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Composting a Mixture of Date Palm Wastes, Date Palm Pits, Shrimp, and Crab Shell Wastes in Vessel System

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Abstract

Composting provides an economical and environmentally significant method to reduce wastes. A vessel system bioreactor was designed to study a composting mixture consisting of 70% date palm wastes and date palm pits and 30% shrimp and crab shell wastes. This mixture took about 13 weeks to mature. The compost so prepared had all the quality of a good fertilizer as exhibited by its various consyituents. The final compost product had 57.1% moisture content with pH 7.9 and an organic matter of 891.0 g/kg dry matter with significant amounts of 2.2, 0.82, 14.3, and 1.3 g/kg calcium, phosphorus, potassium, and sodium, respectively.

Key words: date palm wastes, date palm pits, shrimp and crab shell wastes, bioreactor, composting, mesophilic, thermophilic

Introduction

Date palm is the most important fruit tree found in arid, tropical, and sub-tropical regions of the world. Saudi Arabia is considered as one of the world's major producer of dates. In 2005, Saudi Arabia had more than 22.6 million date palm trees and this number is increasing gradually (Ministry of Agriculture, 2008). Date trees produce large quantity of agricultural waste. For example, each date tree produces about 20 kg of dry leaves yearly. Other wastes such as date pits represent an average of 10% of the date fruits (Ministry of Agriculture, 1998; Barreveld, 1993). Although these agriculture wastes consist of cellulose, hemicelluloses, lignin and other compounds which could be used in many biological processes, they were burned in farms causing serious threat to environment.

Shellfish is considered the second significant biological wastes in Saudi Arabia due to the large fishing areas surrounding the country. The shrimp catch from the Red Sea and Arab Gulf was 5639 ton in the year 2000 and increased to 8316 ton in the year 2005 (Ministry of Agriculture, 2008). Shrimp shell wastes and its derivatives are considered the major source of chitin, the second most abundant biomass on earth after cellulose, hence approximately 10^{10}–10^{11} tons chitin is formed annually. Bioconversion process is the most desirable method to treat such wastes (Bhattacharya et al., 2007) to obtain value-added products.

Composting (bioconversion) is a straightforward and simple solution for reducing biodegradable waste volumes, because it converts biological organic components of the solid wastes in controlled conditions to other states that can be handled, stored, and applied to the land without adversely affecting the environment (Golueke, 1977).

In this study, a vessel system bioreactor was designed for the composting process and constructed to obtain the necessary environment for thermophilic microorganisms. The vessel was supplied with a mixture of shrimp and crab shell wastes and shredded date palm wastes and date palm pits. The mixture was also supplied with soil samples collected from extreme environments to enhance thermophilic microorganism growth.

Materials and methods

2.1 Vessel system

A custom-made vessel system (Fig. 1) designed for composting was constructed from a 5 liter glass bottle to

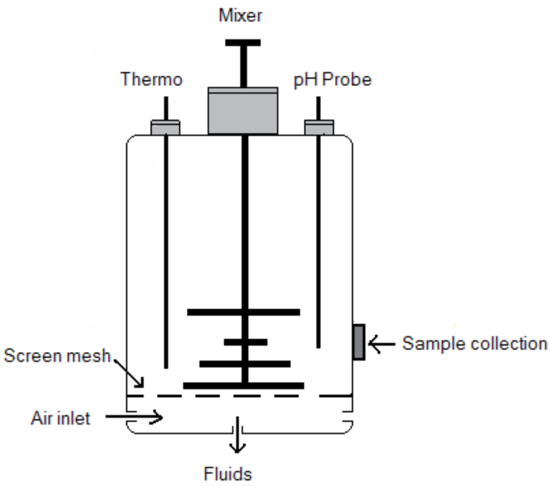

Figure 1. A custom-made vessel system was designed for composting process.

which three glass ports were fused on the top, three ports to the side, and one port to the bottom. A mixer was connected to the first top port, which was used to add the composting mixture. The second top port was connected to a pH probe to detect the pH change of the mixture. The third top port was connected to a thermometer (Brannan) to monitor any change in compost temperature. One of the side ports was coupled with closure to collect samples. The other two side ports were constructed for aeration purposes. The bottom port was used to let the fluids pass out. Also, the bottom of the vessel system was supplied with a 4 mm mesh screen. It was fixed to let the fluids pass out and keep the compost particles inside the vessel system.

2.2 Raw materials

Shrimp and crab shell wastes (SCSW) were collected from the local market in Riyadh, Kingdom of Saudi Arabia, and stored in a freezer at -20°C prior to use. The moisture content of SCSW was 56%. The woodchips, a mixture of shredded date palm wastes and date palm pits (DPWDPP) were collected from the local farms in Riyadh, Saudi Arabia. The moisture content of the woodchips was 40%. The SCSW and DPWDPP materials were shredded in a large hog to an average size of 5– 20 mm, which is recommended for good aeration of composting systems (Biddlestone and Gray, 1985). The compost mixture approximately consisted of 70% DPWDPP and 30% SCSW.

The mixture was also supplied with 200 gm of soil collected from sebkha Al-Oahaziah, which has an extreme environment to increase the number of thermophilic microorganisms (Khiyami, 2007). The materials were first thoroughly mixed using the vessel manual mixer and then later it was mixed every week. The mixture was composted for 13 weeks. The moisture content, pH, and the physico-chemical properties of the mixture were within the average recommended starting conditions for rapid composting (Rynk, 1992).

2.3 Composting samples

A triplet composite samples (one gram each) collected from different locations of the vessel were collected at the end of each week and transported to the laboratory for testing within 4 hrs.

2.4 Analysis of microbial activity

The microbial population analysis for bacteria was carried out using a plate count method. Counts were performed by taking 1.0 gm of each sample and adding it to 9.0 ml of sterile 0.9% NaCl distilled water in a universal bottle before running a series of dilutions to prepare from $1x10^{-1}$ to $1x10^{-7}$ dilutions. The dilutions were plated out onto agar media by inoculating centrally 100 µl of the dilution onto Tryptone Soya Agar (TSA) plates and spreading it using a sterilized glass plate spreader. All plates were incubated at 30 °C and inspected every 24 hrs for any colony formation. When the first colonies appeared, they were counted and then recounted until no further colonies appeared. The number of colony forming units (CFU) related to compost mass was then calculated. Isolation of thermophiles were carried when 100 µl of the dilutions were plated out onto a minimal medium with Gelrite Gellan Gum (Sigma) and spreading it using a sterilized glass plate spreader. The minimal medium contained (g/l) 8 g of $NH_2H_2PO_4$, 0.2 g of yeast extract, 2 g of K_2HPO_4, 0.5 g of $MgSO_4.7H_2O$, 0.5 g of Na_4SO_4, 0.5 g of NaCl, 10 mg of $ZnCl_2.2H_2O$, 8 mg of $MnSO_4.7H_2O$, 10 mg of $FeSO_4.7H_2O$, 50 mg of $CaCl_2$, and 10 g of Gelrite Gellan Gum. The inoculated plates were incubated at 65°C. All plates were inspected after 24 hrs for any colony formation and repeated inspection were carried out every 24 h. When colonies first appeared they were counted and then recounted until no further colonies appeared. The number of CFU related to compost mass was then calculated.

2.5 Analysis items

A glass electrode pH 211 microprocessor pH-meter (Hanna Instruments) was used to measure the pH of 12 g samples after mixing each sample with 60 ml deionized water, shaking it for a few seconds, and letting it stand for one hr. The pH was reported as average of three reading at the compost mixture. (Sundberg and Jonsson, 2008).

The moisture content of the sample was determined by an oven drying method. Three samples per compost mixture were oven dried overnight at 105°C. The temperature of compost mixture was observed during the composting process and the average of triplet daily reading was reported.

Organic matter content was determined by burning the dried sample at 550°C for 4 hrs (Clesceri et al., 1998). The organic matter was converted to carbon content using a factor of 54% (Barrington et al., 2002). Total Kjeldahl nitrogen (TKN) was determined by the semi-micro-Kjeldahl method (Clesceri et al., 1998). Organic nitrogen (organic-N) was calculated by subtracting Ammonia-N from TKN. Various elements including phosphorus, potassium, calcium, sodium, and other elements (Table 1) of the samples were analyzed according to the US EPA 3050B method (Anon, 1996).

Results and discussion

The organic wastes of SCSW and DPWDPP have become an environmental problem in Saudi Arabia. The uncontrolled degradation of organic wastes causes a negative impact on the environment. Thus, composting of organic wastes is an important part strategy for reducing waste going to landfill and clean the environment. Composting is characterized by typical chemical and physical changes that occur during the aerobic degradation process of organic wastes.

Temperature is one of the key indicators for microbiological reactions of composting processes. It is an important parameter to monitor composting efficiency, because it affects not only the biological reaction rates and the dynamic population of microbes, but also the physicochemical characteristics of composts (Antizar-Ladislao et al., 2005; Namkoong et al., 2002). During the entire composting process, the temperature of the composted mixture changed between mesophilic and thermophilic, reaching a maximum value of 65°C. However, the temperature in the compost mixture was higher than the environmental temperature, indicating that an active

Table 1. Comparison of physico-chemical properties between initial and final compost. Data are mean value ± deviation of three replicates.

Parameter	Unite of measurement	Initial compost	Final compost
Moisture content	wet basis %	0.1 ± 63.2	0.1 ± 57.1
pH		0.01 ± 8.2	0.07 ± 7.9
Ash	g/kg dry matter	13.4 ± 198	14.1 ± 187
Organic matter content	g/kg dry matter	12.0 ± 897.0	8.6 ± 891.6
Organic carbon	g/kg dry matter	8.4 ± 567	7.8 ± 539.8
C/N		0.7 ± 31.5	0.2 ± 14.8
Organic-N	g/kg dry matter	0.8 ± 33.2	1.1 ± 25.4
NH_4 - N	g/kg dry matter	0.5 ± 4.4	0.3 ± 6.1
Phosphorus (P)	g/kg dry matter	0.25 ± 1.35	0.3 ± 2.2
Potassium (K)	g/kg dry matter	0.1 ± 0.8	0.2 ± 0.82
Calcium (Ca)	g/kg dry matter	0.12 ± 13.7	0.11 ± 14.3
Sodium (Na)	g/kg dry matter	0.1 ± 0.6	0.07 ± 1.3
Magnesium (Mg)	g/kg dry matter	0.22 ± 7.7	0.2 ± 7.9
Sulfur (S)	g/kg dry matter	0.06 ± 2.7	0.1 ± 3.0
Iron (Fe)	g/kg dry matter	0.01 ± 0.7	0.04 ± 1.0
Zinc (Zn)	mg/kg dry matter	2.5 ± 25.3	0.1 ± 24.9
Manganese (Mn)	mg/kg dry matter	5.3 ± 88.3	3.3 ± 88.4
Copper (Cu)	mg/kg dry matter	1.1 ± 5.4	0.8 ± 5.7
Boron (B)	mg/kg dry matter	0.4 ± 5.3	0.2 ± 5.7

microbial population was present (Fig. 2). Maturation of compost mixture took approximately 3 months. From these observations, it is easy to conclude that compost incubation is a reasonable method for treating mixtures of polymers whose biodegradation is difficult to achieve.

Microbial population during the composting process was dominated by the presence of mesophilic and thermophilic bacteria throughout the degradation process (Fig. 3).The number of mesophilic bacteria was almost stable during the thermophilic stage of composting (week 6 to week 11) but they increased significantly during weeks 3 to 5. Thermophilic bacteria increased in number from Week 6 to week 12, which can be attributed to the increase in temperature during thermophilic period. The population of mesophilic and thermophilic bacteria decreased significantly during the maturation stage.

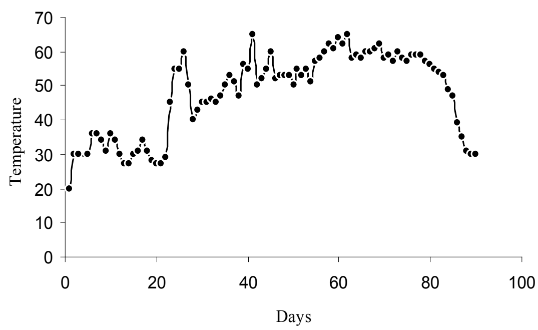

Figure 2. Temperature profile changes during the composting period. Data are mean values of three replicates.

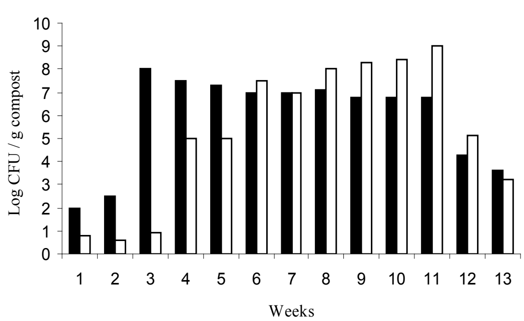

Figure 3. Number of mesophiles (■) and thermophiles (□) present during composting period. Data are mean values of three replicates

During the composting process microorganisms transform organic raw materials into compost by breaking them down to simple compounds and reforming them into new complex compounds. The availability of easily usable organic substances such as sugars, proteins, starches, and fats enables the proliferation of the fast-growing microorganisms (Hu et al., 2008). Therefore, in early stage the mesophiles predominated the microbial population (Fig. 3). These bacteria release heat by breaking down large amounts of easily degraded organic matter which were immediately available for microbial utilization. When the compost reaches higher temperatures, thermophiles begin to dominate the bacterial community. The active stage is typically the stage where most of the organic matter is converted into carbon dioxide and humus indicating the growth of thermophiles population. The thermophilic population continues generating more heat by decomposing large polymers. Normally, composting proceed at a higher rate under thermophilic conditions (Davis et al., 1992). However, in our study the active stage sustained for a longer time compared to the early stage, which might refer to lignocellulosic and chitinolytic polymers (Vizcarra, et al., 1993), and the moisture provided from SCSW.

Moisture content has significant effects on enzyme activities and microbial respiration of the composting process (Margesin et al., 2006). Several researchers (Horng, 2003; Li and Jang, 1999) have reported that water content of the incubated materials should be controlled within the range of 50–80%. Water content depends on the properties of the organic components within the composting mixtures (Li and Jang, 1999). In general, a 50% moisture is the minimum requirement for maintaining high microbial activity (Liang et al., 2003). In this study, due to high ambient temperature and aeration during the composting process, water constantly evaporated from the compost. The final compost mixture had a lower moisture ratio than the initial mixture (Table 1). However, the SCSW provided enough moisture to the mixture.

The pH in this compost process ranged between 7.4 and 8.4 (Fig. 4). During the early stages of composting, a rapid growth of microbes reduced the pH value due to the formation of short chain organic acids, mainly lactic acid and acetic acid (Eklined et al., 1997). After that, the pH value of the composting materials was gradually rised due to the increament in NH_3 amount generated by the biochemical reactions of nitrogen-containing materials (Tai and He,

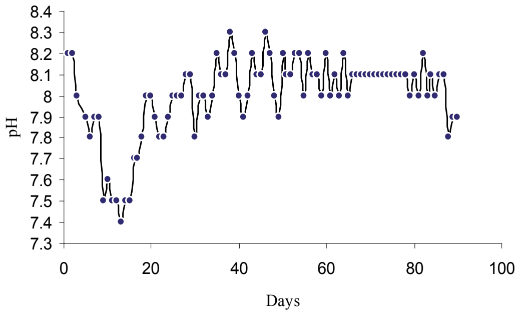

Figure 4. pH profile changes during the composting period. Data are mean values of three replicates.

2007). Theoretically, the composted products should have a neutral pH value during the final stage of composting (Li and Jang, 1999). This observation was clear only during the early stage of composting which was around the first two weeks of the composting period. However, after day 30 the pH increased again to alkalin levels as illustrated in figure 4. This pH level remained alkalin towards the end of the composting stage. This phenomenon may be attributed to the properties of the raw materials.

The physico-chemical properties of initial and final compost are summarized in Table 1. The decrease in organic matter, organic carbon and organic nitrogen ratio from 897 to 891, 567 to 539.8 and 33.2 to 25.4 respectively was primarily caused by the decomposition during active stage of composting. The chemical analysis showed that total nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), sodium (Na), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), Copper (Cu), and boron (B) concentrations of final compost slightly increased after 13 weeks of composting. The contents of phosphorus, potassium, calcium, and sodium changed depending on the composting materials. For instance, composted garbage products were containing more than 0.5%, 0.2%, and 0.25% of N, P, and K elements, respectively (Fubern, 1986). Composted plant wastes were containing 0.53%, 0.16% and 0.35% of elements N, P and K, respectively (Tai and He 2007). In this study, P, K, Ca, and Na elements changed from 1.35, 0.8, 13.7 and 0.6 to 2.2, 0.82, 14.3, and 1.3 g/kg respectively (Table 1). The increase in nutrient concentration can be attributed to the net loss of compost dry mass associated with organic matter degradation, which led to the concentration effect on the nutrients (Saludes et al., 2008). In this study, the chemical composition suggested that the mixture of SCSW and DPWDPP compost could potentially be used for plant growth. It has been reported that more than 80% of potassium and sodium are likely to be immediately available for plant growth (Horng, 2003).

Conclusion

The results indicate that composting of date palm wastes, date palm pits and shrimp and crab shell wastes is an environment friendly method that produces fairly hygienic products. The final compost products had high levels of nitrogen content, organic matter 25.4 ± 1.1 g/kg and 891.0 ± 8.6 g/kg dry matter respectively, with considerable amount of calcium, phosphorus, potassium, sodium and other micronutrients, which could be of good fertilize value to plants.

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المعالجة الحيوية في نظام مغلق لخليط من مخلفات النخيل ونوى التمر ومخلفات الجمبري والقشريات البحرية

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مدينة الملك عبدالعزيز للعلوم والتقنية، ص ب ٢٣٢٦٧٢ ، الرياض ١١٣٢١
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الملخص

تعد المعالجة الحيوية طريقة إقتصادية وبيئية فعاله للتخلص من النفايات. في هذه الدراسة تم تصميم معالج حيوي لمعالجة خليط من النفايات مكون من ٧٠٪ نفايات نخيل ونوى تمور و ٣٠٪ مخلفات جمبري وقشريات بحرية. بعد عملية المعالجة والتي استمرت لمدة ١٣ أسبوع. أظهرت نتائج المعالجة إحتواء الخليط على خصائص جيدة لاستخدامه كمخصب زراعي. وبتحليل خليط ناتج المعالجة أظهرت التحاليل إحتوائه على جم/كلجم ٨٩١,٠ مواد عضوية ، و ٢,٢ كالسيوم ، و ٠,٨٢ فوسفات ، و ١٤,٣ بوتاسيوم ، و ١,٣ صوديوم ، بالاضافة الى ٥٧,١ ٪ رطوبة ، و ٧,٩ أس هيدروجيني.