Monitoring the Changes of Some Physical, Chemical, Microbial and Enzymatic Parameters during Composting of three Garden Wastes

A. I. Khalil [1*], M. N. Ahmed[1] and H. H. Badry[2]

ABSTRACT

The present study aimed to evaluate the composting (during 25 days) of three garden wastes through the changes in its physical, chemical, microbial and enzymatic parameters by using the bioreactor method. The used wastes were grass clippings and fallen leaves of Jambul trees, Eucalyptus trees and Ficus trees. The obtained results revealed that the physical changes such as temperature reached the maximum value after 10 days and then gradually decreased by the end of composting, while that of ouder and colour showed exhibited clear changes. The values of the chemical parameters including: ash content, total nitrogen (TN), and cation exchange capacity (CEC) were increased by the end of composting, while organic matter (OM), organic carbon (OC) and carbon: nitrogen ratio (C/N ratio) were decreased. The decrease in pH was recorded after 10 days and then gradually increased and reached the maximum value (from 5.63, 5.00 and 5.89 to 6.72, 6.76 and 7.07 for Jambul, Eucalyptus and Ficus, respectively) by the end of composting. Electrical conductivity (EC) increased during the first ten days and then gradually decreased by proceeding the composting. Both mesophilic bacteria and fungi gradually decreased with time, whereas the thermophilic ones gradually increased and reached the maximum after 10 days and then gradually decreased with time and disappeared by the end of composting. The activity of α-amylase increased and reached the maximum value (0.02, 0.02 and 0.03 μmol/ml/min for the three garden wastes, respectively) after 5 days and then decreased gradually by the end of composting, while the activity of Carboxymethyl cellulase (CMC ase) increased and reached the maximum value (0.04 μmol/ml/min) for the three garden wastes from starting composting process after 5 days and then decreased gradually by the end of composting. Finally, the activity of xylanase increased and reached the maximum value (0.23, 0.23 and 0.24 μmol/ml/min) for Jambul, Eucalyptus and Ficus garden wastes, respectively, after 10 days and then decreased gradually by the end of composting.

Key words: Composting, garden wastes, total nitrogen, organic carbon, enzymes activities.

INTRODUCTION

Garden waste consists of different organic materials, such as grasses, hedges and tree cuttings, small branches, leaves and wood debris, in addition to some inorganic materials, such as plastic bags, soil and stones. It is heterogeneous, low density component resulting from maintenance of private and public gardens. There are many factors that can affect the composition and properties of garden waste including housing, and waste management strategies, urbanization and climate (Boldrin, 2009). Garden waste is usually burned or deposited with solid municipal wastes. In addition to the harmful effects of burning on the environment, it is economically considered a loss. The emission of toxic gases to the air and hindering the soil microbial activities are among the harmful effects of burning. The accumulation of large quantities of this biomass over a long period of time is a main cause of environmental deterioration, in addition, it leads to potential losses in a material that can be processed into food, feed, and fuel (Bisaria, 1991).

There are increasing amounts of organic wastes, meanwhile, organic matter is continuously lost from the soils due to climatic conditions and intensive farming systems (Massiani and Domeizel, 1996). Nonetheless, it is not recommended to add the untreated organic wastes directly to the soil, to avoid any undesirable impacts (Bass *et al*., 1992). On the other hand, organic wastes can undergo appropriate biological treatments and then recycled into useful organic matter that can be of great interest to countries suffering from soil degradation (Hassen *et al.*, 1998).

Compositing is one of the proposed alternatives to the disposal of organic wastes, because of its low costs and less impact on the environment (Bustamante *et al.*, 2008; Lu *et al.*, 2008 and Kalib *et al.*, 2018), in addition to its contribution to improve soil fertility (Weber *et al.*, 2007 and Suvendu *et al.* 2017), and the possibility of its use as growing media in horticulture (Pérez-Murcia *et al.*, 2005 and Nazim, 2019). Compost is reported to

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improve soil biophysical properties and organic matter content, thus, supplying the plants with essential nutrients, which will be reflected on higher yields (Reddy *et al*., 2005).

Compositing is done through a biological oxidative decomposition of the organic components in the collected wastes. This process usually takes place under controlled conditions, in which the aerobic microorganisms can grow and develop and biodegrade the organic components into a useful final product that can be stored and later used without any harmful effects to the environment (Adhikari *et al*., 2008). In addition to reduction of the waste's volume, thus occupying less space, compositing destroys the pathogens and transforms nitrogen from the unstable ammonia to other stable organic forms (Zhu, 2007; Lin, 2008). In the composting process, microorganisms and their enzymes play a crucial role in the biological and biochemical conversion of the compost components (Guo *et al.*, 2012). The microorganism's activity, during compositing, transforms the organic matter into a humus-rich product (Vargas-García *et al*., 2010).

The quality of the end products is mainly dependent on the compositing process, which is considered a successful strategy for sustainable recycling organic waste (Mondini *et al.*, 2004). Most of the compositing research relied on the physico-chemical parameters as an indicator to the success of the process and quality of the end product (Said-Pullicino *et al.*, 2007; Albrecht *et al.*, 2008). However, recently, microbiological and biochemical parameters started to gain more attention as valid indicators for the composting process (Raut *et al.*, 2008; Vargas-García *et al.*, 2010; Liu *et al.*, 2011)

The aim of the current study, therefor, was to evaluate and optimize the composting of garden wastes through tracking and quantifying the changes in their physical, chemical, microbial and enzymatic parameters using a small-scale bioreactor.

MATERIAL AND METHODS

Garden Wastes:

Three garden wastes were collected from three different locations at Alexandria Governorate, Egypt: (1) grass clippings and fallen leaves of Jambul trees (Jambul) from water falls area, (2) grass clippings and fallen leaves of Eucalyptus trees (Eucalyptus) from El Hadeed Wa El-Solb garden and (3) grass clippings and fallen leaves of Ficus trees (Ficus) from El- Montaza gardens. These collected garden wastes were cut into small pieces (0.5-3 cm), air- dried for two weeks.

Preparation of garden wastes for composting: This treatment included wetting the wastes by tap water and also by solution of 0.1 M $(NH_4)_2SO_4$. Rewetting was carried out several times in order to maintain C/N ratio of about 30/1 with moisture content of 60%.

Composting system (bioreactor): A static composting unit was designed and used (Fig 1). The bioreactor has cylindrical shape (55 L capacity) and it is made of a plastic container and thermal resistant material (galvanized stainless steel) from inside. It is surrounded with 2 cm insulator material to maintain minimum heat loss. A constant air flow (10 L/min) was applied, from a compressor, into the bottom of the bioreactor for 5 min. every day. In addition, two thermometers were inserted at the bioreactor center for temperature measurement.

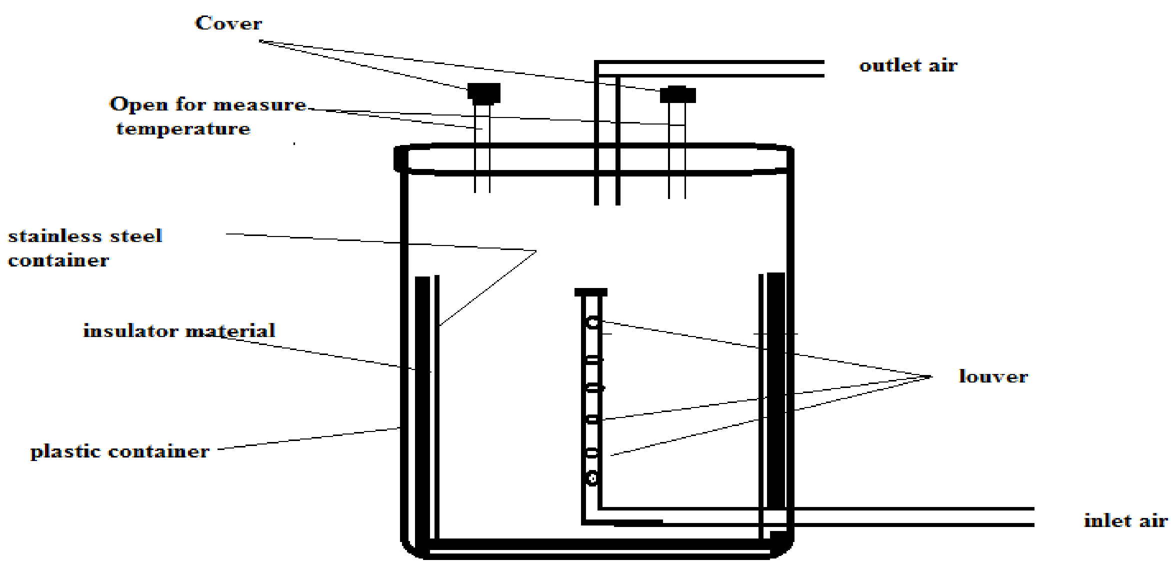

Fig. 1. Schematic diagram of the laboratory composting system (bioreactor)

Composting Material:

The garden waste of the adjusted C/N ration (~ 30/1) with 60 % moisture content was transfered into the bioreactor which filled up to 80% of its total volume ($0.03m^3$). Air inflow was intered the bioreactor during the composting period. Afterwards, the compost from the bioreactor was pooled and transferred to a container for maturation (10 days). During the composting process, some physical, chemical, microbial and enzymatic parameters were monitored. The period of composting was 25 days.

Sampling:

Three samples (10.0 g) were taken at random from different locations of the bioreactor. The formed composite sample was then transferred, to the laboratory aseptically in closed bag under cooling for analysis. The compost sampling was carried out every five days.

Analysis:

Physical analysis: The following measurements were carried out,

(i) Temperature was measured by the thermometer inserted inside the compost mixture in the bioreactor (Alkoaik et al., 2011; Khalil et al., 2014 b)

(ii) The colour was assessed by visual observation, while the odour was through olfactory judgment (Khalil 1996; Pan and Sen, 2013).

(iii) Water holding capacity WHC: Wet compost sample of initial moisture content (Wi) was placed in a beaker, soaked in water for 1-2 days, and the excess water was drained through Whatman filter paper No.2. The weight of the saturated sample was measured (Ws) and the WHC was calculated (Ahn et al., 2008) as follows:

$$WHC (\%) = (W_s - W_i) + MC X Wi/ (1- MC) X Wi$$

Where; MC is the initial moisture content of the sample, and WHC is in g water/g dry material.

(iv) Bulk density: Approximate known volume container was filled with compost sample. This sample was slightly compacted to ensure absence of large void spaces. The bulk density (g/cm^3) was calculated by dividing the weight of sample (g) by its volume (cm^3) according to Khater (2015)

Chemical analysis: The following measurements were carried out,

(i) Ash content (X) was determined (5 g) after drying the fresh sample at 105ºC to 24 hrs and then ashing at 550 ºC in a muffle furnace for 5 hrs (WHO, 1978; Cabanas-Vargas et al., 2005; Jindo et al., 2012)

(ii) Organic matter (OM) and organic carbon (OC) were estimated as follows:

$$OM (\%) = 100 - X (\%)$$

$$OC (\%) = OM (\%) / 1.8$$

(WHO, 1978; Faure and Deschamps, 1990; Abdullah and Chin, 2010)

(iii) Total nitrogen (TN) was determined by Kjeldahl method as described by WHO (1978), Half gram oven-dried (65 ºC/24 hrs) compost sample was digested in 10 ml conc. H_2SO_4 and 1.1 g catalyst (1: 2: 74 parts of selenium: $CuSO_4$.5 H_2O: K_2SO_4). After distillation, the produced ammonia was received in Boric acid indicator solution and titration with 0.05 NH_2SO_4 solution. TN was calculated as follows:

$$TN (\%) = N \times V \times 0.014 / \text{weight of sample, g}$$

(iv) The pH was determined by shaking 5.0 g compost sample with 50 ml distilled water for 30 min. and the pH was measured in the suspension using pH metes (Moldes *et al.*, 2007).

(v) The electrical conductivity (EC) was measured by shaking 5.0 g compost sample with 50.0 ml distilled water for 30 min., filtered through Whatman filter paper No. 42 and the EC was measured by conductivity meter (Petric and Selimbasic, 2008; Madan *et al*. 2012)

(vi) Cation exchange capacity (CEC) was determined according to the method described by (Bache, 1976).

Microbiological analysis: One gram compost sample was suspended in 99.0 ml sterile saline solution (9 g NaCl/L) and shaken for 30 min. Bacteria and fungi (both mesophilic and thermophilic) were isolated as described by Nakasaki *et al*. (1992). Nutrient ager (NA) and potatos dextrose agar (PDA) media were used for bacteria and fungi, respectively. Incubation temperature of 30 ºC was used for isolation of mesophiles and 50 Cº was used for isolation of thermophiles. Incubation time was 3 days for mesophylic and thermophilic bacteria, and 5 days for mesophilic and thermophilic fungi. The average number of microorganisms isolated on three plates was expressed as colony-forming units (CFU) per wet weight of compost (Khalil *et al*., 2014 a and 2014 b)

Enzymatic analysis: Compost extract was obtained by transferring 10.0 g fresh compost to a conical flask containing 50.0 ml acetate butter solution (0.1 M, pH 5.0), shaken at 150 rpm for 30 min, then filtered through a cheese cloth. Ten ml from the filtrate were centrifuged at 5000 rpm for 15 min, and the supernatant was used for the determination of enzymes activities (Khalil et al., 2001 and 2014 a)

The activities of α-amylase, carboxymethyl cellulase (CMC) and xylanase were determined by measuring the reducing sugar liberated from starch, CMC and beechwood xylan, respectively by dinitrosalicylic acid

(DNSA) method of Miller (1959). The absorbance of the resultant colour was measured at 540 nm using spectrophotometer (Thermo Scientific Co, USA). All assays were done in 4 replicates. One unit (U) of enzyme activity was defined as the amount of enzyme that release 1 µmol glucose from the starch and CMC substance or xylose from the beechwood xylan substrate per min under assay conditions stated (Ja'afaru, 2013; Fusawat and Rakariyatham, 2014).

Statistical Analysis:The obtained data were statistically analyzed for variance (ANOVA) using IBM SPSS software package version 20.0. The values were compared for the significance difference using least significant difference (LSD) at $p \geq 0.05$ (Kikpatrick and feeney, 2013)

RESULTS AND DISCUSSION

This study evaluates the efficiency of composting process of three sources of garden wastes through monitoring the changes in their physical, chemical, microbial and enzymatic parameters.

Physical Changes:

Temperature: Figure (2) showed gradual increases of the temperature from 33.2 to 40.5, from 37.5 to 55.6 and from 33.2 to 59.3 C° for Jambul, Eucalyptus and Ficus tree, respectively during the incubation time 0 and 10 days. The highest temperature (59.3 C°) was that of Ficus tree garden waste and the lowest (40.5 C°) was that of Jambul tree garden waste, while the moderate (55.6 C°) was that of Eucalyptus tree garden waste at the 10th day of composting (Fig 2). Afterwards, the temperature decreased gradually to 30.8, 29.2 and 28 C° at the 25 day of incubation for these three garden wastes, respectively. The increase of temperature during the first 10 days of composting may be due to the abundant and activity of indigenous microorganisms in the row compost materials and also to the suitability of composting conditions for stimulating microbial and enzymatic activities. On the other hand, the decrease of temperature may be attributed to the decrease of microbial and enzymatic activities because most of the easily degradable organic compounds have been metabolized according to Khalil *et al*. (2014 a and 2014 b). This has been also confirmed by Zakarya *et al*. (2015). It is clear from the present study that the compost temperature did not exceed 60 C°. Similar findings have been reported by Fogarty and Touvinen (1991) who declared that the temperature of the composting process should not exceed 60C° in order to avoid thermal inactivation of the desired microbial community necessary for efficient degradation of organic wastes.

Odour: The observed results indicated that the unpleasant odour of the composting materials had decreased with time. By the end of composting (25 days) the compost was nearly odourless. Similar observations were found by Khalil *et al*. (2014 a and b).

Colour: It has been noticed that during composting process there was a gradual darkening of the composted materials which gave an indication of maturity process. The obtained compost was nearly homogenous with a dark brown colour which agrees with those reported by Gotass (1956) and Diaz *et al*. (1993) who mentioned that the matured compost should be greyish- black or brownish-black in colour.

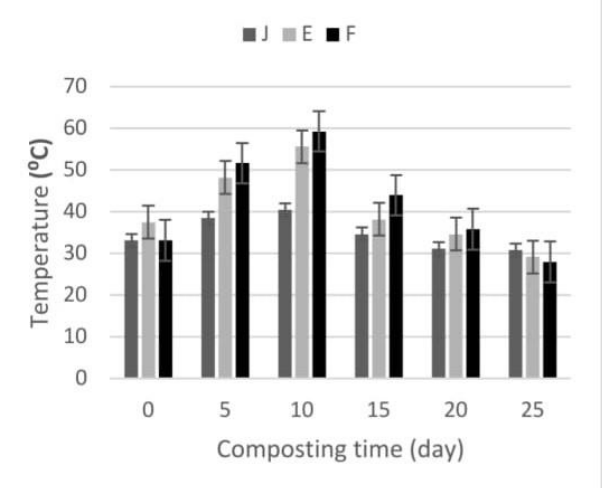

Fig.2. Changes in temperature during the composting of garden wastes of Jambul (J), Eucalyptus (E) and Ficus (F) trees. Values are means of six replicates ± standard errors

Chemical Changes:

Ash content: Figure (3) showed that ash content in the three garden wastes gradually increased by proceeding composting time. It increased from 14.50 to 36.47, from 14.58 to 36.81 and from 14.40 to 37.08 % by the end of composting process (25 days) for Jambul, Eucalyptus and Ficus tree waste, respectively. The results revealed that there were significant differences between the ash contents with time. Similar results have been reported by Khalil (1996); Beheary (2000); Shaheen (2007); Khalil (2011, 2014 a, 2014 b). It has been reported that the increase of ash content due to composting is a result of a decrease in OM content due to mineralization and humification (Auldry *et al*., 2009). The highest rate of change in ash percentage was recorded during the first 5 days of composting with values of + 0.23, + 1.83 and +2.31% per day in the case of Jambul, Eucalyptus and Ficus garden waste, respectively. However, there were lower values of rate of change in ash percentage during the last 5 days (20- 25 day) of composting with values of + 0.024, + 0.110 and + 0.038 % per day for the three garden wastes, respectively.

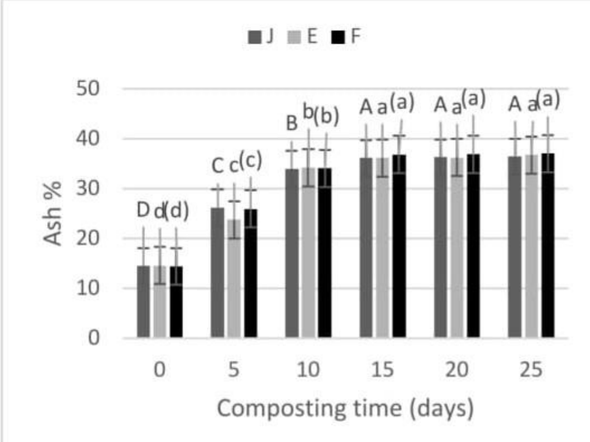

Fig. 3. Changes in ash content (%) during the composting of garden wastes of Jambul (J), Eucalyptus (E) and Ficus (F). Values are means of four replicates ± standard errors

(Bars marked with the same capital letter indicate no significant deference for Jambul leaves, small letter is for Eucalyptus leaves, small letter between bracket's is for Ficus leaves)

Organic matter (OM): Figure 4 showed that OM content gradually decreased by time since it decreased from 85.50 to 63.53, from 85.43 to 63.19 and from 85.60 to 62.92 % by the end of composting process (25 days) for Jambul, Eucalyptus and Ficus garden waste, respectively. The obtained results agree with those found by Khalil (1996); Beheary (2000); Shaheen (2007); Khalil *et al*. (2011, 2014 a, 2014 b). The reduction in OM content is due to decomposition and use of OM as a source of energy by microorganisms (Gajalakshima and Abbasia, 2008; Kalamdhad and Kamsi, 2009). It was stated that the amount of OM degraded was higher in the first week of composting than in the rest time of composting process which is attributed to high microbial activities (Saludes *et al*., 2008). The highest degradation of OM, due to composting, occurred in the first 5 days as indicating by the values of rate of change which were – 2.34, 1.84 and 2.31 percent of OM/ day while these values were – 0.024, - 0.112 and – 0.038 percent OM/ day during the last 5 days (20-25 day) in the case of Jambul, Eucalyptus and Ficus garden waste, respectively.

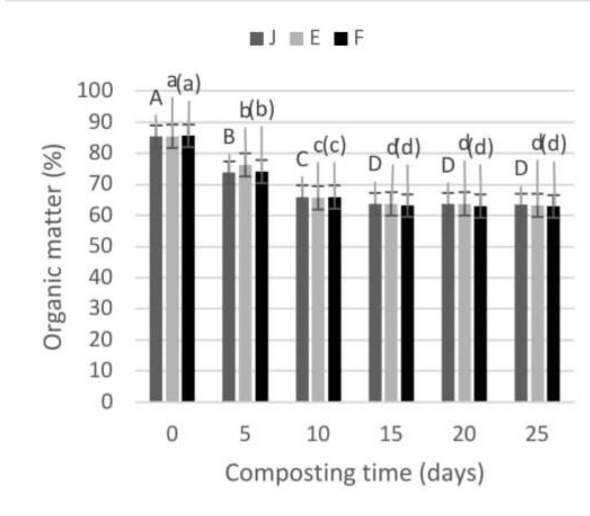

Fig.4. Changes in organic matter (OM) during the composting of garden wastes in case of Jambul (J), Eucalyptus (E) and Ficus (F). Values are means of four replicates ± standard errors

(Bars marked with the same capital letter indicate no significant deference for Jambul leaves, small letter is for Eucalyptus leaves, small letter between bracket's is for Ficus leaves)

Organic carbon (OC): Figure 5 showed that the amount of OC in the three garden wastes gradually decreased by proceeding composting time. It decreased from 47.48 to 35.27, from 47.45 to 35.10 and from 47.55 to 34.95 % by the end of composting process (at 25 days) for Jambul, Eucalyptus and Ficus garden waste, respectively. There were also significant differences in the amounts of OC between time periods. The values of rate of change in OC percentage per day in the first 5 days were – 1.30, 1.02 and 1.28 and in the last 5 days (20-25 day) were – 0.016, - 0.062 and – 0.022 in the case of Jambul, Eucalyptus and Ficus garden waste, respectively. These data indicate lower degradation rate of OM at the end of composting process (20-25 day) as compared with those occurred during the start (0-5 days) of composting process. These results agree with those found by Khalil (1996), Shaheen (2007), Khalil et al. (2011, 2014 a, 2014 b) and Awasthi et al. (2015). The reduction in the amount of OC is the result of evolution of C as CO_2 and assimilation in microbial biomass as suggested by Cabrera *et al*. (2005). It was also reported that the rate of OC decomposition is strongly related to the microbial activity in the compost (Zmora-Nahum *et al.,* 2005).

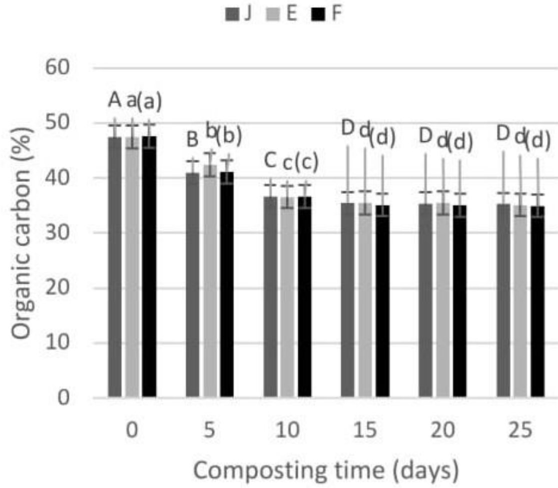

Fig. 5. Changes in organic carbon (OC) during the composting of garden wastes of Jambul (J), Eucalyptus (E) and Ficus (F). Values are means of four replicates ± standard errors

(Bars marked with the same capital letter indicate no significant deference for Jambul leaves, small letter is for Eucalyptus leaves, small letter between bracket's is for Ficus leaves)

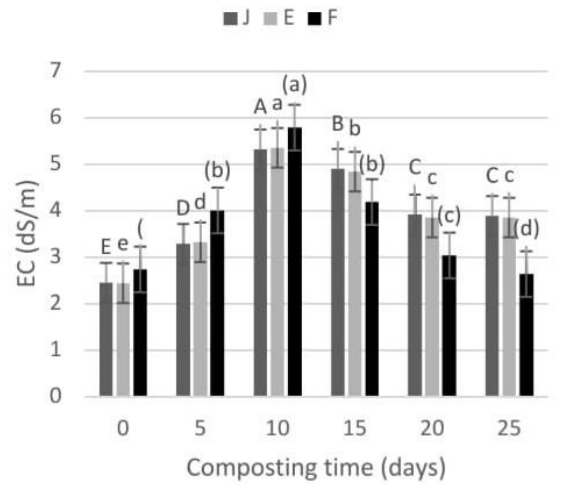

Fig. 6. Changes in total nitrogen (TN) during the composting of garden wastes of Jambul (J), Eucalyptus (E) and Ficus (F). Values are means of four replicates ± standard errors

(Bars marked with the same capital letter indicate no significant deference for Jambul leaves, small letter is for Eucalyptus leaves, small letter between bracket's is for Ficus leaves)

Total nitrogen (TN): Figure 6 showed that the amount of TN in the three garden wastes gradually increased by increasing composting time. It increased from 1.65 to 1.80, from 1.66 to 1.78 % for Eucalyptus and Ficus garden wastes, respectively, up to the end of composting process. However, it decrease from 1.7 to 1.5 % for Jambul garden waste up to the end of composting. It is also recorded that there were significant difference in the amount of TN of the three garden wastes during each time period. Very close results were obtained by Khalil (1996), Shaheen (2007), Kalamdhad *et al*. (2009) and Jusoh *et al*., (2013). The decrease of TN in Jambul garden waste compost may be attributed to ammonia volatilization in the initial stage of composting. This could be due to the loss of N in the form of ammonia which depends on type of material and C/N ratio (Goyal *et al*., 2005 and Khalib *et al.*, 2018). The values of rate of change of TN percentage per day were + 0.006 and + 0.008 in the case of Eucalyptus and Ficus garden wastes, respectively in first 5 days of composting and were + 0.008 and 0.002 in the last 5 days (20-25days) of composting, respectively. However, Jambul garden wastes behaved appositively and the values of rate of change in TN percentage per day were -0.014 and 0.000, in the first 5 days and the last 5 days of composting, respectively.

Carbon: Nitrogen ratio (C/N ratio): Figure (7) indicated that C/N ratio gradually decreased by time of composting. It decreased from 28.01 to 23.55, from 28.85 to 19.52 and from 28.64 to 19.63 by the end of composting process (25 days) in the cases of Jambul, Eucalyptus and Ficus garden wastes, respectively. There were also significant differences in the levels of C/N ratio between composting time of the three garden wastes composts. These results agree with those reported by Khalil (1996); Shaheen (2007); Beheery (2000) Alkoaik *et al*. (2011); and Khalil *et al*. (2014 a, 2014 b). It have been reported that the decrease of C/N ratio may be due to the use of OC as a source of energy by microorganisms, and to utilization of N for building cell structure of deferent groups of microorganisms (Adhikari et al. 2009; Yadav and Garg, 2009; Yadav *et al*., 2011 and Jusoh *et al*., 2013). In addition, the loss of C as CO_2 decreased C/N ratio (Goyal *et al*., 2005).

pH: Figure (8) showed gradual decrease of pH of the three garden wastes as a result of composting. It decreased from 6.92, 6.87 and 6.47 of the initial state of the three garden waste to 5.63, 5.00 and 5.89 after 10 days composting in the case of Jambul, Eucalyptus and Ficus garden waste, respectively. The pH then gradually increased to 6.72, 6.76 and 7.07 for the three garden wastes respectively at the end of composting (25 days).

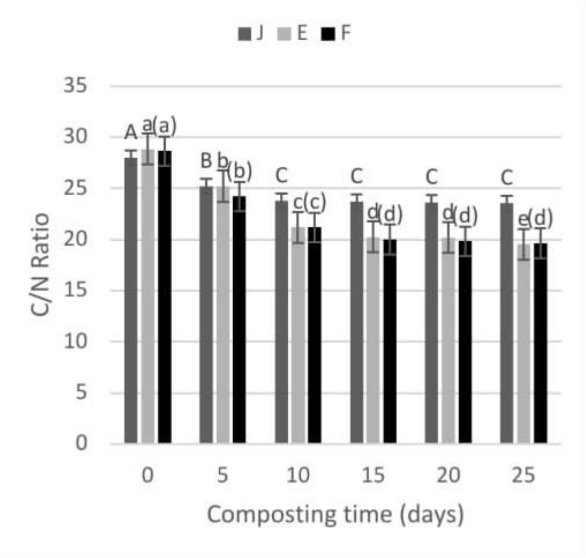

Fig. 7. Changes in C/N ratio during the composting of garden wastes of Jambul (J), Eucalyptus (E) and Ficus (F). Values are means of four replicates ± standard errors

(Bars marked with the same capital letter indicate no significant deference for Jambul leaves, small letter is for Eucalyptus leaves, small letter between bracket's is for Ficus leaves)

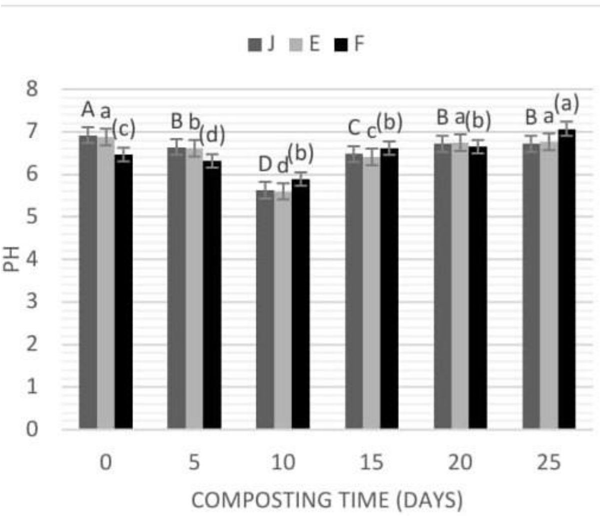

Fig.8. Changes in pH during the composting of garden wastes of Jambul (J), Eucalyptus (E) and Ficus (F). Values are means of four replicates ± standard errors

(Bars marked with the same capital letter indicate no significant deference for Jambul leaves, small letter is for Eucalyptus leaves, small letter between bracket's is for Ficus leaves)

There were significant difference between the pH values with each time period. The decrease of pH values of these three wastes could be attributed the presence of organic acids in garden wastes. This also has been confirmed by Smars *et al*. (2002) and Adhikari *et al*. (2009). It has been reported also that the decrease of pH during composting could be attributed to loss of ammonia and accumulation of organic acids (Chukwujindu *et al*., 2006; Banegas *et al*., 2007; Kayikcioglu; Okur, 2011 and Khalib *et al*., 2018).

Electrical conductivity (EC): Figure (9) indicated an increase of EC value from 2.45, 2.44 and 2.73 dS/m at the 10th day of composting then gradually decreased to 3.88, 3.85 and 2.46 dS/m at the end of composting (at 25 days) for Jambul, Eucalyptus and Ficus garden wastes, respectively. The results indicated significant differences in EC values with time. The increase of EC could be attributed to increased salts concentrations as a result of mineralization of OM and production of ammonium, nitrate or nitrite ions which usually occurred in the beginning of composting (first 10 days) as reported by Michel and Reddy (1998), Gumez-Brandum *et al*. (2008); Villasenor *et al*. (2011) and Wang *et al*. (2016).

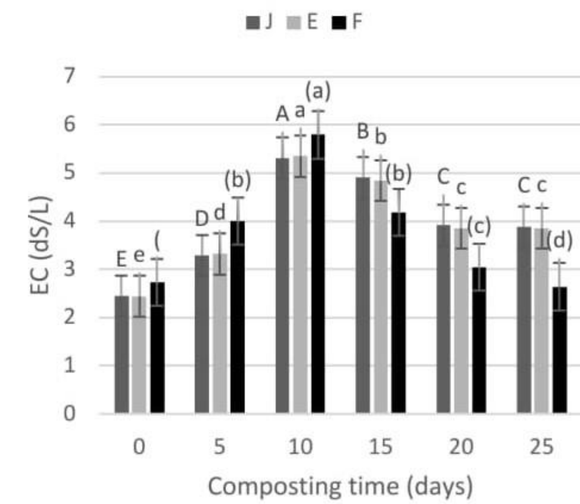

Fig. 9. Changes in electrical conductivity (EC) during the composting of garden wastes of Jambul (J), Eucalyptus (E) and Ficus (F). Values are means of four replicates ± standard errors

(Bars marked with the same capital letter indicate no significant deference for Jambul leaves, small letter is for Eucalyptus leaves, small letter between bracket's is for Ficus leaves)

Cation exchange capacity (CEC): The values of CEC of the three garden wastes composts increased from 13.10, 13.40 and 14.15 cmol/kg for initial garden wastes of Jambul, Eucalyptus and Ficus wastes, respectively with proceeding composting process to 21.20, 24.80 and 23.40 cmol/kg with the end of composting process (25 days), respectively. These increases have been suggested to be attributed to humification of organic materials and formation of carboxyl and phenolic function groups (Benito *et al*., 2003; and Saharinen, 1998).

Microbial Changes:

Mesophilic bacteria: It is clear from Fig. 10 that the number of mesophilic bacteria gradually decreased with proceeding composting process. It decreased from 2.29 × 10^8, 2.23 × 10^8 and 2.34 × 10^8 cfu/g wet compost in the initial garden waste of Jambul, Eucalyptus and Ficus, respectively, to 4.16 × 10^7, 3.71 × 10^7 and 3.89 × 10^8 respectively by the end of composting process (at 25 days). It is clear also from Fig. 10 that there were significant differences between the microbial counts with time. These decreases may be due to high temperature and low moisture content during composting period, as reported by Khalil et al. (2014 a and b). Similar results were found by Chang and Hudson (1967); Khalil et al. (1999); Hassen et al. (2001); Shaheen (2007).

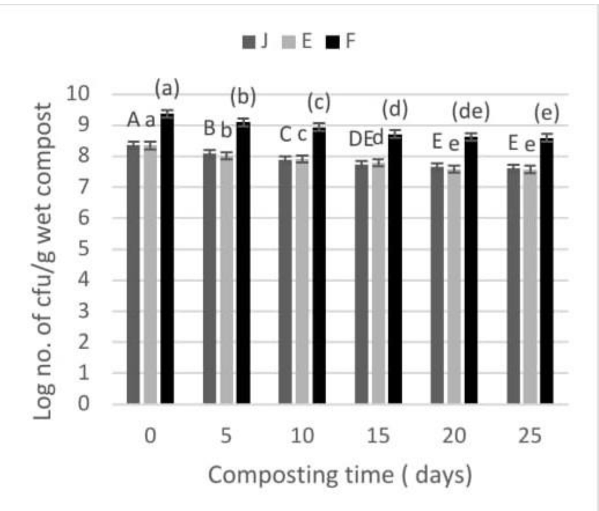

Fig.10. Changes in total counts of mesophilic bacteria during the composting of garden wastes of Jambul (J), Eucalyptus (E) and Ficus (F). Values are means of three replicates ± standard errors. c.f.u.: colony-forming units

(Bars marked with the same capital letter indicate no significant deference for Jambul leaves, small letter is for Eucalyptus leaves, small letter between bracket's is for Ficus leaves)

Thermophilic bacteria: As shown in Fig 11, the number of thermophilic bacteria gradually increased and reached the maximum (1.17 × 10^8, 1.25 × 10^8, and 1.34 × 10^9 cfu/g wet compost) after 10 days of composting in case of Jambul, Eucalyptus and Ficus leaves wastes, respectively. These bacteria gradually decreased with proceeding composting and disappeared by the end (25 days). Chang and Hudsm (1967) found that the number of thermophilic bacteria had increased during the first 2 days of composting and then gradually decreased at the end of composting. The obtained results (Fig 11) indicated significant differences between numbers of thermophilic bacteria with time. The decrease in number of thermophilic bacteria could be due to the low temperatures as reported by Khalil *et al*. (2014 a, 2014 b). Similar results were found by Khalil *et al*., (2001); Shaheen (2007). Jimenez and Garcia (1989) stated that the number of thermophilic bacteria had decreased in the last phases of composting as the product reaches maturity, and this can be indicative to the state of compost maturity. It has been also reported that during the thermophilic phases; most of the biological activity is attributed to spore forming thermophiles, and high temperatures accelerate the breakdown of proteins, fats, and complex carbohydrates such as cellulose and hemicellulose (Fujio and Kume, 1991; Elango *et al*., 2008).

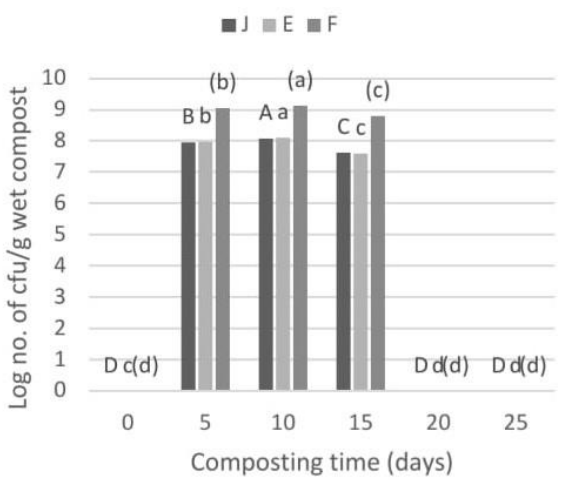

Fig. 11. Changes in total counts of thermophilic bacteria during the composting of garden wastes of Jambul (J), Eucalyptus (E) and Ficus (F). Values are means of three replicates ± standard errors. c.f.u.: colony-forming units

(Bars marked with the same capital letter indicate no significant deference for Jambul leaves, small letter is for Eucalyptus leaves, small letter between bracket's is for Ficus leaves)

As these compounds are exhausted, the compost temperatures decreases and the mesophilic microorganisms once again take part for the final phase of curing or maturation of the remaining organic matter (Shilev *et al*., 2006).

Mesophilic fungi: Figure 12 showed that the number of mesophilic fungi gradually decreased with proceeding composting process from 6.76×10^7, 7.24×10^8 and 7.07×10^7cfu/g wet compost at zero day to 1.38×10^6, 1.12×10^7 and 1.20×10^7 cfu/g wet compost by the end of composting in case of Jambul, Eucalyptus and Ficus leaves wastes, respectively, There were also significant differences between number of mesophilic fungi with time. These decreases in number of mesophilic fungi could be due to the high temperature of the compost as reported by (Khalil *et al*., 2001; Shaheen 2007; Khalil *et al*., 2013).

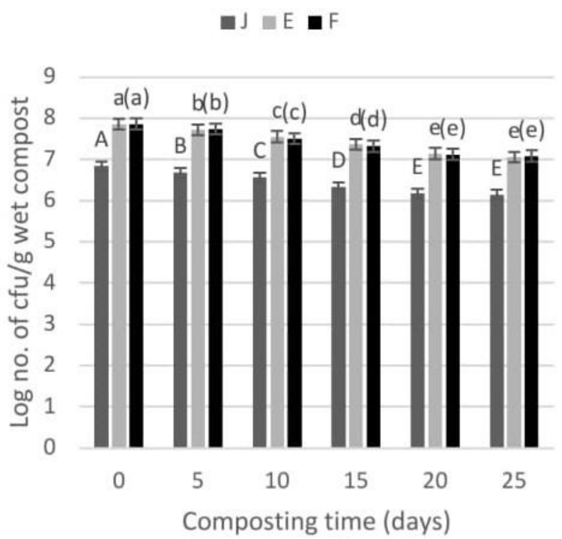

Fig. 12. Changes in total counts of mesophilic fungi during the composting of garden wastes of Jambul (J), Eucalyptus (E) and Ficus (F). Values are means of three replicates ± standard errors. c.f.u.: colony-forming units

(Bars marked with the same capital letter indicate no significant deference for Jambul leaves, small letter is for Eucalyptus leaves, small letter between bracket's is for Ficus leaves)

Thermophilic fungi: Figure (13) showed gradual increase in the number of thermophilic fungi and then reached the maximum value after 10 days of composting which were 6.45×10^6, 6.76×10^6 and 7.76×10^7 cfu/ g wet compost of Jambul, Eucalyptus and Ficus garden wastes, respectively. It is then gradually decreased with time and disappeared by the end of composting (Fig 13). There were also significant differences between the fungi numbers with time (Fig 13). The recorded increase in numbers of thermophilic fungi could be due to high temperature maintained during composting as reported by (Khalil *et al*., 2014 a, b). Similar findings were reported by Shaheen (2007).

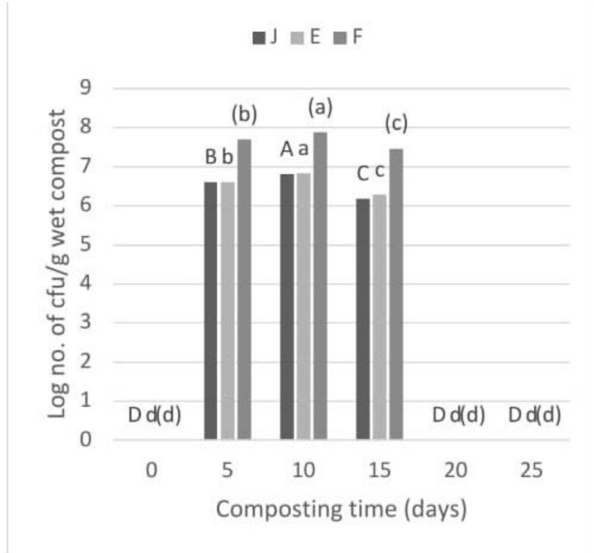

Fig. 13. Changes in total counts of thermophilic fungi during the composting of garden wastes of Jambul (J), Eucalyptus (E) and Ficus (F). Values are means of three replicates ± standard errors. c.f.u.: colony-forming units

(Bars marked with the same capital letter indicate no significant deference for Jambul leaves, small letter is for Eucalyptus leaves, small letter between bracket's is for Ficus leaves)

Monitoring microbial changes during composting process provides information about the degree of stabilization of organic materials in the studied garden wastes. The results obtained indicated that the most effective microorganisms are mesophilic and thermophilic bacteria. However, the mesophilic fungi has a short time span in the composting process. Bacteria had high ability to grow rapidly and are mostly tolerant to high temperature (Miller, 1992). It is clear from the obtained results that mesophilic bacteria and fungi are responsible for the initial decomposition of organic materials and that the generation heat is responsible for increasing composting temperature (Fogarty and Tuovinen, 1991). It can be observed that the microbial biomass of thermophilic bacteria had decreased in the last phase of composting as the product reaches maturity. Thus, a total count of bacteria throughout the composting period can be the indicative to the state of the compost maturity (Jimenez and

Garcia, 1989). It is clear, that the gradual decrease in both temperature and in counts of bacteria and fungi towards the end of composting process indicate the depletion of nutrients and that this process is approaching stability, as result less heat is generated in the compost as by reported by Kutsanedzie *et al*., (2012).

Enzymatic Changes:

α- Amylase: The obtained results showed that the activity of α- amylase increased as a result of composting of Jambul, Eucalyptus and Ficus garden wastes and reached the maximum significant values (0.02, 0.02 and 0.03 µmol/ml/min for the three garden wastes, respectively) at the 5th day of composting. It then gradually decreased and reached zero activity at the 10th days of composting process. The maximum enzyme activity, was reached in the 5th day, which could be attributed to the fast degradation of cellulose and hemicellulose as found by Khalil *et al*., (2014 a). Several studies reported that the maximum activity of α-amylase has been recorded after 7 days of composting (Khalil *et al*., 1999), after 9 days of composting (Raut *et al*., 2008), after 10 days of composting (Khalil *et al*., 2012; 2013, 2014 a) then had decreased after that. Rout *et al*. (2008) and Zameer *et al*. (2010) found that the early degradation of starch may be a result of increasing microbial biomass during the initial phase of composting. The obtained results showed also very low activity of α- amylase in the final stage of composting (15- 25 days).

Carboxymethyl cellulase (CMC ase): Figure 14 showed that the activity of CMC ase had increased and reached the maximum value after 5 days (0.04 µmol/ml/min) for the three garden wastes from starting composting process, then decreased reached the minimum at the 10th day of composting (0.03 µmol/ml/min) for the three tree garden wastes. There were also significant differences between enzyme activity with time. However, the studied caried out by Khalil *et al*. (1999, 2001 and 2012) showed that maximum activity of CMC ase was found after three weeks from composting, while it was during 10-30 days from composting as reported by Khalil *et al*. (2013), and at 30 days from composting as found by Goyal *et al*. (2005), and between 30-40 days of composting according to Shaheen (2007) and 40 days as found by Khalil *et al*. (2014 a), then decreased afterwards.

Xylanase: Figure 15 indicated that the activity of xylanase had increased and reached the maximum values (0.23, 0.23 and 0.24 µmol/ml/min) for Jambul, Eucalyptus and Ficus garden wastes, respectively at the 10th day of composting and then gradually decreased.

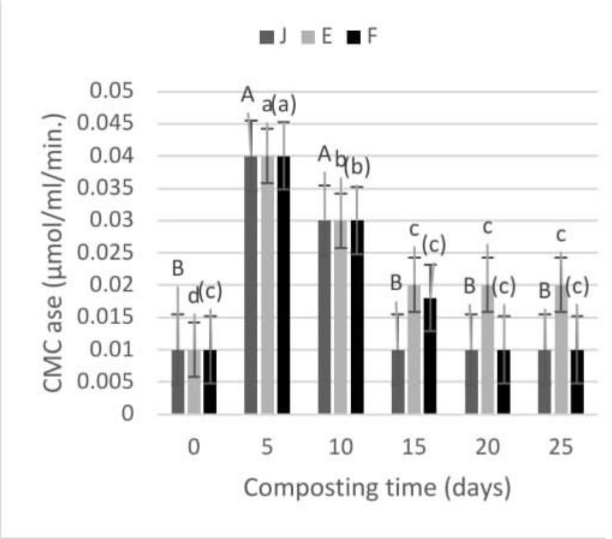

Fig. 14. Changes in CMC ase activity during the composting of garden wastes of Jambul (J), Eucalyptus (E) and Ficus (F). Values are means of four replicates ± standard errors

(Bars marked with the same capital letter indicate no significant deference for Jambul leaves, small letter is for Eucalyptus leaves, small letter between bracket's is for Ficus leaves)

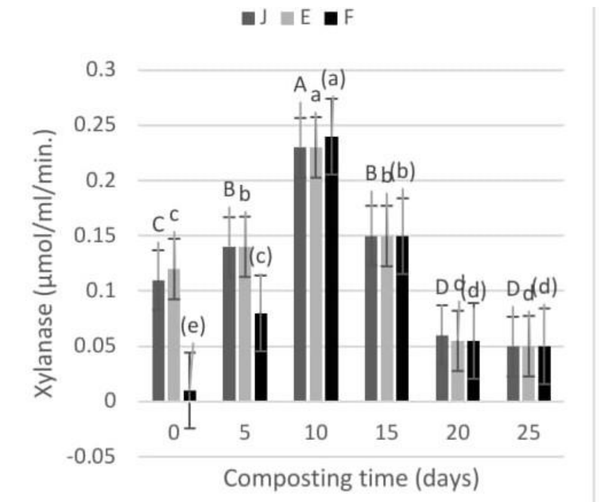

Fig.15. Changes in Xylanase activity during the composting of garden wastes of Jambul (J), Eucalyptus (E) and Ficus (F). Values are means of four replicates ± standard errors

(Bars marked with the same capital letter indicate no significant deference for Jambul leaves, small letter is for Eucalyptus leaves, small letter between bracket's is for Ficus leaves)

The results also showed significant differences between enzyme activities with time. It has been reported that the activity of xylanase increased and reached the maximum value after 30 days of composting (Shaheen, 2007; Khalil *et al*., 2012; 2013, 2014 a) and then decreased. However, Goyal *et al*. (2005) found that the maximum activity of xylanase was recorded after 60 days of composting then decreased afterwards.

CONCLUSIONS

The obtained results indicated that the changes in microbial populations and enzymatic activities during composting of garden wastes could be used as suitable indicators to characterize the dynamic of composting process and compost maturity when combined with some physical and chemical parameters such as temperature and C/N ratio. Composting, by using bioreactor technique can be a suitable method for converting garden wastes into compost that can be used as an organic fertilizer and soil conditioner. Thus, the obtained results recommend the use of the static composting system (bioreactor) for composting organic raw wastes.

The results also showed that the quality and maturity of generated compost depend mostly on the type of raw organic materials used in the production processes. Different organic wastes will give rise to different quality of the final produced compost, with different characteristics and different potential markets.

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الملخص العربي

متابعة التغيرات في بعض الصفات الفيزيائية، الكيميائية، الميكروبية و الإنزيمية خلال عملية صناعة السماد البلدي لثلاثة توليفات من مخلفات الحدائق

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تهدف الدراسة الحالية لتقيم عملية صناعة السماد العضوي (الكمبوست) لثلاثة توليفات من مخلفات الحدائق عن طريق متابعة التغير في بعض الصفات الفيزيائية، الكيميائية، الميكروبية والإنزيمية خلال عملية صناعة الكمبوست والتي أجريت بإستخدام المفاعل الحيوي. المخلفات المستخدمة هي قصاصات العشب والأوراق المتساقطة لأشجار الزامبوزيا، قصاصات العشب والأوراق المتساقطة لأشجار الكافور وأخيرا قصاصات العشب والأوراق المتساقطة لأشجار الفيكس. النتائج الخاصة بمتابعة التغيرات الفيزيائية تفيد بزيادة درجة الحرارة لتصل لأعلى قيمة لها بعد عشرة أيام من بداية عملية الكمبوست ثم تقل تدريجيا بنهاية العملية، كذلك وجود تغير واضح في اللون والرائحة. أما عن الصفات الكيميائية فقد شملت كل من كمية الرماد، نسبة النيتروجين الكلي و السعة التبادلية الكاتيونية فقد زادت قيمهم معنويا بزيادة عملية التخمر. حدث إنخفاض في قيمة pH بعد ١٠ أيام ثم بدأ في الزيادة تدريجيا حتى وصل لأعلى قيمة له بنهاية عملية الكمبوست. أما التوصيل الكهربي فقد زاد خلال العشرة أيام الأولى ثم انخفض تدريجيا بنهاية التخمر. بالنسبة لكل من البكتيريا و الفطريات المحبة لدرجة الحرارة المتوسطة فحدث لهم إنخفاض مع تقدم زمن التخمر بينما البكتيريا و الفطريات المحبة لدرجة الحرارة المرتفعة فقد زاد عددها لأعلى قيمة بعد عشرة أيام من بداية عملية الكمبوست و من ثم قلت تدريجيا و إختفت تماما بنهاية التخمر. نشاط إنزيم α- amylase زادت قيمته لأعلى قيمة له بعد خمسة أيام (٠.٠٠٢، ٠.٠٠٢ و ٠.٠٠٣ ميكرومول /مللي/ دقيقة لكل من مخلفات أشجار الزامبوزيا، الكافور و الفيكيس بالترتيب) ثم إنخفض تدريجيا، بينما كانت أعلى قيمة لنشاط إنزيم كاربوكسي ميثيل سيليولايز (٠.٠٠٤ ميكرومول/ميللي/دقيقة لمخلفات الأوراق للثلاثة أشجار موضع الدراسة و ذلك بعد خمسة أيام من بداية التخمر ثم إنخفضت القيم تدريجيا بنهاية العملية. و أخيرا ، وجد بمتابعة نشاط إنزيم الزايلينيز أنه وصل لأعلى قيمة (٠.٢٣، ٠.٢٣، و ٠.٢٤ ميكرومول/ مللي/دقيقة) لكل من مخلفات أوراق أشجار الزامبوزيا ، الكافور و الفيكس بالترتيب و ذلك بعد عشرة أيام من بداية التخمر ثم أخذ بالإنخفاض بنهاية العملية.