International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 4 Issue 08, August-2015

Composting of Food Waste using Indigenous Microorganisms (IMO) as Organic Additive

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***Abstract*— Municipal solid wastes usually contain the component of organic solid waste like food waste that disposed directly into the landfill. Direct disposal to landfill can cause impacts to the environment. Composting of organic solid waste is seen as a waste treatment method to avoid the waste from being dumped at the landfill. The utilization of organic additives towards composting process would produce an environmental product of compost. The objective of this study was to evaluate the performance of composting food waste by using indigenous microorganisms in term of the compost quality (pH, temperature, moisture content, C:N ratio and nutrient content). The compost have been prepared from three different mixtures of food waste for 30 days. IMO used as an organic additive during composting were prepared according to the method from previous study. The preparation of IMO consists of several phases include phase I until V with a mixture of various materials for each phase. During the composting process, all the parameters of IMO-compost obtained in a range like; pH value 5-9, temperature 29-55oC, moisture content 35-75%, nitrogen 1-7%, phosphorus 4-15%, potassium 11-23% and C:N ratio 5-20. The result showed that all compost quality for IMO-compost obtained in an acceptable range for final compost to establish.**

Keywords*— Composting, Indigenous Microorganisms, Food Waste, Compost Quality

I. INTRODUCTION

Municipal solid waste is suitable for composting because the presence of a high percentage of biodegradable organic matter, acceptable moisture content and carbon to nitrogen ratio in the waste [1]. In Malaysia, food waste was a larger average component of municipal solid waste produced. Food waste is organic solid waste that mostly consists of waste from food preparation and uneaten food, especially from cafeteria, restaurant, and residences and also from institutions. This waste usually sent directly to landfill as a final disposal.

Presently, the only technique used in Malaysia for the disposal of municipal solid waste is by landfilling. Unfortunately, most of the landfill sites areas in Malaysia are open dumping. Furthermore, this landfill is filling up at a very fast speed day by day and become an issue since the construction of new landfill required some consideration [2]. Landfill can cause negative impact to the environment and social threats [3]. Improper landfill management causes different environmental impacts include leachate contamination, problem of pest and odor, land degradation and also disturbs the residents near the landfill area in term of their health hazard [2]

Due to the excessive amount of waste at landfill that being filled up very fast, the disposal of waste becomes a serious problem. Food waste that contribute a larger component in municipal solid waste is seen can be treated in other ways instead of disposing in landfill. Recently, the composting process gets an attention from researcher and some entrepreneur to manage organic solid waste by return it to the useable product known as compost. Composting is a one of the waste treatment technology that facilitates the reduction of waste need to dispose at landfill and produce a beneficial product used in cultivated soils [4]. Kitchen and food waste contain of high moisture content, a loose physical structure and a high organics-to-ash ratio, the composting process seems to be an ideal disposal method [5].

A composting process occurs naturally, but it takes a long time for the decomposition of organic materials. Under control conditions, the composting process can happen in a short time, around a month or two months, depending on the waste materials used with the addition of additives during the process. The utilization of bulking agents has been studied by researchers in composting of food waste. Rice husk, rice bran and sawdust were used in composting of synthetic food waste in order to adjust the moisture content and carbon to nitrogen ratio of the compost mixtures [6]. Beside that, alginic chalk, rock dust, rock phosphate, clay granulate and straw also been used an additives to improve the compost [7]. However, to obtain an environmentally product of compost, an organic additives were more proposed to be used.

Usage of organic additives lately was seen to get an attention from the researcher because of the time consuming. It utilization not only improve the composting process, but also help in producing an environmental product of compost. An indigenous microorganism (IMO) is organisms that enrich the nutrient of soil quality and act as a reserve source for nutrient [8]. It contains beneficial microorganisms that play an important role in decomposition of organic matter. Organic additives can be prepared at home by self without the need to obtain from the manufacturer, thus it reduces the cost. This study was conducted to evaluate the compost quality of IMO-compost by composting the food waste with indigenous microorganisms (IMO) as an organic additive.

II. MATERIALS AND METHODS

Indigenous Microorganisms (IMO) Preparation

The method of indigenous microorganisms (IMO) preparation was obtained from the Department of Agriculture and from studies conducted by several researchers [9,10].

A small plastic container with size 0.19 m height × 0.26 m width × 0.01 m thick was filled with 200 g of rice and covered with white paper. Rubber bands were tied around the top of the container to secure the white paper in place. The box was then covered with a sheet of plastic to protect it from rain before placing it under the bamboo clumps to avoid direct sunlight. After 72 hours, the rice was covered with white mould (mycelium) and the smell was mildly sour. During this phase, indigenous microorganisms (IMO), IMO (I) were obtained.

A hundred grams of IMO, I then was mixed with 0.1 kg of granulated brown sugar in the ratio of 1:1. This mixture was then placed in a plastic container in a cool spot for 5 days to allow the fermentation process to take place. After this period, the second phase of IMO II will begin.

Three grams of IMO II was then mixed with 3.0 kg of rice bran and 0.75 L of fermented rice wash water until the mixture appeared semi moist (about 65% moisture and temperature of not exceeding 70°C). A mound of mixture was placed above the sack and covered with 20 cm height of dried leaves to protect it from rain. The third phase of IMO III was produced after 5 days.

IMO III was mixed with soil based on the ratio of 1:1. About 1.0 kg of IMO III was mixed with 1.0 kg of soil and 0.25 L fermented rice wash water was added into this mixture. The mixture was kept at 65% moisture content and temperature not exceeding 70°C for a period of 5 days. The height of the mixture did not exceed 70 cm, and 20 cm height of dried leaves were used to cover the mound from rain. IMO IV was produced during this phase.

Based on a ratio of 10:1, 8.0 kg of dried goat dung were mixed with 0.8 kg of IMO IV. 2.0 L of fermented rice wash water was used to flush the mixture to maintain the moisture level of 65%. The daily temperature was maintained at a temperature not exceeding 70°C and the temperature was measured daily using a thermometer. After 14 days, the fifth phase produced IMO V and this was used as an additive during the composting process.

Collection of Food Waste

Food waste (FW) used in this study was obtained from several foods stalls and restaurants near the School of Environmental Engineering, UniMAP. They contained waste from the uneaten and preparation of food such as fish or chicken bones, spoilt rice and vegetable remains. FW was washed first with tap water before they were used in the composting process. This process was required to remove the excess oil that contained in the collected FW. The oil will affect the activity of the microorganisms during the composting process. All FW was blended to reduce its size and accelerate the process.

FW was analyzed for pH, temperature, moisture content and C:N ratio before composting process was performed. Dried chicken dung (CD) was used since it was difficult to obtain fresh chicken dung. The CD was mixed with organic waste and prepared IMO during the composting process as a source of nitrogen. The CD was obtained from a commercial chicken farm in Pauh, Perlis and it was characterized for pH, moisture content and C:N ratio before use.

Composting Process

The composting process was carried out in plastic bin containers. The size of container was 0.29 m height x 0.25 m width, respectively. They were easily available, inexpensive and can readily be used at home. The plastic bin composter was covered with aluminium foil to enable the absorption of heat from the sun. FW were the main materials in the composting process with the inclusion of IMO as additive and CD as a source of nitrogen based on a range of different ratios. Water was added in the course of mixing organic waste with IMO and CD to maintain the moisture content at 40-60%.

The FW used to be on a wet weight basis; meanwhile IMO and CD used for composting with FW were on dry weight basis. All the proportions of mixing was in a semi wet-dry weight for FW. The ratios for FW were:

a) Ratio 1; 2:4:1 (1 kg of FW + 2 kg IMO + 0.5 kg CD)
b) Ratio 2; 4:2:1 (2 kg FW + 1 kg IMO + 0.5 kg CD)
c) Ratio 3; 4:4:1 (2 kg FW + 2 kg IMO + 0.5 kg CD)

III. RESULTS AND DISCUSSIONS

In this study, no control was made. This is because composting of food waste without any addition of bulking agents or additives will not happen. All of these mixtures treatment was characterized for pH, temperature, moisture content, total nitrogen, carbon to nitrogen ratio, phosphorus and potassium.

Utilization of IMO rapidly increases the composting process and odour emission will not occur during the process. IMO-compost FWC1 and FWC3 treatments matured in 30 days of the composting period, whereas, FWC2 treatment matured after 48 days. The different period of maturation process occurred because of the different ratios used in the composting process. FWC1 has more amount of additive used over food waste and FWC3 has the same amount of additive used with food waste. FWC2, however, used lesser additives during the process, which meant that the decomposition process took a long time to be completed.

Effect of pH during composting process

Fig. 1. shows the pH value for all treatments of food waste over a time period of 30 days for FWC1 and FWC3. The composting process to complete for FWC2 was longer where the time required was 48 days. The pH value for FWC1, FWC2 and FWC3 were in an acidic condition to alkaline. The pH for IMO-compost FWC1 was 6.31 on day 3 and 9.11 on day 30. IMO-compost FWC2 recorded a pH of 5.4 on day 3 and 9.32 on day 48. On day-3, 6.34 pH value was obtained by IMO-compost FWC3 and 9.10 on day 30.

The changes from acidic to alkaline conditions were caused by the turning frequency during the composting process. The production of a short-chain organic acid like acetic acid and butyric acid caused acidic condition for all IMO-compost at the beginning of the process [11,12]. These organic acids were produced by the microorganic reaction during the composting process.

However, after day 18 at pH 8.82 for FWC1 and pH 8.33 for FWC3 and day 27 at pH 8.07 for FWC2 until the end of composting days, the IMO-compost was in alkaline condition because of the release of proteins [13]. The source of protein came from the mixture of vegetables remains used during the composting process.

The sharp increase of pH to 9.0 also was caused by the transformation of organic nitrogen into ammonium hydrogen and followed by the decomposition of organic acids [14]. During the last stage of composting process, the emission of ammonium hydrogen continued although the degradation of organic matter was completed with little acid produced and this also contributed to the consistent rise in pH values [15].

The ranges of pH values obtained during this study of food waste composting was satisfactory and was the same as those obtained in previous studies at the range of 5.0 to 9.0, despite different materials being used and the difference in the method of composting [16,17,18].

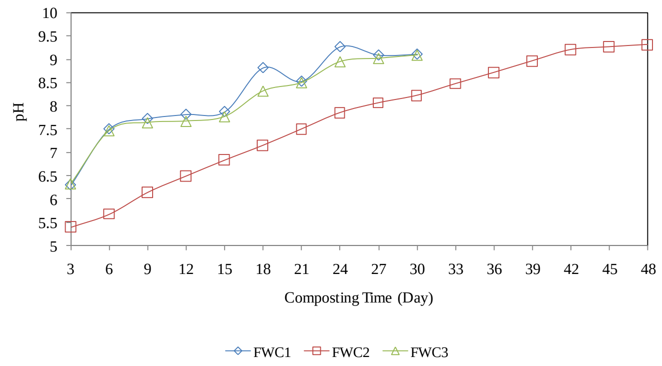

Fig. 1. The changes of pH over composting period

Effect of temperature during composting process

The variation of the temperatures for FWCI, FWC2 and FWC3 of IMO-compost with days of composting times are described in Fig. 2. The three stages of typical degradation phases: mesophilic, thermophilic and cooling stage occurred during the composting time.

IMO-compost entered thermophilic stage on day 9 for both FWC1 and FWC3 under the same temperature at 44°C. However, IMO-compost FWC2 began the thermophilic stage on day 12 at 42°C, which lasted a longer time of 25 days compared to the other treatments. This thermophilic phase occurred because of the decomposition of easily available carbon [19].

The highest temperature was recorded for IMO-compost treatment FWC2 at 55°C around 3 days, on day 21 before falling to temperature of 53°C on day 24. Some researcher [13], found that the increase of temperature from mesophilic to thermophilic stages entirely depended on the method of aeration and the amount of the waste substrate. Besides that, the rise in temperature during thermophilic phase also was caused by microbial activity during the composting process that resulted in the heat generation in the compost pile [20]

The highest number of indigenous microorganisms was attributed to the passage from mesophilic to thermophilic phase [21]. The high content of available nutrients, relatively small size of organic fraction particles and the readily degradable compounds were attacked by theses indigenous microorganisms during the transitional phase [22].

After that, at the end of the process, the cooling stage took place starting on day 24 for FWC1 at 33°C, on day 45 for FWC2 at 32°C and on day 18 for FWC3 at 34°C. The cooling stage occurred when the temperature drops to ambient temperature. Due to the lower level of decomposition of available organic matter, the microbial activity in the cooling stage decreases. When the degradable available carbon was exhausted, the microbial reaction during this phase also stopped and entered the cooling phase [19,23]. This indicated that the composting process was completed.

IMO-compost treatment FWC2 was seen as a good ratio for composting food waste with IMO due to the higher temperature achieved, which was 55°C compared to the other IMO-compost treatments. At this temperature, most pathogens were killed.

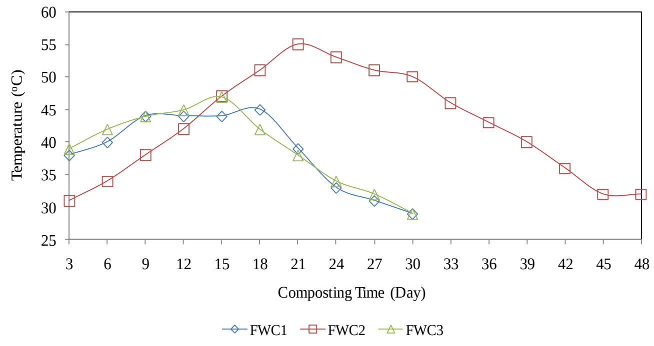

Fig. 2. The changes of temperature over composting period

Effect of moisture content over composting period

The moisture content of the IMO-compost for FWC1 and FWC2 over 30 days of composting time is presented in Figure 4.12. The values of moisture content obtained in this study are in the range of 40% to 75%. The highest value achieved for FWC1 was on day 18 at 51.54 %, 75.62% on days 21 for FWC2 and day 15 for FWC3 at 58.06%.

Temperature distribution during the composting process affects the loss of moisture content. This is because the loss of moisture content during the composting process was caused by the heat generated from the microorganisms such as bacteria and fungi [13]. Higher moisture content occurred due to the bio degradation of organic materials. It also indicated a maximum respiratory activity of the organisms at that time [20].

Although the values of moisture content obtained in the range was acceptable for finished compost, no leachate was produced during the composting process as obtained in previous studies [24]. The low moisture content of IMO could be the reason for the non-production of leachate, thus becoming a good absorbent for food waste during the composting process. The moisture content remained during the process because of the water vapour produced from decomposition process that condensed to the top of the cap container of the bin composter.

If the moisture content rises above 60%, anaerobic condition will take place. When the compost pile is excessively wet, it becomes heavy and difficult to uniformly apply [25]. However, in this study, IMO-compost treatment FWC2 recorded the value of moisture content of more than 60% starting from day 6 until day 36 with the highest temperature recorded at 75.62% on day 21. This is because the amount of IMO used is lower than food waste during the process. With high moisture content at this ratio, it required a long decomposition time and low degradation efficiency compared to the other IMO-compost treatment [26].

Although the moisture content for IMO-compost treatment FWC2 was above 60%, no foul odour was released during the decomposition process. This indicated that the application of IMO, similar to effective microorganisms (EM), was able to control the production of odour. The best ratio of IMO-compost recommended based on moisture content obtained were IMO-compost FWC1 and FWC3 because the moisture content was within the range of finished compost.

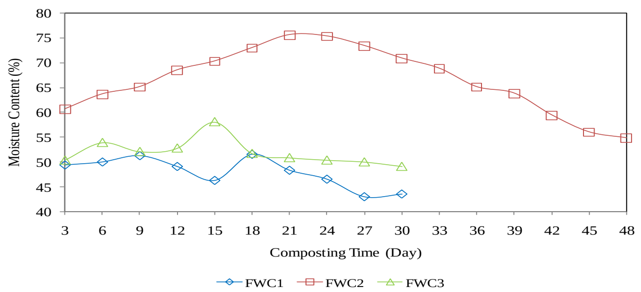

Fig. 3. The changes of moisture content over composting period

Effect of C:N ratio over composting period

The values of C:N ratio for all IMO-compost treatments of FWC1, FWC2 and FWC3 also showed a decrease relative to composting time, as indicated in Figure 4.13. The C:N ratio for all treatments was lower at the end of the composting time compared to that in the earlier stage. During the process, the increase in the degree of humidification and organic matter decomposition were reflected by the changes of C:N ratio [27].

The function of microorganisms in the process of composting was to break down biodegradable components and produce carbon dioxide (CO_2), other small molecules and water (H_2O). These microorganisms use carbon as a source of energy and nitrogen for building cell structure during the C:N ratio decomposition of organic matter.

The lowering of C:N ratio at the end of the composting time occurred when the rate of organic carbon was higher than the rate of organic nitrogen mineralization [19] and by the enhanced decomposition of organic matter. As stated by [28], to reduce the amount of additives used during the composting process, a low initial C:N ratio could be applied. However, the time required for the decomposition process will be longer than usual.

IMO-compost FWC2 required a longer time for decomposition process because of the lower C:N ratio in the initial days of composting compared to the other treatments. Although the other IMO-compost treatments of FWC1 and FWC3 showed a low initial C:N ratio, the IMO-compost FWC2 was much lower in initial C:N ratio and lesser than IMO ratio.

All IMO-compost treatments in this study have a C:N ratio of between 7 and 10 at the end of the composting process. This indicated that the compost has reached maturity stage. The final C:N ratio of lower than 20 is as an indication of proper compost maturity and is acceptable for maturity indices, although, a ratio of 15 or less is much preferred. If the compost reaches a value of 15, nitrogen immobilization can be avoided when the finished compost is applied to the soil [29,30].

However, several researchers considered that the value of C:N ratio of less than 20 as stabilized [31]. The complete decomposition of compost at the end of the process should have a C:N ratio between 16 and 20 [23].

IMO-compost treatment FWC3 had the best ratio recommended based on the end value of C:N ratio achieved during the process. IMO-compost treatment FWC2 is not recommended because it achieved the lowest end value of C:N ratio, although it recorded the highest value of temperature during the thermophilic phases.

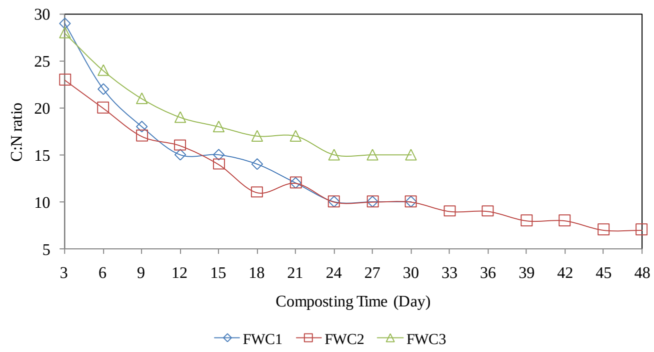

Fig. 4. The changes of C:N ratio over composting period

Effect of total nitrogen over composting period

The total nitrogen content of IMO-compost for all treatments of food waste had shown increases during the decomposition process. The continuous increase of total nitrogen in the composting stages has reduced the dry mass because of the degradation of organic compounds and loss of ammonia volatilization [32]. According to [33], higher degradation and concentration effects also cause an increase in total nitrogen during the whole composting process. The total nitrogen obtained during the FW composting was within a range of 2% to 6%.

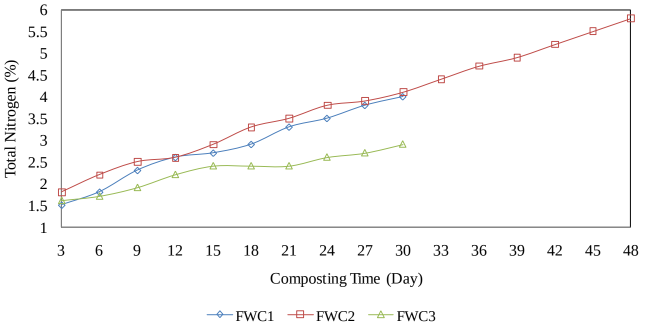

Fig. 5. The changes of total nitrogen over composting period

Effect of total phosphorus over composting period

As shown in Fig. 6, total phosphorus increased as decomposition progresses. The value of total phosphorus was in a range of 8% to 15%. Huang et al., (2004) indicated that the increase of total phosphorus at the later stages of composting time was due to the net loss of dry mass. More mineralization due to the higher microbial activity during the process which also contributed to the higher total phosphorus content [34].

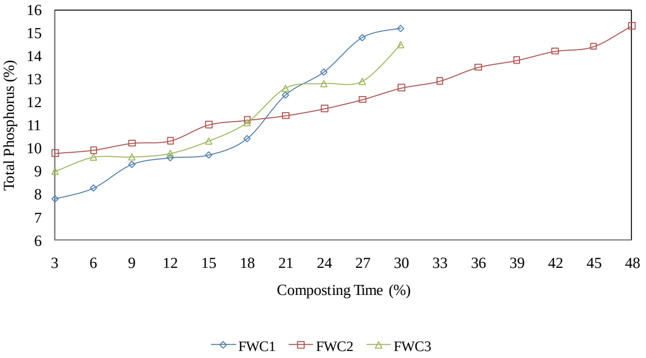

Fig. 6. The changes of total phosphorus over composting period

Effect of total potassium over composting period

Similar to total nitrogen and total phosphorus, the value of total potassium obtained during the FW composting process increased as well. The total potassium obtained was within a range of 16% to 25%. The role of microorganisms in solubilising insoluble potassium during the decomposition process has produced an acid that affects the amount of total potassium in the later stage [35]. Besides that, the increase was caused by the higher mineralization rate due to higher microbial activity [36].

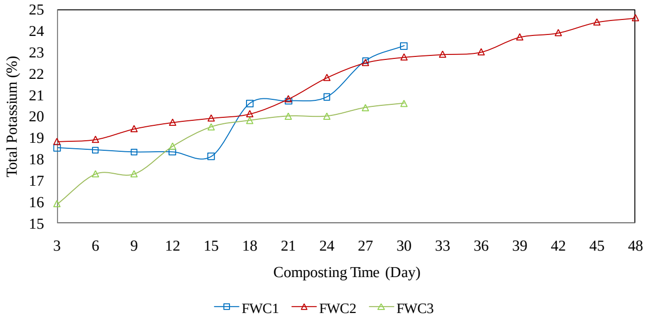

Fig. 7. The changes of total potassium over composting period

CONCLUSION

Composting of organic waste with IMO resulted in the maturity and stability of compost after 60 days for garden waste and 30 to 48 days for food waste. The pH obtained during the composting process was in the range of 8.0 to 9.0 for IMO-compost GW and 5.0 to 9.0 for IMO-compost FW. The temperature recorded for IMO-compost GW was in the range of 30ºC to 48ºC and 29ºC to 55ºC for IMO-compost FW. IMO-compost GW showed moisture content to be in the range of 36% to 65%, whereas 50% to 75% moisture content was recorded by IMO-compost FW. The NPK values for IMO-compost GW were in the range of 2% to 7%, 4% to 8% and 12% to 18%. The C:N ratios for all treatment of IMO-compost GW showed a value of 6 to 12. For IMO-compost FW, 1-5%, 7-15% and 15-25% were obtained for NPK values during the decomposition process. The range of C:N ratio of IMO-compost FW was 7-15.

The best ratios recommended to be used, based on this study during the composting process with three different ratios for each garden and food waste, were IMO-compost GWC2 and FWC3. This is because, IMO-compost GWC2 and FWC3 recorded a respectively higher temperature of 48ºC and 55ºC during the 60 days and 30 days of composting period. Beside that, the end C:N ratio of 12 and 15 also recorded during the process was the highest among the other ratios.

The utilization of IMO as organic additives during the composting of organic waste has accelerated the rate of the decomposition process. IMO is seen as a good absorbent during food waste composting with low moisture content, which was proven when no leachate was produced during the composting process. Besides that, no foul odour was released during the process indicating that the application of IMO allowed the control of odour production.

The quality, stability and maturity of finished composts depended on the composition of raw materials used for compost production. Different organic waste and types of substrate used will give rise to different quality of finished compost, different characteristic and different potential markets.

ACKNOWLEDGMENT

This research was funded by Research Acculturation Collaborative Effort (RACE) Grant Scheme (Grant number: 9017-00021).

REFERENCES

[1] S.P. Gautam, P.S. Bundela, A.K. Pandey, M.K. Awasthi, and S. Sarsaiya, "Composting of municipal solid waste of Jabalpur City". *Global Journal of Environmental Research, 4 (1)*, 43-46, 2010.

[2] R.P. Sigh, P. Singh, A.S.F. Araujo, M.H. Ibrahim and O. Sulaiman, "Management of Urban Solid Waste: Vermicomposting a Sustainable Option". *Resources, Conservation and Recycling, 55*, 719-729, 2011.

[3] M.N.M. Yunus, and K.A. Kadir, "*The Development of Solid Waste Treatment Technology Based on Refuse Derived Fuel and Biogasification Intergration".* Paper presented at the International Symposium on Renewable Energy, 2003

[4] C. Sundberg, D. Yu, I. Franke-Whittle, S. Kauppi, S. Smars, and H, Insam, "Effects of pH and Microbial Composition on Odour in Food Waste Composting". *Waste Management, 33*, 204-211, 2013.

[5] J.I. Chang, and T.-E. Hsu, "Effects of Compositions on Food Waste Composting". *Bioresource Technology, 99*, 8068-8074, 2008.

[6] J.I. Chang, and Y.J. Chen, "Effects of Bulking Agents on Food Waste Composting". *Bioresource Technology, 101*, 5017-5924, 2010.

[7] B.G. Yvette, and J.H. Robert, Composting of Organic Wastes: A Main Component for Successful Integrated Solid Waste Management in Philippine Cities. 2000

[8] T. Sumathi, A. Janardhan, A. Srilakhmi, D.V.R. Gopal, D. and G. Narasimha,. Impact of Indigenous Microorganisms on Soil Microbial Activity and Enzyme Activities. *Archieves of Applied Science Research, 4 (2)*, 1065-1073, 2012.

[9] A.N. Hanim, M.N.M Majid, O.H. Ahmed, and K.S.A. Khairulmazmi, "*Selection of Indigenous Microorganisms in Enhancing Imo-Compost Production".* Paper presented at the 11th International Annual Symposium on Sustainability Science and Management, UMT, 2012

[10] H. Park, and M.W. DuPonte, "How to Cultivate Indigenous Microorganisms". *Biotechnology. BIO-9, College of Tropical Agriculture and Human Resources, University of Hawaii, Mãnoa*, 2008.

[10] Y. Eklind, and H. Kirchmann, "Composting and storage of organic household waste with different litter amendments. II: nitrogen turnover and losses". *Bioresource Technology, 74*(2), 125-133, 2000.

[11] G.A. Ogunwande, J.A. Osunade, and L.A..O. Ogunjimi, "Effects of Carbon to Nitrogen Ratio and Turning Frequency on Composting of Chicken Litter in Turned-Windrow Piles". *Agricultural Engineering International, Vol.X*, 16, 2008.

[12] S.A. Tweib, R.A. Rahman, and M.S. Khalil, M. "Composting of Solid Waste from Wet Market of Bandar Baru Bangi Malaysia". *Australian Journal of Basic and Applied Sciences, 5 (5)*, 975-983, 2011.

[13] B. Beck-Friis, S. Smårs, H. Jönsson, and H. Kirchmann, "SE—Structures and environment: gaseous emissions of carbon dioxide, ammonia and nitrous oxide from organic household waste in a compost reactor under different temperature regimes". *Journal of Agricultural Engineering Research, 78*(4), 423-430, 2001.

[14] H. Yu, and G.H. Huang, "Effects of sodium acetate as a pH control amendment on the composting of food waste". *Bioresource Technology, 100*(6), 2005-2011, 2009.

[15] M. Aulinas Masó, M. and A. Bonmatí Blasi, "Evaluation of composting as a strategy for managing organic wastes from a municipal market in Nicaragua". *Bioresource Technology, 99*(11), 5120-5124, 2008.

[16] M. Kumar, Y.-L. Ou and Y.-L.Lin, "Co-composting of green waste and food waste at low C/N ratio". *Waste Management, 30*(4), 602-609, 2010.

[17] N. Zhu, "Effect of low initial C/N ratio on aerobic composting of swine manure with rice straw". *Bioresource Technology, 98*(1), 9-13, 2007.

[18] F. Yang, G. X. Li, Q.Y. Yang and W.H. Luo, "Effect of bulking agents on maturity and gaseous emissions during kitchen waste composting". *Chemosphere, 93*(7), 1393-1399, 2013.

[19] J.I. Chang, J. J. Tsai, and K.H. Wu, "Thermophilic composting of municipal solid waste". *Bioresource Technology, 97*(1), 116-122, 2006.

[20] O. Fourti, "The maturity tests during the composting of municipal solid wastes". *Resource, Conservation and Recycling, 72*, 43-49, 2013.

[21] E.I. Jimenez, and V.B, Garcia, "Composting of domestic refuse and sewage sludge evolution of temperature, pH, C/N ratio and cation exchange capacity". *Resource, Conservation and Recycling, 6*(45-60), 45, 1991.

[22] D. Elango, N. Thinakaran, P. Panneerselvam, and S. Sivanesan, "Thermophilic composting of municipal solid waste". *Applied Energy, 86*, 663-668, 2009.

[23] R. Mohee, and A. Mudhoo, Analysis of the physical of an in-vessel composting matrix. *Powder Technology, 155*, 92-99, 2005.

[24] W.D. George, "Description and use of municipal solid waste composts in New Mexico". *Extension Horticulture Specialist*, 2010.

[25] Z. Li, H. Lu, L. Ren, and L. He, "Experimental and modeling approaches for food waste composting: A review". *Chemosphere, 93*(7), 1247-1257, 2013.

[26] M. K. Iqbal, T. Shafiq, A. Hussain, and Ahmed, K. "Effect of enrichment on chemical properties of MSW compost". *Bioresource Technology, 101*, 5969-5977, 2010.

[27] G.F Huang, J.W.C. Wong, Q.T. Wu, and B.B. Nagar, "Effect of C/N on composting of pig manure with sawdust". *Waste Management, 24*(8), 805-813, 2004.

[28] J.-D Kim, J.-S. Park, B.-H. In, D. Kim, and W. Namkoong, "Evaluation of pilot-scale in-vessel composting for food waste treatment". *Journal of Hazardous Materials, 154*(1–3), 272-277, 2008.

[29] I. van Heerden, C. Cronjé, S.H. Swart, and J.M. Kotzé, "Microbial, chemical and physical aspects of citrus waste composting". *Bioresource Technology, 81*(1), 71-76, 2002.

[30] S.P. Mathur, G. Owen, H. Dinel, and M. Schnitzer, "Determination of compost biomaturity, literature review". *Biological Agriculture and Horticulture, 10*, 65-85, 1993.

[31] M. Ros, A. Garcia, and T. Herandez, "A full-scale study of treatment of pig slurry by composting: kinetic changes in chemical and microbial properties". *Waste Management, 26*, 1108-1118, 2006.

[31] X. Wang, A. Selvam, M. Chan, and J.W.C. Wong, "Nitrogen conservation and acidity control during food wastes composting through struvite formation. *Bioresource Technology, 147*, 17-22, 2013.

[32] A.S. Kalamdhad, Y.K. Singh, M. Ali, M. Khwairakpam, and A.A. Kazmi, "Rotary drum composting of vegetable waste and tree leaves". *Bioresource Technology, 100*, 6442-6450, 2009.

[33] M. Khwairakpam, and R. Bhargava, "Vermitechnology for sewage sludge recycling". *Journal of Hazardous Materials, 161*, 948-954, 2009.

[34] S. Suthar, Vermicomposting potential of Perionyx sansibaricus (Perrier) in different waste materials. *Bioresource Technology, 98,* 1231-1237, 2007.