Monitoring of Physical, Chemical, Microbial and Enzymatic Parameters during Composting of Municipal Solid Wastes: A Comparative Study

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(Received: 17 September 2013; accepted: 26 December 2013)

Changes in physical, chemical, microbial and enzymatic parameters were monitored during the composting of organic fraction of municipal solid wastes under compost plant normal operating conditions (CPNOC) (pile size, moisture and turning were not adjusted) and compost plant adjusted conditions (CPAC) (pile size (1.5 m height and 3.0 m width), then moisture (40-60%) and turning (twice a week)).The results showed that the temperature reached its maximum (71.5 and 65.5 °C) after 26 and 19 days in the CPNOC and CPAC, respectively; then decreased. The final compost is odourless and dark brown, especially in case of CPAC. Marked changes in pH were found. Organic matter (OM) and organic carbon (OC) decreased, whereas ash, nitrogen (N), phosphorus (P) and potassium (K) increased and consequently C/N, C/P and C/K ratios decreased with time. The decrease was higher in case of CPAC. Also, Microbial populations (bacteria and fungi) were higher in the CPAC and bacteria were many. Activity of enzymes was higher in the CPAC. The maximum activity was at the beginning for α-amylase, after 40 days for carboxymethylcellulase (CMCase) and after 30 days for xylanase. The current study proves that CPNOC is not suitable for composting, whereas CPAC provides a favourable environment for microorganisms and their enzymatic activities thereby, making the final compost reached its full maturity. Generally, changes in microbial populations and enzymatic activities during composting could be used as suitable indicators to characterize the composting process and the compost maturity when combined with some physical and chemical parameters. Therefore, composting could be an appropriate technology to produce a useful product (compost) if optimum conditions are performed.

Key words: Organic fraction of municipal solid wastes, Composting, Evaluation parameters.

One outstanding characteristic of modern society is its capacity to produce wastes. Most human activities generate large amounts of apparently useless materials (Vargas-Garcia *et al.*, 2010). Large amounts of municipal solid wastes are produced in the modern society, the disposal represents a serious environmental, social and economic problem (Castaldi *et al.*, 2008). Production of municipal solid waste including organic waste is increasing while the soils are progressively losing organic matter due to intensive cultivation and climatic conditions. This

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makes the recycling of organic waste for soil amendments a useful alternative to incineration, landfill or rubbish dumps (Massiani and Domeizel, 1996).

Composting can be regarded as the most usual method of recycling organic fraction of the municipal solid wastes, since it provides an agricultural amendment capable of mitigating serious deficit of organic matter suffered by many agricultural soils caused by low use of the organic materials in the fertilization programmes of crops (Canet and Pomares, 1995). During composting, organic matter is transformed into a humus-rich product by the action of microorganisms and their enzymes. Most modifications undergone by organic matter during composting is mediated by the enzymes (Vargas-Garcia *et al.*, 2010). The microbes and their secreted enzymes play a key role in the biological and bio-chemical transformations of compost matrixes during the process of composting (Guo *et al.*, 2012). Microbial enzymes are capable of degrading large organic molecules with complex structures into simple water-soluble compounds composed of small molecules (Castaldi *et al.*, 2008). Therefore, characterizing microbial communities with the composting process may provide valuable information regarding the evolution of the process, the rate of biodegradation and, finally, the maturity of the product (Ryckeboer *et al.*, 2003). Microbial activity is achieved through the action of the enzymes responsible for the hydrolysis of complex macromolecules that constitute the organic wastes (Vargas-Garcia *et al.*, 2010). Characterizing and quantifying the enzymatic activities during composting can reflect the dynamics of composting process in terms of the decomposition of organic matter (Goyal *et al.*, 2005) and may provide information about its stability (Mondini *et al.*, 2004) and maturity of compost (Tiquia, 2002). Since organic substrates are characterized by a high complexity, their complete biotransformation during composting demands joint action of many different enzymes (Vargas-Garcia *et al.*, 2010). Composting as a successful strategy for the sustainable recycling of organic wastes relies mainly on the quality of the end products (Mondini *et al.*, 2004). Generally, many studies on composting have focused on physicochemical parameters to evaluate the both process of evolution and compost quality (Said-Pullicino *et al.*, 2007; Albrecht *et al.*, 2008). Also, microbiological and biochemical parameters have recently arisen as good indicators for the characterization of composting process (Raut *et al.*, 2008; Vargas-Garciae *et al.*, 2010; Liu *et al.*, 2011).

In Alexandria city, Egypt, there are three compost plants for composting of organic fraction of municipal solid wastes. These plants operate under normal operating conditions, focusing on the increase of the turnover rate of waste streams and not on quality of the end product. Therefore, the aim of this study is to evaluate the composting process under compost plant normal operating conditions (CPNOC) and compost plant adjusted conditions (CPAC) (that could produce compost of desired quality) through changes in the physical, chemical, microbial and enzymatic parameters.

MATERIALS AND METHODS

Composting methods

Municipal solid wastes (MSW) were collected for over 24hrs from the city of Alexandria, Egypt, and transferred to Abis-I compost plant. After sorting, the organic fraction was transferred to a rotating drum (classifier) that tears off the organic material into small pieces to produce a compostable material. Then, a conveyor with a tipper mechanism dropped the compostable material down to the fermentation area in order to form a longitudinal windrow. A comparative study was carried out to see if dividing the windrow into two similar parts could optimize the system of composting. Part of them was left for processing under compost plant normal operating conditions (CPNOC) (pile size, moisture content and turning were not adjusted as usual). The other part was processed under compost plant adjusted conditions (CPAC) (pile size (1.5 m height and 3.0 m width), moisture content (40-60%) and turning (twice a week)). After fermentation period (3 months), the fermented compost was transferred to maturation area for one month without turning or adding water. The changes in physical, chemical, microbial and enzymatic parameters were monitored during the composting process.

Sampling procedure

Samples from each windrow were taken from six places at random from a depth of 90cm and mixed together. Composite samples were transferred aseptically in closed bags under cooling to the laboratory for analysis. The sampling was performed twice a week to determine the moisture content and the pH recorded every ten days for the chemical, microbial and enzymatic analysis.

Analytical methods

Physical analysis

The temperature was monitored near the center of the pile with a metal probe thermometer (Poincelot and Day, 1973). It was checked twice a week at five points along the pile. The colour was assessed visually while the odour by smelling (Khalil, 1996).

Chemical analysis

Samples were oven-dried (60-70°C), grinded in a porcelain mortar and then by a hammer mill. The grinded samples were stored in dry, airtight containers before use. The pH was determined by shaking 5.0g compost in 50.0ml distilled water (1:10, w/v) for 30mins then the pH was measured (Albonetti and Massari, 1979). The ash content was determined after drying the sample at 105°C and ashing at 550°C in a muffle furnace for about 3hrs. The organic matter (OM) and organic carbon (OC) were estimated as follows: OM (%) = 100 - ash (%), OC (%) = OM (%)/1.8 (WHO, 1978). The total nitrogen (N) was determined by the Kjeldahl method while the C/N ratio was calculated using values of the organic carbon and the Kjeldahl total nitrogen (WHO, 1978). Phosphorus (P) was determined by spectrophotometer at 470nm while potassium (K) was determined by atomic absorption spectroscopy (WHO, 1978). All determinations were carried out in triplicate.

Microbiological analysis

Quantitative estimation of different culturable aerobic microorganisms was conducted during the composting process by inoculating the appropriate media with 0.1ml volumes of different tenfold serial dilution. Bacteria and fungi, both mesophilic and thermophilic were isolated from the compost samples as described by Nakasaki *et al.* (1992). Nutrient agar (NA) and potato dextrose agar (PDA) media were used for the bacteria and the fungi, respectively. Incubation temperatures were 30°C for isolation of mesophiles and 50°C for thermophiles. The incubation time was three days for mesophilic bacteria, and two days for thermophilic bacteria, and seven days for either mesophilic fungi or thermophilic fungi. All microbial counts were calculated on a dry weight basis. The average number of microorganisms isolated on the three plates was expressed as colony-forming units (CFU) per dry weight of compost.

Enzymatic analysis

The activities of relevant enzymes were determined using aqueous compost extracts. Thus, 10g of each fresh sample was transferred to a flask containing 50ml acetate buffer (0.1 M, pH 5.0). The flask was shaken at 150rpm for 1hr. The flask content was clarified by filtration through cheesecloth, and then 10ml of the filtrates were centrifuged at 4°C for 15mins at 5000rpm. Subsequently, supernatant was used for the measurement of enzymatic activity. The reducing sugars were measured to carry out the assay of α-amylase, carboxymethylcellulase (CMCase) and xylanase activity as described by Shambe and Ejembi (1987). All determinations were carried out in triplicate.

Statistical analysis

One-way analysis of variance (ANOVA) was used to compare the mean values from the different samples. Where significant differences were obtained, individual means were tested using the Least Significance Difference test ($P < 0.05$).

RESULTS AND DISCUSSION

Physical changes

Temperature

Composing is a biological and biochemical process involving microbes and their secreted enzymes (Zeng *et al.*, 2007, 2010). The change in composting temperature indicates the changes of microbes in the compost matrix and the temperature increase of the compost matrix is as a result of the accumulation of microbial metabolic warmth of the compost matrix thus indicating metabolic intensity and organic matter transformation rate of microbes of the matrix (Wang *et al.*, 2011). Temperature is one of the main parameters to evaluate the composting process since its value determines the rate at which many of the biological reactions take place as well as the sanitation capacity of the process (Bustamante *et al.*, 2008).

In the present study, changes in temperature that occurred in the different windrows are shown in Figure 1. The ambient temperature was about 32 ± 3°C in the day and 22 ± 3°C in the night. During the first 55days of composting, the temperature profiles were almost similar under the CPNOC and CPAC. Afterwards, the temperature of compost under the CPAC decreased gradually, while under the CPNOC remained stable at high values. The temperature reached the maximum values (71.5 and 65.5°C) after 26 and 19days and then decreased gradually, reached to 54.0 and 38.0°C by the end of composting in the case of CPNOC and CPAC, respectively. Generally, the

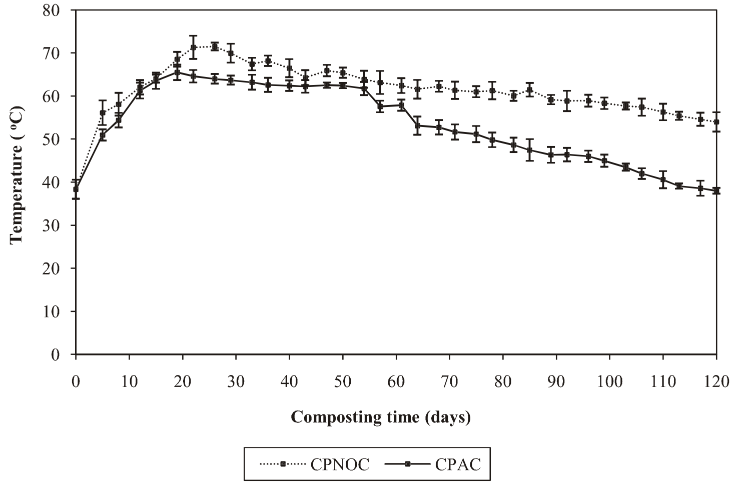

Fig. 1. Changes in temperature (°C) during the composting of municipal solid wastes. Values are means of five replicates ± standard deviations.

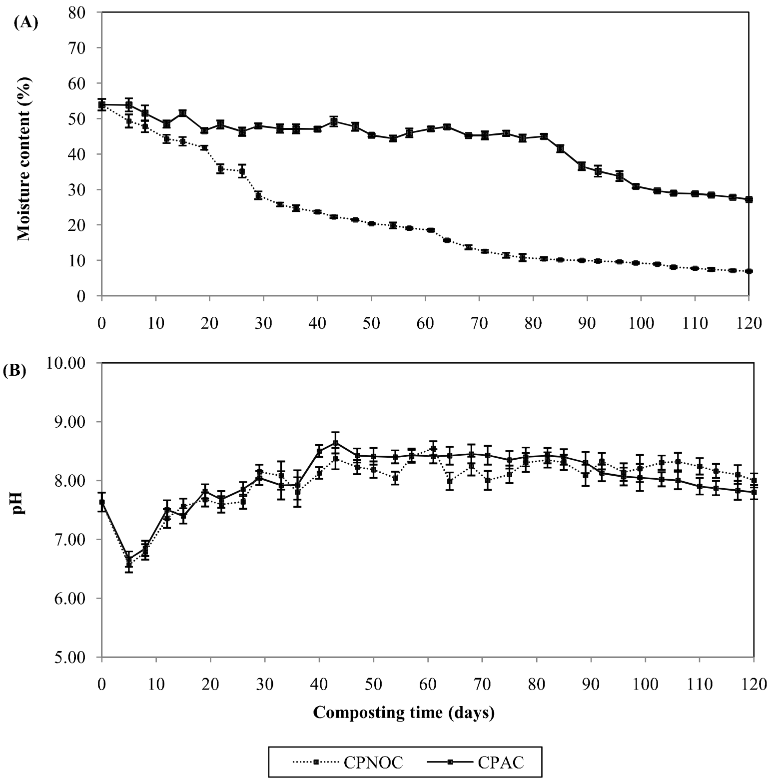

Fig. 2. Changes in moisture content (%) (A) and pH (B) during the composting of municipal solid wastes. Values are means of three replicates ± standard deviations

increase in temperature may be attributed to abundant and active indigenous microorganisms in the raw composting materials, also to the suitability of the composting conditions (pile size, aeration and moisture content) for microbial and enzymatic activities. On the other hand, the decrease in temperature after may be attributed to the decrease of microbial and enzymatic activities because most of the easily degradable organic matter had been metabolized. It can be seen that the changes in temperature during the composting process followed a pattern typical of many composting processes as described by several authors (Poincelot, 1974; Inbar *et al.*, 1993; Khalil *et al.*, 2001). It is noticed that during the composting under the CPAC, the temperature remained in the range of 40-60°C (for about 70days) which is suitable with the other parameters such as pile size, aeration and moisture content for microbial and enzymatic activities, therefore, the increase of organic matter degradation remained above 60°C for about 75days in case of CPNOC and the

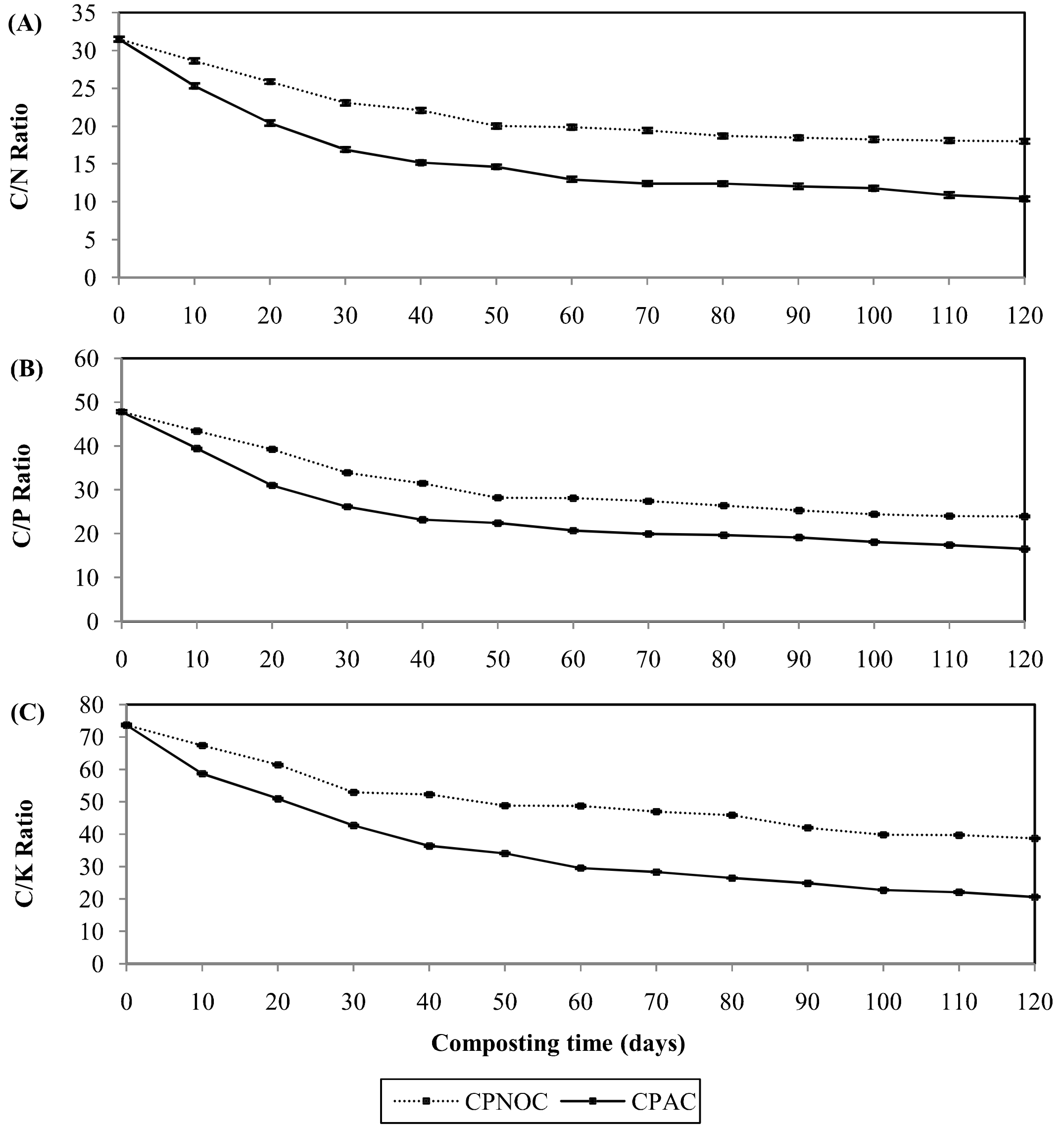

Fig. 3. Changes in C/N (A) C/P (B) and C/K (C) ratios during the composting of municipal solid wastes. Values are means of three replicates ± standard deviations.

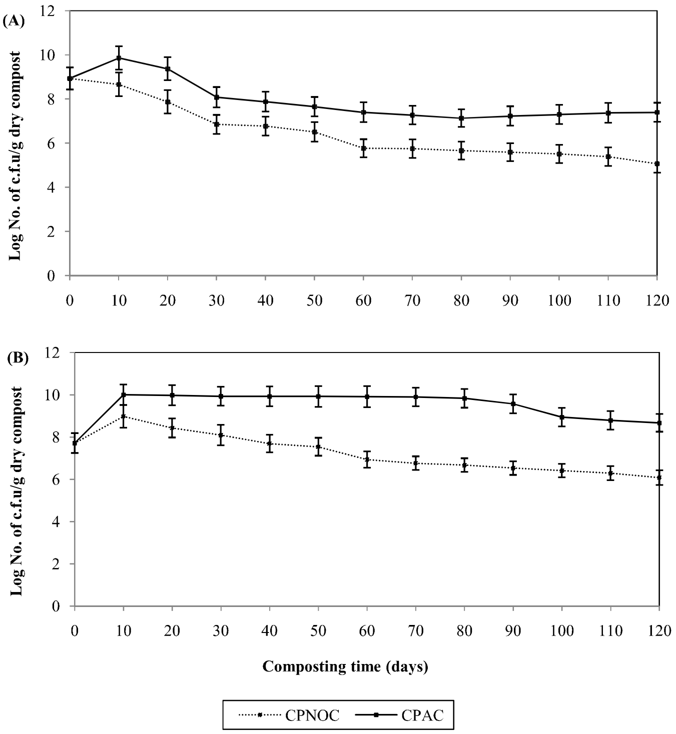

Fig. 4. Changes in counts of mesophilic (A) and thermophilic (B) bacteria during the composting of municipal solid wastes. Values are means of three replicates ± standard deviations. c.f.u. colony-forming units

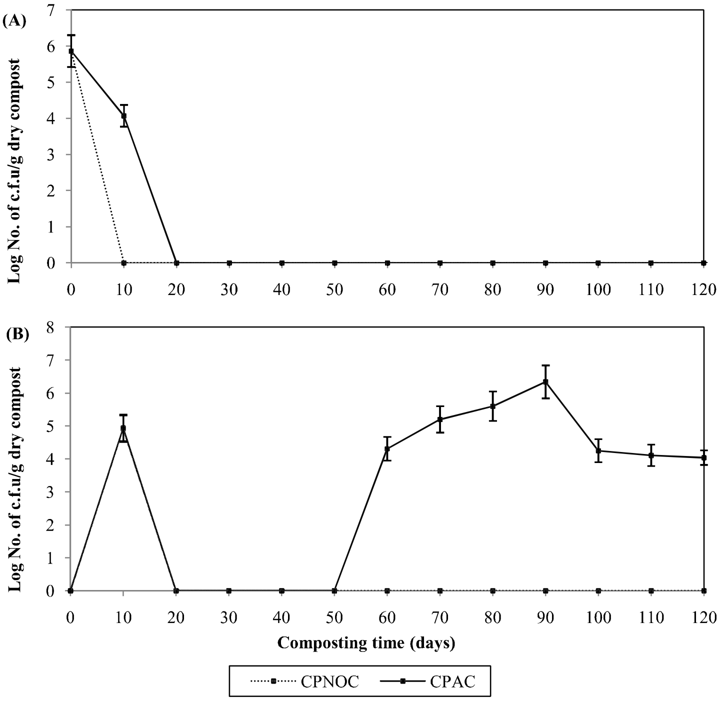

Fig. 5. Changes in counts of mesophilic (A) and thermophilic (B) fungi during the composting of municipal solid wastes. Values are means of three replicates ± standard deviations. c.f.u. colony-forming units

degradation of organic matter was very slow. It is generally agreed that the temperature of the composting process should not exceed 60°C to avoid thermal inactivation of the desired microbial community necessary for efficient degradation of the organic wastes (Fogarty and Tuovinen, 1991). The temperature of the end product in case of CPAC was lower than that of CPNOC and this could be attributed to the completion of compost maturity when adjusted conditions were performed under the CPAC. Consequently, this parameter may be considered a good indicator at the end of the bio-oxidative phase in which the compost achieves some degree of maturity (Jiménez and Garcia, 1989).

Odour

Odour was observed during the composting process. It was found that unpleasant odour of the composting materials decreased with time. Malodour increased immediately after turning but within a short time (≈30 min) it becomes as before turning. Generally, the unpleasant odour decreased after 30 to 35 days of composting but did not disappear completely. By the end of composting, the compost was nearly odourless or

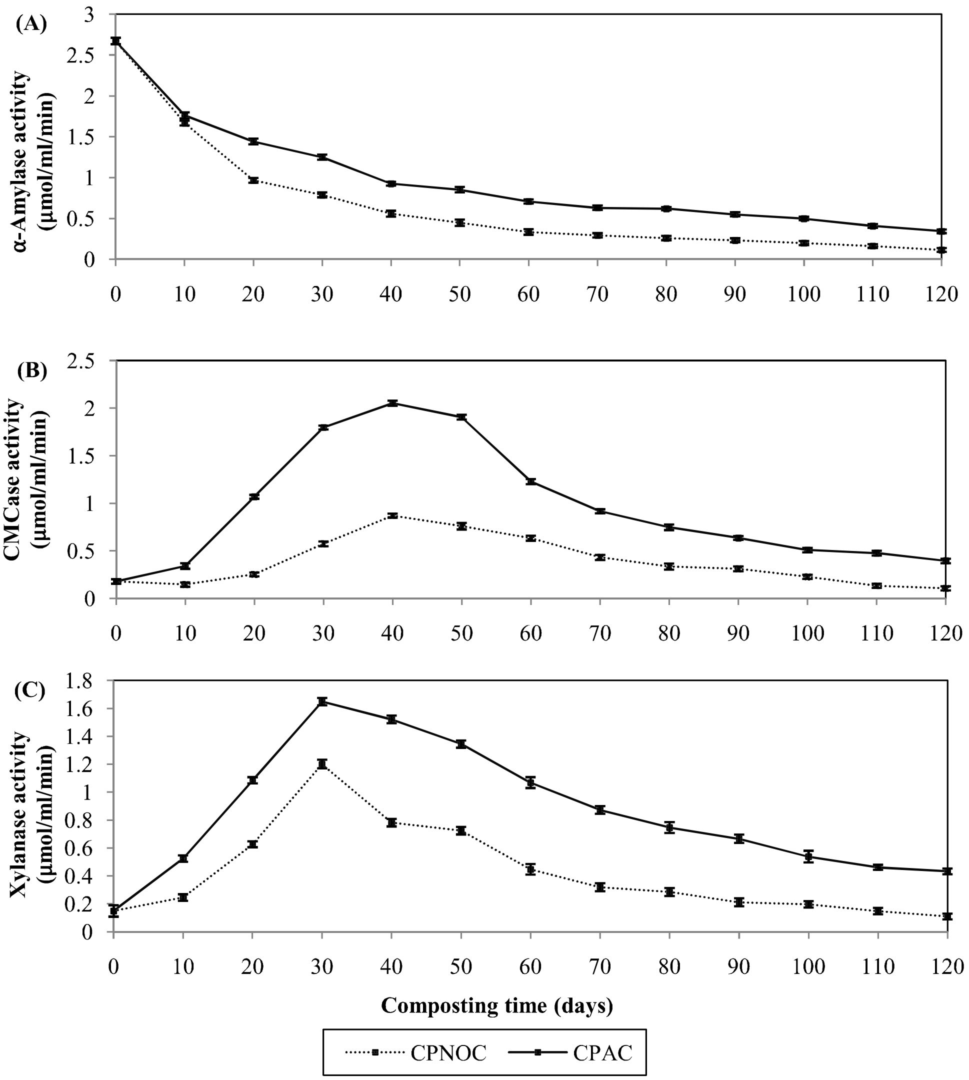

Fig. 6. Changes in α-amylase (A), carboxtmethylcellulase (CMCase) (B) and xylanase (C) activity during the composting of municipal solid wastes. Values are means of three replicates ± standard deviations

earthy odour, especially in the case of CPAC and this could be attributed to the adjustment of moisture content and turning frequency. The observations agree with those observed by Haug (1980) who mentioned that the odour emission rate dropped significantly during the first stage and then fluctuated somewhat during the remaining of the composting period. The odour emission rate increased immediately after turning but within about an hour, it returned to the rate before turning. It was stated that the final material of composting should be odourless or a slightly earthy odour or a musty odour of moulds with fungi (Gotass, 1956; Alexander, 1990). The disappearing of the smell coincided with the onset of dark colour of the waste and the levelling off the temperature (Mbuligwe *et al.*, 2002).

Colour

During the composting process, a gradual darkening of the material took place and this gave an indication of maturity progress. Morphologically, the final compost of the CPAC was heterogeneous with a dark-brown colour or greyish black while in case of the CPNOC, the final compost was light-brown. The obtained results, especially in case of the CPAC are in agreement with those reported in previous studies mentioned; the matured compost should be greyish-black or brownish-black in colour depending on whether tannins, melanin or other materials containing brown pigments were originally present (Gotaas, 1956; Diaz *et al.*, 1993). Also, Jiménez and Garcia (1989) pointed that the final product after a sufficiently long period of maturation should have a dark brown or almost black colour.

Chemical changes

Moisture content has significant effects on enzyme activities and microbial respiration of the composting process (Margesin *et al.*, 2006). Biological activity can be greatly reduced at a moisture content of less than 30% (Gray *et al.*, 1971). On the other hand, higher moisture content could lead to anaerobic conditions that result in slower decomposition. As mentioned by Poincelot (1974), above 60%, the compost tends to become anaerobic, causing it to emit foul odours. Other investigators mentioned that optimal moisture levels are usually between 40 and 60% (Hachicha *et al.*, 2009). For these reasons, during this study, under the CPAC, especially in the fermentation period, moisture content was maintained within the optimum range (40-60%) through water addition, whereas in the maturation period, water was not added. On the other hand, under the CPNOC, moisture content was not adjusted throughout the composting period. Therefore, the moisture content decreased from 53.9% (at the beginning of composting) to 7.0 and 27.2% by the end of composting in case of CPNOC and CPAC, respectively (Figure 2a). Generally, it is noticed that adjustment of moisture content was suitable for microbial populations and their enzymatic activities in case of the CPAC, whereas in case of the CPNOC, it was not suitable so the degradation of organic matter was very slow.

The average changes in pH value during the composting process are shown in Figure 2b. The starting pH value was 7.63. After 5days of composting, the pH decreased to 6.57 and 6.66 then gradually increased and reached the maximum values (8.57 and 8.64) after 61 and 43days, and decreased gradually again to 8.0 and 7.8 at the end of composting in the CPNOC and the CPAC, respectively. It is noticed that the pH started near the neutrality, decreased and then increased with time to the alkalinity, and returned again to the neutrality at the end of composting. A fluctuation in pH value was found during the themophilic stage. The slight alkalinization occurred as soon as the mass temperature increased, whereas during cooling down it decreased to nearly neutral value and then stabilized. Generally, the pattern of pH during the composting process was typical of many composting processes as described by several authors (Chang and Hudson, 1967; Poincelot, 1974; Inbar *et al.*, 1993). It was also reported that the decrease in pH during the first period of composting is expected due to the acids formed during metabolism of the readily available carbohydrates. After this initial stage, the pH is expected to rise with the evolution of free ammonia and stabilize or drop slightly again to nearly neutral as a result of humus formation with its pH-buffering capacity at the termination of composting activity (Poincelot, 1974; Fogarty and Tuovinen, 1991).

The results obtained showed that organic matter (OM) and organic carbon (OC) decreased gradually by time, whereas ash, nitrogen (N), phosphorus (P) and potassium (K) increased gradually; consequently, the C/N, C/P and C/K ratios decreased. The changes in C/N, C/P and C/K ratios are shown in Figure 3. The results indicated that decrease in C/N, C/P and C/K ratios was higher in case of the CPAC compared to the CPNOC; this could be attributed to the turning frequency which is more in the CPAC than in the CPNOC and to the adjusted moisture content and pile size.

The C/N ratio is often used as an index of compost maturity, despite many pitfalls associated with this approach but it seems to be a reliable parameter for following the development of composting process (Inbar *et al.*, 1990). The results showed that C/N ratio decreased gradually with time. It decreased from 31.5 to 18.0 and 10.4 at the end of composting in case of the CPNOC and CPAC, respectively (Figure 3a). This could be attributed to the increase in microbial populations and their enzymatic activities when composting conditions were performed under the CPAC. Similar results were found by Khalil *et al.* (1999). As decomposition progressed due to loss of carbon mainly as carbon dioxide, carbon content of the compostable material decreased with time and N content per unit material increased thereby resulting in the decrease of C/N ratio (Goyal *et al.*, 2005). It was also reported that a C/N ratio below 20 is indicative of an acceptable maturity (Poincelot, 1974), a ratio of 15 or even less is preferable (Jiménez and Garcia, 1989). Generally, the decrease in C/N ratio can be taken as a reliable index of compost maturity when combined with other parameters as mentioned by Goyal *et al.* (2005).

The present results showed that P and K levels of composts were very high when compared to the starting values and consequently, the C/P and C/K ratios decreased with time (Figure 3b,c); similar results obtained by several investigators (Inbar *et al.*, 1993; Khalil, 1996; Shaheen, 2007). Inbar *et al*. (1993) related similar results to concentration of these elements since no leaching took place during composting while there was a corresponding loss in organic matter.

Generally, the best performance was obtained with the CPAC for chemical parameters; it could be attributed to the more turning frequency and also to the adjusted moisture content and pile size. Aeration is the most important factor in composting systems (Diaz *et al.,* 2002). From the fermentation study, it is known that aerobic conditions prompt rapid and complete degradation (stabilization) of organic materials by microorganisms. Therefore, aerobic conditions are recommended to maintain a rapid and complete breakdown of readily decomposable organic compounds (Jann *et al.*, 1959; Jeris and Regan, 1973b). It was concluded that frequent turning could achieve this better under less aeration (Jann *et al.*, 1959). Moreover, it was mentioned that the overall goal of the aeration is to maintain compost temperature in the range of 50-55^{o}C to obtain efficient thermophilic decomposition of organic wastes and pathogen destruction (Jeris and Regan, 1973a; Raut *et al.*, 2008).

Microbial changes

In the process of composting, the succession of various microbial groups plays a crucial role and the appearance of nutritionally specialized microbial groups reflects the maturity of composts (Goyal *et al.*, 2005). Monitoring of the microbial succession may provide important information for effective management of the composting process and the appearance of certain groups of microorganisms is believed to reflect the degree of stabilization of organic matter during the process (Ryckeboer *et al.*, 2003).

The changes in the number of mesophilic and thermophilic microorganisms during the composting process are shown in Figures 4 and 5. The figures show the logarithm of the number present. Significant increase in the number of microbial populations was noticed under the CPAC compared to that of the CPNOC. As shown in Figure 4a, the mesophilic bacteria decreased with time in case of the CPNOC and this could be attributed to the high temperature maintained and also to the decrease of moisture content, whereas in case of the CPAC, these bacteria increased and reached maximum after 10days; decreased (when the temperature rose to above 60^{o}C) and then slightly increased again after 90days (when the temperature decreased to below 47^{o}C) during the maturation period. Similar results found by several investigators (Chang and Hudson, 1967; Khalil *et al.*, 1999; Hassen *et al.*, 2001). Chang and Hudson (1967) noticed a reduction in the numbers of mesophilic bacteria during the high temperature phase (55-70^{o}C) but when the temperature falls below, there was a striking development of these mesophiles. They also stated that mesophilic bacteria behave more like the thermophilic fungi rather than the mesophilic fungi; this may partly be due to the fact that they have high maximum increase in temperature. On the other hand, the thermophilic bacteria increased and reached maximum after 10days then gradually decreased with time (Figure 4b). The decrease in the number of thermophilic bacteria after this time could be attributed to the higher temperature (above 60 ^{o}C). Similar results found by some investigators (Chang and Hudson, 1967; Khalil *et al.*, 2001). Chang and Hudson (1967) stated that thermophilic bacteria increased in numbers during the first 2days of composting and continued to increase during the maximum temperature phase then gradually decreased at the end of composting. This further gives support to the general thesis that some thermophilic bacteria can tolerate higher temperatures than thermophilic fungi. The mesophilic fungi appeared at the beginning and disappeared after 10 and 20days in case of the CPNOC and the CPAC, respectively (Figure 5a). These fungi appeared at the beginning when the temperature was low but disappeared when the temperature increased. On the other hand, the thermophilic fungi disappeared at the beginning, and appeared and disappeared after 10days in case of the CPNOC, whereas in case of the CPAC, these fungi reappeared after 60days (when the temperature was below 60^{o}C), increased and reached the maximum after 90days (when the temperature was below 50^{o}C) then decreased at the end of composting (Figure 5b). Generally, the disappearance of thermophilic fungi after 20days in case of the CPNOC could be attributed to higher temperature (above 60^{o}C). The disappearance of these fungi under the CPAC at the period from 20 to 50days could be attributed also to this reason, whereas the subsequent reappearance after 60days is due to the fall in temperature below 60^{o}C.

From the results obtained, it can be seen that the most common microorganisms in the composting process are bacteria (mesophilic and thermophilic). It was mentioned that bacteria are usually considered to be the main decomposers in the composting process (Hassen *et al.*, 2001). The mesophilic and thermophilic fungi had a short time span in the composting process because the temperature was above 60^{o}C. Bacteria flourished because of their ability to grow rapidly on soluble proteins and other readily available substances and because they are the most tolerant to high temperature as mentioned by Miller (1992). Although a large number of mesophilic bacteria could be isolated from the composted materials even at thermophilic range of 60^{o}C, their respiratory activity at 60^{o}C was found to be negligible (Nakasaki *et al.*, 1985). Moreover, it was stated that most fungi are eliminated at temperatures above 50^{o}C; only a few have been isolated from compost that can grow at all up to 62^{o}C. Their survival was due to their thermotolerance property. During composting, temperatures above 55^{o}C discourage fungal growth. Fungi are excluded from waste composting during the earlier high temperature stage (Miller, 1992). The disappearance or decrease of fungi could be attributed to the effect of pH (> 7.0) as found in this study, because the fungi favour an acidic pH range as mentioned by Fogarty and Tuovinen (1991). Generally, mesophilic microorganisms are responsible for the initial decomposition of organic materials and the generation of heat responsible for the increase in compost temperature (Fogarty and Tuovinen, 1991). As the temperature begins to rise, thermophilic microorganisms begin to dominate while during the cooling phase of composting, mesophilc microorganisms reappear again (Poincelot, 1974; Fogarty and Tuovinen, 1991). The microbial biomass of some groups of microorganisms, especially thermophilic bacteria, decreases in the last phases of composting as the product reaches maturity, so that a total count of microorganisms (principally bacteria) throughout the process can be indicative to the state of compost maturity (Jiménez and Garcia, 1989).

Enzymatic changes

Composting is mainly a degradation process wherein complex organic molecules are broken down to simpler components (Zameer *et al.*, 2010). Microbes reproduced in the composting pile metabolize insoluble particles of organic matter by secreting different hydrolytic enzymes. These various hydrolytic enzymes are thought to control the degradation rates of different substrates, and they are the main mediators of various degradation processes (Tiquia, 2002). Measurement of enzyme activity is helpful in understanding microbial metabolism during composting (Mondini *et al.*, 2004). Thus, the monitoring of various enzyme activities throughout the process provides useful information on the dynamics of important nutritional elements such as C and N and is beneficial for understanding the transformations occurring during composting (Vargas-Garcia *et al*., 2010). Therefore, different enzymatic activities were measured to find out which enzymes participate in the bioconversion of the given organic waste material. Due to the complex composition of the composting mixture, the enzymatic activities to be measured were chosen according to the presence of their possible inducers such as starch, cellulose and hemicellulose. So, the changes in the activities of three important enzymes; α-amylase, CMCase and xylanase which are responsible for hydrolysis of starch, cellulose and hemicellulose, respectively, were studied to understand the degradation of organic wastes during the composting of municipal solid wastes. The results obtained revealed that the activities of enzymes were higher under the CPAC than under the CPNOC (Figure 6) and this could be attributed to the optimal condition prevailed at the adjusted conditions that led to higher count of microorganisms and therefore more enzymes for degradation of organic matter.

The maximum activity of α-amylase (2.671µmol/ml/min) occurred at the beginning of composting and decreased gradually to 0.113 and 0.342µmol/ml/min by the end of composting in case of the CPNOC and CPAC, respectively (Figure 6a). The maximum activity at the beginning of composting could be attributed to the starchy materials, which degraded faster than other materials (cellulose and hemicellulose). This findings agrees with the fact that has been stated by Chang and Hudson (1967) and Poincelot (1974); that some substrates in natural materials such as sugars, starch, protein and lipids are more easily degraded than substrates such as cellulose, lignin and other long chain polysaccharides. The results are in conformity with the findings of other researchers. It was stated that maximum activity of α-amylase occurred after 7days (Khalil *et al.*, 1999), 9days (Raut *et al*., 2008) and declined after that. It was mentioned that early degradation of starch could have been attributed as a result of increasing microbial biomass during this initial phase (Raut *et al*., 2008). Zameer *et al.* (2010) also stated that the activity of amylase was highest during the initial stage and lowest during the final stage of composting. The lower activity during the final stage, indicates the mere completion of decomposition process.

Cellulase activity is dependent on the types of cellulolytic microorganisms that develop on the organic waste (Goyal *et al.*, 2005). The cellulase activity is closely related to cellulose degradation and carbon metabolism during the composting process (Castaldi *et al.*, 2008; Guo *et al.*, 2012). The activity of CMCase increased and reached the maximum values (0.87 and 2.052mmol/ml/min) after 40days of composting under the CPNOC and CPAC, respectively and then decreased by the end of composting (Figure 6b). Other researchers found related results. Khalil *et al.* (1999; 2001) mentioned that the maximum activity of CMCase was found after 3weeks, whereas Goyal *et al.* (2005) stated that maximum activity of CMCase was found after 30days and declined later on. Generally, initial low CMCase activity could be attributed to the availability of simple compounds in the living microorganisms and the subsequent higher activity at the lower C/N ratio may be attributed to the greater nitrogen availability as mentioned by Ashbolt and Line (1982).

The activity of xylanase increased and reached the maximum values (1.20 and 1.65mmol/ml/min) after 30days of composting under the CPNOC and CPAC, respectively and then decreased by the end of composting (Figure 6c). On the other hand, it was mentioned that the maximum activity of xylanase was found after 60 days and declined after that (Goyal *et al.*, 2005).

It was found that the activity of such enzymes towards the end of composting period decreased and stabilized. The enzymes enumerated can be taken into consideration in estimation of the compost maturity. Generally, the hydrolytic activities monitored in this study were able to reveal the dynamics of organic matter degradation during the composting process.

CONCLUSION

From the obtained results, it can be concluded that the compost plant adjusted conditions (CPAC) were faster and better for composting than the compost plant normal operating conditions (CPNOC). CPAC provided favourable environment for the microorganisms and their enzymatic activities to make higher degradation of organic matter and therefore the final compost reached the full maturity at the end of composting compared to CPNOC. Changes in microbial populations and enzymatic activities during composting could be used as suitable indicators to characterize the composting process and compost maturity when combined with some physical and chemical parameters such as temperature and C/N ratio. Consequently, composting could be an appropriate technology to produce a useful product (compost) if the optimum conditions are performed.

ACKNOWLEDGEMENTS

The authors acknowledge the technical support provided by the working staff at the Abis-1 compost plant, Alexandria, Egypt. The Authors extend their appreciation to the Deanship of Scientific Research at King Saud University for funding the work through the research group project No. RGP-VPP- 028.

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