Solid State Bioreactor for Food Waste Composting: A Process Optimization

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Abstract

Compost production, an aerobic biodegradation process is one of the alternatives ways to manage and reuse the waste in order to produce compost product with high commercial value for agricultural applications. The longer reaction time of the composting process is one of the barriers for high rate of compost production. Therefore, this study is carried out to evaluate the shorter composting period by optimization technique in a solid state bioreactor/composter at thermophilic condition. Among the parameters studied, the selected parameters to be considered were temperature and rotation (mixing) time of the horizontal stirred tank solid state bioreactor (HST-SSB). A statistical design was applied to determine the optimum parameters in the reactor. A set of temperatures at 60-80^{0}C which are under thermophilic conditions was chosen to determine the optimum temperature to produce high nutrient content of compost product and 12,16 and 20 hours as the total rotation time per day (24 hours). The food waste was fed at 20-25 kg/day with 20% of saw dust as bulking agents per batch with the microbial inoculum that contain effective microorganisms (EM). The EM was used for faster biodegradation with highly active hydrolytic enzymes as well as it increases the microbial diversity of soil ecosystem. The optimum temperature and rotation time were determined by two-level fractional factorial design (FFD). Decomposition of the food waste was completed in 6 days and harvesting at day 7. The results showed that the optimum temperature and rotation time of the HST-SSB were 60^0 C and 12 hrs/day with the pH value of 6.2 for the compost product with C/N ratio of 13 and 85% of the germination index.

Keywords: *food waste, compost, effective microorganisms, two-level fractional factorial design, thermophile process*

1.0 Introduction

Food that is fit for human consumption but is not consumed because it is or left to spoil or discarded by retailers or consumers is called food waste. Malaysia is well known for abundance of food, unfortunately, the unique food culture is also turning into a culture of waste. Malaysian food waste is estimated about 15,000 tons of food daily including 3,000 tons that is still fit for consumption and should not be discarded. As the food waste contain high degradable organic materials such as sugars, starch and high moisture content (MC) also very dense [1,2], thus make it most suitable to dispose by composting.

Composting is the biological decomposition and stabilization of organic substrates under the condition of thermophilic temperatures as a result of biologically produced heat [3]. Nowadays, various size of in vessel composting machines have been developed and used by institutions, hotels, restaurants, etc [4, 5]. This is due to increasing food waste production in daily life as well as rapid growth of population and also economic development.

There are several types of composting process such as onsite composting, vermicomposting, aerated windrow composting, aerated static pile composting, in-vessel composting and thermophilic compost [6-8]. In order to choose the best method to do the composting process, there are certain criteria that have to take into account such as type of waste, environmental effect, process conditions, etc. Among the best conditions for the effective composting process, reaction time and conditions are considered to evaluate efficiency and maturity of the compost.

In general composting took longer time (60-90 days) to complete its degradations process [9,10], thus decomposition under thermophilic conditions (high temperature conditions) is getting increasing attention worldwide because of its ability to convert solid wastes into organic fertilizer within a short period of time. Optimization of the vessel composting is an alternative to evaluate the process faster and effective in mature composting process. Recently a few studies have been reserached on the composting vessel optimization including temperarure, pH, agitation, etc. for various feedstocks [4,11]. In this study, decomposition process for food waste under thermophilic conditions can be completed within 7 days while normal composting took about 60-90 days for complete degradation. Due to the abundant amount of food waste generated, normal decompose would not be an effective and efficient solution for composting process. Therefore, the study aims in optimizing the process parameters in the horizontal stirred tank (vessel) solid state bioreactor especially the themophillic temperature and rotating (mixing) time for faster and mature compost within a short period of time (7 days).

2.0 Materials and Method

2.1 Materials

2.1.1 Food Waste

The raw material in this study was food waste. The food waste was obtained from the Educational cafeteria at International Islamic University Malaysia (IIUM). The food waste was sorted manually to separate the unwanted wastes such as plastics, tins and bottles and characterized accordingly.

2.1.2 Bulking Agent

For composting, saw dust (20% w/w) was used as the bulking agents to mix the product to produce bio-compost. Bulking agents also provide dry matter, which gives a porous structure to the compost mixture and absorb the moisture produced by the decomposing food waste. The water absorption capacity of a bulking agent was therefore an important parameter in the formulation of compost recipes.

2.1.2 Inoculum

The effective microbes (EM) as the inoculum were isolated and cultured based on the biodegradation potential in the various substrates. The EM was inoculated and cultured in the nutrient media (LB broth) for initial growth followed by the further growth in the solid media of rice bran and selected carbon source such as glucose. After 2 days of culture in the rice bran media the cells counted were 108 cells/ml. The amount of EM as the inoculum used was 3 kilograms for each experiment.

2.2 Experimental Methods

2.2.1 Composting Process

The process was started by collecting 20-25 kg of food waste from the source. The food waste then characterized manually to seperate the unwanted waste such as plastics and tins. A 50-L capacity of solid state thermophilic (SST) composter was designed and fabricated locally. The SST composter includes the temperature ranges of 30^0 to 90^0C and rotation of 10 to 30 minutes cycle. A 4-5 kg of saw dust as the buking agents was added together with 3 kg of inoculum that contain effective microorganism. This process was repeated for 6 days with the same amount of food waste only. Compost product was collected and harvested at Day 7. TOC,TN pH, moisture content, and germination index analysis were carried out after each set of experiments.

2.2.2 Optimization Process

Temperature and rotation (mixing) time was set differently for each experiment. The FFD was applied to set up the experimental runs. A total of 5 experimental runs obtained by the FFD. The runs were temperature and rotation time were set: run 1, 80°C and 20 hours; run 2, 60°C and 20 hours; run 3, 60°C and 12 hours; run 4, 80°C and 12 hours; and run 5, 70°C and 16 hours, respectively. The parameters as evaluating factors of the compost were total organic carbon (TOC),total nitrogen (TN), C/N ratio, pH, moisture content, and germination index. These parameters were evaluated to determine the optimum conditions. The statistical analysis of the optimization process was done by using Design of Expert (DOE); Two-Level Fractional Factorial Design (FFD) and analysis of varience (ANOVA). The block diagram and optimization process flow chart is shown in Figure 1.

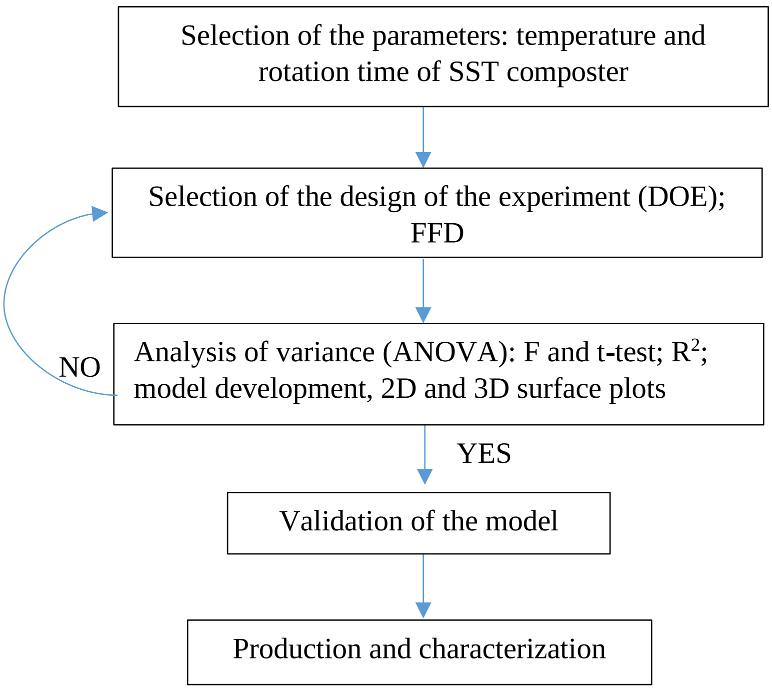


Figure 1: A block diagram and optimization process flow chart of compost production

2.2.3 Analytical analysis

The organic matter (OM) was determined by gravitational loss-on-ignition of oven dried at 105°C for 24 hr based on the procedure of Navarro [12]. Total organic carbon (TOC) and total Kjedahl nitrogen (TKN) was used to calculate the C/N ratio [12]. The germination Index (GI) is used to evaluate the toxicity of composts to seedling and to determine the maturity of the compost [13,14]. pH and moisture content was tested for each set of run. pH test was done by standard pH test procedures. For moisture content test, the standard dry method was used.

3.0 Results and Discussion

A total of 5 experimental runs as the DOE were conducted to evaluate the composting process with various effective parameters as shown in the Table 1. The results showed that the value of the organic carbon content in the food waste compost was about 30% to 40% which gives a good value of carbon. Organic matter in soil usually less than 5% of its total weight. The benefits of organic matter as a carbon supply for beneficial soil microbes. These microbes will later produce enzyme which help to degrade the food waste. Total nitrogen was an essential nutrient for plants. Total nitrogen (TN) is the sum of total kjeldahl nitrogen (ammonia, organic and reduced nitrogen) and nitrate-nitrite From this experiment, value of the total nitrogen was around 1% to 3%. Value of nitrogen should be low as to get better dissolved oxygen in the soils and prevent alteration to the plants.

As composting processes mainly consist of biological degradation reactions, carbon to nitrogen ratio (C/N ratio) plays an important role [14]. The identification of an optimal C/N ratio was a great significance for getting a favorable composting result, and highly depends on the property of composting materials [1]. From the result obtained, the most optimum conditons was experimental runs 2-4. These runs gave the a ratio of about 12 which was a good C/N ratio for mature compost. It was important to know the C/N value in soil as it determined the decomposition rate happen in the process. Above all, the best C/N ratio should be less than 15%, a higher ratio will result in slower composting rates [15]. However, all of these runs were set with different set of temperature and rotation time. As Run 3 was set with minimum rotation time which was 12 hours, thus Run 3 was choose to be the best optimization parameters which required less energy consumption and favorable C/N ratio. Run 1 shows the highest value of C/N ratio, thus this set of parameters and condition was the most unfavorable for the decomposition process as it caused slower rate of degrading process.

Results of pH value shows that all sets of run fall under acidic conditions. The results of moisture content test was within 30% to 40 %. The moisture content was varies among each set. This was because each set paramters was set under different conditions. The moisture content was quite low may due to the high temperature of the process and also the moisture content in the raw material was low. However, this moisture content value was acceptable as the moisture content of soil was also around 30%.

Germination index (GI) and germination percentage (GP) results for each run as shown in Table 1 below gave the highest GI number was Run 3 which was 4.8 rate of index. The higher the rate was preferable as it shows faster growth of plant. This was predictable as Run 3 was the most optimum conditions set of parameters for this project. Run 3 also gave the highest GP value which was 87.5% and that was a very good percentage value. It shows that, this type of fertilizers is good to support the growth of plants compared with others type of fertilizers [2,17].

Table 1. Result of Analysis for food waste composting process with the DOE

Run	TOC (%)	TN (%)	C/N Ratio	pH	MC (%)	GI	GP (%)
1	39.5	2.1	18.8	5.33	30.2	2.5	57.0
2	34.4	2.8	12.3	5.36	32.5	2.2	53.5
3	33.4	2.2	12.0	6.20	35.5	4.8	87.5
4	30.3	2.4	12.6	6.18	39.8	2.0	51.3
5	40.5	2.9	14.0	6.16	35.5	2.6	63.5

Control	48.2	2.2	22	6.8	50	1.92	37.5

3.1 Optimization of Parameters by using Two-Level Factorial Design and ANOVA

The model for optimization of composting process was formulated using Design of Expert (DOE) which used Two- Level Fractional Factorial Design (FFD), where each response was analyzed by model selection, analysis of variance (ANOVA) and 3- dimensional model graphs. The experimental data were used to form the regression equations. Table 2 below shows the data from ANOVA for selected Factorial Model and Table 3 shows the overall analysis of the model.

Analysis of variance (ANOVA) was used to analyze the significance of this statistical model. The result of the ANOVA was listed in Table 2 above. The model "F value" and "Prob > value" are 654.25 and < 0.0001 which imply that the model was significant. There was only 0.001 % of probability to get high model of "F-value" due to creation of noise. In this statistical analysis, terms A, B and AB are highly significant terms ("Prob > value" less than 0.001).

Table 2. Analysis of variance (ANOVA) for optimization of the process parameters

Source	Sum of Squares	DF	Mean Square	F-Value	MC (%)	Remark
Model	305.19	3	101.73	654.25	<0.0001	Significant
A	43.99	1	43.99	282.93	<0.0001	
B	223.87	1	223.87	1439.79	<0.0001	
AB	37.32	1	37.32	240.05	<0.0001	
Curvature	48.14	1	48.14	309.58	<0.0001	
Pure Error	0.78	5	0.16		<0.0001	Significant
Total	354.10	9				

Based on the analysis of the model listed in Table 3, the regression coefficient (R2) from this model was found to be 0.9975 which indicates that this quadratic model is significantly reliable and 99.75 % of the variability in the result can be explained by the model. The adjusted R2 value corrects the R2 value for the sample size and for the number of terms in the model. In this model, the adjusted R2 is 0.9959 which is also considered as a high value which imply that this optimization model was significant. Meanwhile, the "Pred R2" value was 0.9912 also indicates that a good adjustment between the observed and predicted values could occur. The value of "Adeq Precision" which measures the signal-to-noise ratio is 58.801. The "Pred R2" value which was 0.9912 which very close to the "Adj R2" of 0.9959. Additionally, the coefficient of variation (CV) which can be used to measure the reliability and precision of the experiment was found to be 2.3 which was highly approximate. The higher the value of CV, the less reliable was the experiment. This value was a measure of residual variation of the data relative to the size of the mean. Then, the value of predicted residual sum of squares (PRESS) is found to be 3.11 which was very precise value. It was a measurement of how fit of each point in the design. The smaller the PRESS value, the better the model fits the data points.

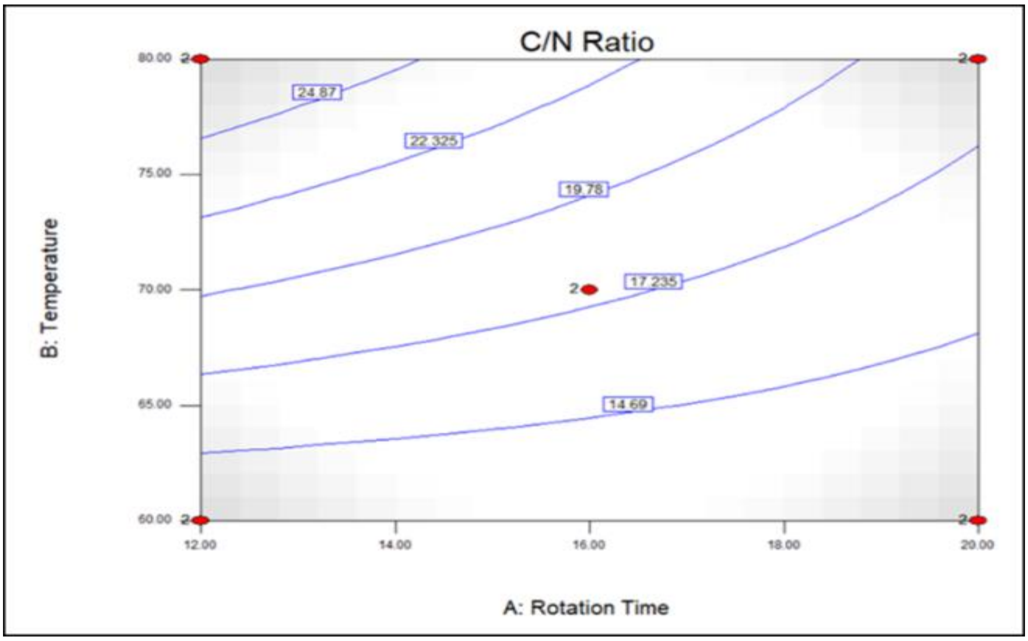
Table 3. Overall analysis of the model

Std. Dev	0.39	R2	0.9975
Mean	16.52	Adj R2	0.9959
C.V	2.3	Pred R2	0.9912
PRESS	3.11	Adeq Precision	58.801

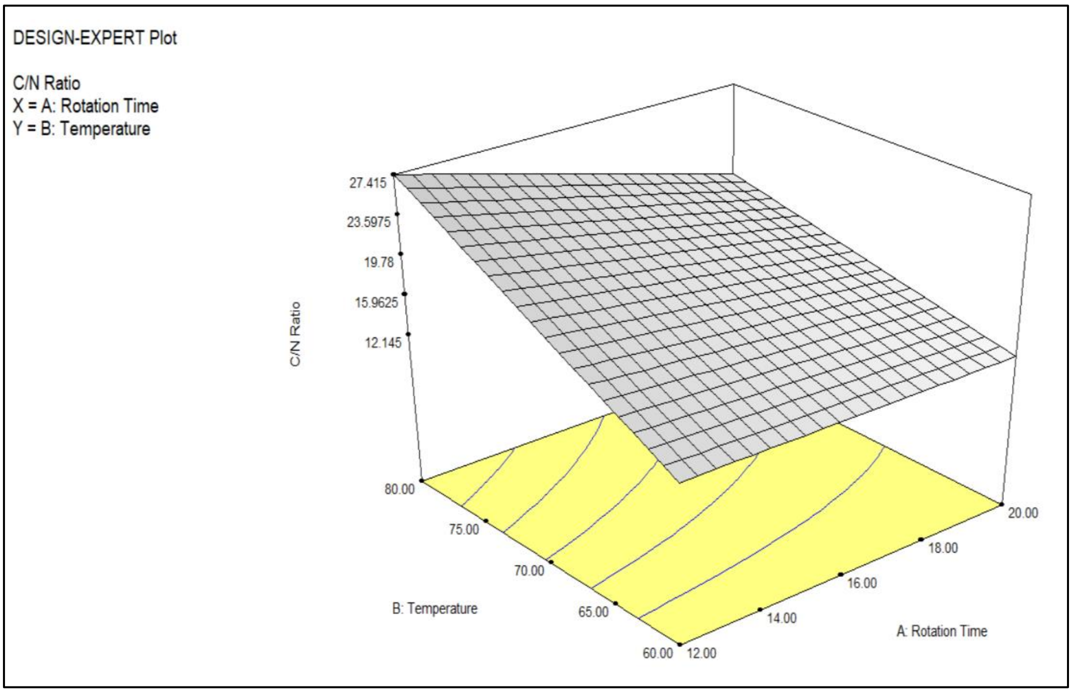
The optimization of parameters of composter for food waste composting process with two factors of rotation time (A), and temperature (B) was predicted by following polynomial equation:

$$\text{C/N Ratio} = 17.62 - 2.35 A + 5.29 B - 2.16 AB \quad (1)$$

The graphical representation of the parameters related to the optimization composter parameters which was temperature and rotation time was illustrated in the contour and 3-Dimensional two level factorial design plots in order to investigate the interaction between variables and to determine the optimum parameters condition for the composting process. The contour and 3-Dimensional plots were based on the function of two parameters which were temperature and rotation time,C/N ratio as the response. Fig 2 (a) and (b) shows the model graphs obtain from the Design-Expert Plot. From the graph, it can be conclude that, the most optimum condition for the parameters was at 60^{0}C at 12 hours rotation time with 12.6 C/N ratio. From 3D model graph the level of the rotation time shows the same level, thus this condition explained, the rotation time between 12 hours to 20 hours was significant, but 12 hour rotation time was choose as the optimum condition because lesser time we result in less energy consumption [18]. The validation of the model was conducted within the design range and found that the experimental results suppoted the model with the error of about 10%. This shows a good agreement between the model and experiment in the optimization process.



(a)



(b)

Figure 2. Optimization parameters of composter for food waste composting process (a) contour plot (b) 3D plot

4.0 Conclusion

The findings conclude that the optimum parameters, temperature and rotation time of food waste under thermophilic condition were sucessfully determined to optimize an effective and efficient compsoting process in terms of the values of TOC, TN, pH, moisture content and germination index. According to the results, the optimum condition for the composter to decompose the food waste with the best C/N ratio was at 60^0 C with 12 hours of rotation time. This study shows a positive route of an effective food waste management through the composting process which would contribute to reduce a significant composting period with thermophilic coditions. Overall, the results can provide alternative ways in managing the uprising amount of food waste produced in the community by gaining some profits from the unused or underused waste.

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References

[1] BK. Adhikari, S. Barrington, J. Martinez, and S. King, “Characterization of food waste and bulking agents for composting’’, *Waste Management*, vol. 28, no. 5, pp.795-804, 2008.

[2][3] JI. Chang, and YJ. Chen, “Effects of bulking agents on food waste composting’’, *Bioresource Technology*, vol. 101, no. 15, pp.5917-5924, 2010.

[3][4] SR. Iyengar, and PP. Bhave, "In-vessel composting of household wastes'', *Waste Management,* vol. 26, no. 10, pp.1070-1080, 2006.

[4] M. Ajmal, S. Aiping, M. Awais, B. Zhou, X. Zihao, "Optimization of pilot-scale in-vessel composting process for various agricultural wastes on elevated temperature by using Taguchi technique and compost quality assessment", *Process Safety and Environmental Protection*, vol. 140, pp. 34-45, 2020.

[5] M. Kucbel, H. Raclavská, J. Růžičková, K. Raclavský, D. Juchelková, "Properties of composts from household food waste produced in automatic composters", *Journal of Environmental Management*, vol. 236, pp. 657-666, 2019.

[6] [2] JD. Kim, JS. Park, BH. In, D. Kim, and W. Namkoong, "Evaluation of pilot-scale in-vessel composting for food waste treatment'', *Journal of hazardous materials,* vol. 154, no. 1-3, pp.272-277, 2008.

[7] D. Cekmecelioglu, A. Demirci, RE. Graves, and NH. Davitt, "Applicability of optimised in-vessel food waste composting for windrow systems", *Biosystems engineering,* vol. 91, no. 4, pp.479-486, 2005.

[8] M. Rasapoor, T. Nasrabadi, M. Kamali, and H. Hoveidi, "The effects of aeration rate on generated compost quality, using aerated static pile method", *Waste Management,* vol. 29, no. 2, pp.570-573, 2009.

[9] M. Chikae, R. Ikeda, K. Kerman, Y. Morita, and E. Tamiya, "Estimation of maturity of compost from food wastes and agro-residues by multiple regression analysis", *Bioresource Technology,* vol. 97, no. 16, pp.1979-1985, 2006.

[10] MK. Iqbal, T. Shafiq, and K. Ahmed, "Characterization of bulking agents and its effects on physical properties of compost", *Bioresource Technology,* vol. 101, no. 6, pp.1913-1919, 2010.

[11] M. Waqas, AS. Nizami, AS. Aburiazaiza, IMI. Ismail, MI. Rashid, "Optimizing the process of food waste compost and valorizing its applications: A case study of Saudi Arabia", Journal of Cleaner Production, vol. 176, pp. 426-438, 2018

[12] AF. Navarro, J. Cegarra, A. Roig, and D. Garcia, "Relationships between organic matter and carbon contents of organic wastes", *Bioresource Technology,* vol. 44, no. 3, pp.203-207, 1993.

[13] JWC. Wong, KF. Mak, NW. Chan, A. Lam, M. Fang, LX. Zhou, QT. Wu, and XD. Liao, "Co-composting of soybean residues and leaves in Hong Kong", *Bioresource Technology,* vol. 76, no.2, pp.99-106, 2001.

[14] F. Zucconi, "Evaluating toxicity of immature compost", *Biocycle,* vol. 22, no. 2, pp.54-57, 1981.

[15] R. Guo, G. Li, T. Jiang, F. Schuchardt, T. Chen, Y. Zhao, and Y. Shen, "Effect of aeration rate, C/N ratio and moisture content on the stability and maturity of compost", *Bioresource technology,* vol. 112, pp.171-178, 2012.

[16] FG. Prahl, JR. Ertel, MA. Goñi, MA. Sparrow, and B. Eversmeyer, "Terrestrial organic carbon contributions to sediments on the Washington margin", *Geochimica et Cosmochimica Acta,* vol. 58, no. 14, pp.3035-3048, 1994.

[17] AH. Molla, A. Fakhru'l-Razi, and MZ. Alam, "Evaluation of solid-state bioconversion of domestic wastewater sludge as a promising environmental-friendly disposal technique", *Water research,* vol. 38, no. 19, pp.4143-4152, 2004.

[18] M. Waqas, AS. Nizami, AS. Aburiazaiza, IMI. Ismail, MI. Rashid, "Optimization of food waste compost with the use of biochar", *Journal of Environmental Management*, vol. 216, pp. 70-81, 2018.