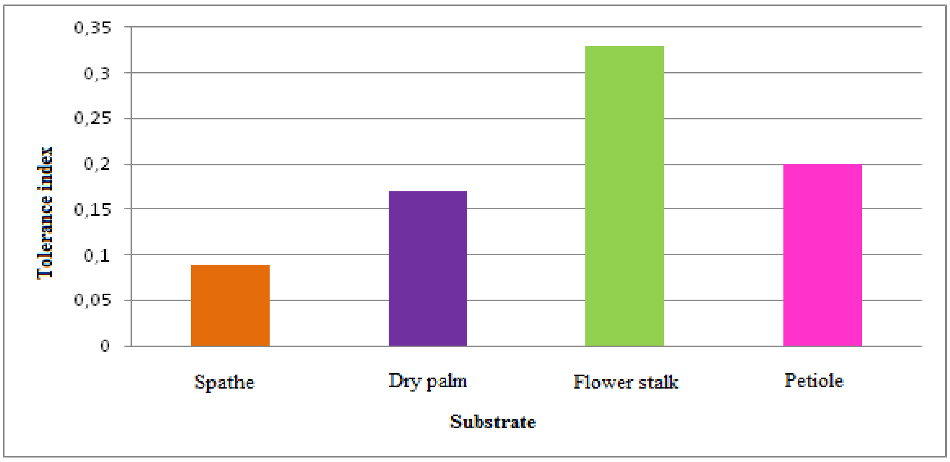

Fig 8: Tolerance index.

5. Conclusion

The results mentioned that the composting process characterized by suitable degradation in the beginning where the temperature increased rapidly in very short mesophilic phase on the 12thday at 56, 56.5,51.5, and 52 °C kornaf, dry palm, spathe, and floral stalk, respectively. Moreover, the temperature of four composts was close to that of ambient temperature during winter. The pH tended towards neutrality for all petiole substrates of dry palm, spathe and flower stalk. The average of pH values was 6.24, 6.82, 6.92, and 6.71. The percentages obtained of humidity were 76.45, 64.43, 76.2, and 78.2% for kornaf, dry palm, spathe, and flower stalk, respectively. The results of electrical conductivity showed that the compost achieved by petiole was very high (7.68 mS.cm-1) compared to others. Hence, a slight decrease in organic matter and total carbon was recorded at the end of composting process. The bio-available phosphorus results exhibited that the phosphorus content of compost achieved by the spathe was very high (478.14 ppm) compared to others. As regards potassium value, it was observed that the substrate composed of petiole has the highest content of 536.4 mg.L-1. The results obtained for monitoring cultivation of cow bean of tadelaght showed that soil gave the best results except for vitality of plants, while floral stalk presented the best results. Plants treated with flower stalk give a good result in stem of growth of 6.72 cm. Thus, spathe and petiole represented the best foliage for leaf composition.

Acknowlegments

This research work was funded by General Directorate of Scientific Research and Technological Development (DGRSDT) Algeria.

REFERENCES

[1] *Georgica P., Mirela Florina C., Ivona Cristina E., Daniela-Simina S.,* The influence of some composts on the growth and fruiting processes in the species aronia melanocarpa (michx.) Elliot, U.P.B. Sci. Bull., Series B, **vol. 83**, 2021, pp.101-112.

[2] *Vico, A., Pérez-Murcia, M. D., Bustamante, M. A., Agulló, E., Marhuenda-Egea, F. C., Sáez, J. A.,* Valorization of date palm (Phoenix dactylifera L.) pruning biomass by co-composting with urban and agri-food sludge, Journal of Environmental Management. **vol. 226**, 2018, pp. 408-415.

[3] *El Kinany, S., Achbani, E., Faggroud, M., Ouahmane, L., El Hilali, R., Haggoud, A., & Bouamri, R.,* Effect of organic fertilizer and commercial arbuscular mycorrhizal fungi on the growth of micropropagated date palm cv. Feggouss, Journal of the Saudi Society of Agricultural Sciences, **vol.18**, 2019, pp.411-417.

[4] *Chandrasekaran, M., & Bahkali, A.H.,* Valorization of date palm (Phoenix dactylifera) fruit processing by-products and wastes using bioprocess technology – Review, Saudi Journal of Biological Sciences, **vol.20(2)**, 2013, pp.105–120.

[5] *Chang H., Zhu X., Wu J.,* Dynamics of microbial diversity during the composting of agricultural straw, Journal of Integrative Agriculture, **vol.20(5)**, 2021, pp.1121–1136.

[6] *Xiao-xia G., Hong-tao L., Jun Z.,* The role of biochar in organic waste composting and soil improvement: A review, Waste Management, **vol.102**, 2020, pp.884–899.

[7] *Wang, X., Fernandes de Souza, M., Li, H., Tack, F. M. G., Ok, Y. S., Meers, E., Zn* phytoextraction and recycling of alfalfa biomass as potential Zn-biofortified feed crop, Science of The Total Environment, **vol.760**, 2020 143424.

[8] *Zhou, Q., Gibson, C. E., Zhu, Y.,* Evaluation of phosphorus bioavailability in sediments of three contrasting lakes in China and the UK, Chemosphere, **vol.42**, 2001, pp.221-225.

[9] *Mathieu C, Pieltain F..* Analyse Chimique des Sols, TEC. & DOC : 2003, pp.387.

[10] *Koenig, A., & Bari, Q. H.,*Application of Self-Heating Test for Indirect Estimation of Respirometric Activity of Compost: Theory and Practice, Compost Science & Utilization, **vol.8(2),** 2000,pp.99–107.

[11] *Yuan L., Jie L.,* Seed germination test for toxicity evaluation of compost: Its roles, problems and prospects, Waste Management, **vol.71**, 2018, pp.109-114.

[12] *Mathur, S. P., Owen, G., Dinel, H., Schnitzer, M.,* Determination of Compost Biomaturity. I. Literature Review, Biological Agriculture & Horticulture, **vol.10(2),** 1993, pp.65–85.

[13] *Adani, F., Genevini, P. L., Gasperi, F., Zorzi, G.,* Organic Matter Evolution Index (OMEI) as a Measure Of Composting Efficiency, Compost Science & Utilization, **vol.5(2)**, 1997, pp.53–62.

[14] *Tiquia, S. M., & Tam, N. F. Y.,* Characterization and composting of poultry litter in forced-aeration piles, Process Biochemistry, **vol37(8),** 2002, pp.869–880.

[15] *Abdelmadjid H., Slimane K., & Lyès B.*, Follow the degradation of organic matter during composting of date palm (phoenix dactylifera L) waste by physicochemical properties, UV-visible and FT-IR analysis, International Journal of Environmental Analytical Chemistry, 2020, pp.1-18.DOI: 10.1080/03067319.2020.1761347,

[16] *Mupondi Lt., Mnkeni Pns., Brutsch Mo.* The effcts of goat manure, sewage sludge and effctive microorganisms on the composting of pine bark, Compost Sci Util, **vol.14**, 2006, pp.201–210.

[17] *Smith Dc., Hughes Jc.,* Changes in chemical properties and temperature during the degradation of organic wastes subjected to simple composting protocols suitable for small-scale farming, and quality of the mature compost, S Afr J Plant Soil, **vol.19**, 2002, pp.53–60.

[18] *Dumitrescu L., Manciulea I., Sauciuc A., Zaha C.,* Obtaining fertilizer compost by composting vegetable waste, sewage sludge and sawdust, Bulletin of the Transilvania, **vol. 2(51)**,2009, pp.117–122.

[19] *Abid, W., Mahmoud, I. B., Masmoudi, S., Triki, M. A., Mounier, S., & Ammar, E.,* Physico-chemical and spectroscopic quality assessment of compost from date palm (Phoenix dactylifera L.) waste valorization, Journal of Environmental Management, **vol.264**, 2020 110492.

[20] *Loh, S. K., James, S., Ngatiman, M., Cheong, K. Y., Choo, Y. M., & Lim, W. S.,* Enhancement of palm oil refinery waste – Spent bleaching earth (SBE) into bio-organic fertilizer and their effects on crop biomass growth. Industrial Crops and Products, **vol.49**, 2013, pp.775–781.

[21] *Ajmal, M., Shi, A., Awais, M., Mengqi, Z., Zihao, X., Shabbir, A. Ye, L.*, Ultra-high temperature aerobic fermentation pretreatment composting: Parameters optimization, mechanisms and compost quality assessment. Journal of Environmental Chemical Engineering, **vol.9(4)**, 2021. 105453.

[22] *Liu, X., Bai, X., Dong, L., Liang, J., Jin, Y., Wei, Y., Qu, J.,* Composting enhances the removal of lead ions in aqueous solution by spent mushroom substrate: Biosorption and precipitation. Journal of Cleaner Production, **vol.200**, 2018, pp. 1–11.

[23] *Ezzariai, A., Barret, M., Merlina, G., Pinelli, E., & Hafidi, M.,* Evaluation of the antibiotics effects on the physical and chemical parameters during the co-composting of sewage sludge with palm wastes in a bioreactor,Waste Management, **vol.68,** 2017, pp.388–397.

[24] *Rothé, M., Darnaudery, M., & Thuriès, L,,*Organic fertilizers, green manures and mixtures of the two revealed their potential as substitutes for inorganic fertilizers used in pineapple cropping, Scientia Horticulturae, **vol.257**, 2019, 108691.

[25] *Nie, E., Zheng, G., Gao, D., Chen, T., Yang, J., Wang, Y., & Wang, X*., Emission characteristics of VOCs and potential ozone formation from a full-scale sewage sludge composting plant. Science of The Total Environment, **vol.659**, 2019, pp664–672.