FOOD WASTE COMPOSTING WITH THE ADDITION OF *SABAH RAGI* USING PASSIVE AERATION-AUTO TURNING COMPOSTER

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FACULTY OF ENGINEERING
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DECLARATION

I hereby declare that the work in this thesis titled 'Food Waste Composting with the Addition of *Sabah Ragi* using Passive Aeration-Auto Turning Composter' has been carried out with my own work. The information derived from previous study has been duly acknowledged and list of references are provided.

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ABSTRACT

Organic wastes generated can cause environmental problems if not treated properly. In-vessel Composting is an alternative biological treatment method used to convert waste into a stabilized, valuable end-product. However, identifying the process biodegradation mechanism and the uncertainty measures in controlling the system are critical for good performance. Thus, the purposes of this study were to determine the optimum turning frequency and ragi dosage, its kinetic analysis based on volatile solids, evaluate the performance of passively aerated in-vessel composting process, examine the effect of compost on the plant growth and to determine the feasibility of composting system in terms of economic analysis. Four sets of experiments (TF for every 0, 1, 3, and 5 days) were conducted to investigate turning frequency (TF). Four different ragi compositions were studied: 0 g (control), 0.5 g, 1.0 g and 1.5 g ragi/200 g initial compost using a compost bottle with turning every three days for 15 days. The elemental kinetics of the process were determined using zero-, first-, second- and n-order equations. Subsequently, the optimum condition obtained from the experiments were used for passively aerated in-vessel composting process. Food waste and dry leaves (2.6:1 by weight) composting process was conducted in two trials for 40 days. The physical, chemical, biological and morphological changes that occurred during the composting process were identified and evaluated. The power consumption during the composting process was also evaluated. Dwarf crape jasmine (*Tabernaemontana divaricata*) were grown in media containing compost and top soil with nine different proportion (0%, 2.5%, 5%, 10%, 20%, 30%, 40%, 50%, or 100% of compost) and the plant growth was measured for 90 days. Based on organic matter loss, the turning frequency of every three days and 1.0 g ragi/200 g of the initial compost resulted in the highest OM loss of 79.2% and 61.3%, respectively. The n-order model successfully estimated the degradation profile for 3-days TF and 1.0 g ragi/200 g of the initial compost with rate constant value (k) of 8 x 10^{-5} $VS^{(1-n)}$.day^{-1} and 1.30 x $10^{(1-n)}$ VS^{-1}.day^{-1}, respectively. For passively in-vessel composting process, the highest average compost temperatures of 54.2 °C and 46.7 °C were recorded on days 7 and 10 of Trials 1 and 2, respectively. The highest average heat generation rate per initial mass of compost dry matter of 4098 kJ kg−1 day−1 was achieved on day 7. In this study, application of the second-order model resulted in good responses with rate constant (k) of 0.0003 TOC^{-1}.day^{-1} and 0.0002 TOC^{-1}.day^{-1}

for Trials 1 and 2, respectively. The pH value increased while the electrical conductivity decreased during the composting process for both trials. The TOC decreased from 50.3% to 37.1% and 47.8% to 38.8% and the mass reduction after 40 days of composting process is 72% and 65% from the total weight of the feedstock for trial 1 and 2, respectively. In terms of mass balance, the mass reduction was mainly due to water evaporation, leachate, excess moisture and dry matter loss and gas emissions. The total average mass reduction and compost produced was ~67% and ~27 % of the initial mass, respectively. The average power consumption of 6.78 kWh was observed for one cycle of a composting process. Low pathogens level and higher nitrogen content were detected in the final compost while some of the nutrients are not in the recommended range. Among the treatments, the 5%-30% compost mixture shows the greatest growth development. Results in this study indicate that food waste composting can be used to promote dwarf crape jasmine growth. Kinetic obtained is essential to determine waste biodegradability and develop a valuable measure for the loss of organic matter during composting. Based on the cost analysis, the applicability of composting system in UMS is economically feasible and could possibly generate a profit of RM 14,824.61 per year.

ABSTRAK

PENGKOMPOSAN SISA MAKANAN DENGAN SABAH RAGI MENGUNAKAN KOMPOSTER AUTO-TURNING PENGUDARAAN PASIF

Sisa organik yang terhasil yang tidak dirawat dengan baik boleh mengakibatkan masalah kepada persekitaran. Pengkomposan dalam vesel merupakan satu alternatif bagi rawatan biologikal untuk menukarkan sisa kepada bahan yang lebih berguna dan stabil. Walaubagaimanapun, menentukan mekanisma proses biodegradasi dan ketidakpastian dalam pengawalan sistem adalah kritikal bagi prestasi yang baik, Maka, tujuan kajian ini adalah bagi menentukan kesan kekerapan pengadukan dan penambahan Sabah Ragi pada profil fizikokimia dan biologikal dalam pengkomposan, mengkaji kesan kompos terhadap pertumbuhan tanaman dan untuk menentukan kebolehlaksanaan sistem pengkomposan dari segi analisis ekonomi. Seterusnya, keadaan optimum yang diperoleh daripada eksperimen akan digunakan untuk proses pengkomposan reaktor dalam vesel. Proses pengkomposan sisa makanan dan daun kering (2.6:1 mengikut berat) telah dijalankan dalam dua ujian selama 40 hari. Perubahan fizikal, kimia, biologi dan morfologi yang berlaku semasa proses pengkomposan dikenal pasti dan dinilai. Penggunaan kuasa semasa proses pengkomposan juga dinilai. Bunga melur (Tabernaemontana divaricata) ditanam dalam media yang mengandungi kompos dan tanah atas dengan sembilan perkadaran berbeza (0%, 2.5%, 5%, 10%, 20%, 30%, 40%, 50%, atau 100% kompos) dan pertumbuhan tumbuhan diukur selama 90 hari. Berdasarkan kehilangan bahan organik, kekerapan pusingan setiap tiga hari dan 1.0 g ragi/200 g kompos awal menghasilkan kehilangan OM tertinggi masing-masing sebanyak 79.2% dan 61.3%. Model tertib-n berjaya menganggarkan profil degradasi untuk TF 3 hari dan 1.0 g ragi/200 g kompos awal dengan nilai pemalar kadar (k) 8 x 10-5 $VS^{(1-n)}$. $hari^{-1}$ dan 1.30 x $10^{(1-n)}$ VS^{-1}.$hari^{-1}$. Untuk proses pengkomposan reaktor dalam vessel secara pasif, purata suhu kompos tertinggi iaitu 54.2 °C dan 46.7 °C telah direkodkan pada hari ke-7 dan ke-10 Percubaan 1 dan 2, masing-masing. Purata nilai tertinggi bagi kadar penjanaan haba per jisim awalan kompos adalah 4098 kJ kg^{-1} $hari^{-1}$ dicapai pada hari ke 7. Dalam kajian ini, aplikasi model tertib kedua menghasilkan tindak balas yang baik dengan pemalar kadar (k) masing-masing 0.0003 TOC^{-1}.$hari^{-1}$ dan 0.0002 TOC^{-1}.$hari^{-1}$ untuk Percubaan 1 dan 2. Nilai pH meningkat manakala kekonduksian elektrik menurun semasa proses pengkomposan untuk kedua-dua *percubaan. TOC menurun daripada 50.3% kepada 37.1% dan 47.8% kepada 38.8% dan pengurangan jisim selepas 40 hari proses pengkomposan ialah 72% dan 65% daripada jumlah berat bahan stok suapan untuk percubaan 1 dan 2, masing-masing. Untuk terma jisim imbangan, pengurangan jisim adalah disebabkan oleh penyejatan air, enap cemar, kelembapan berlebihan, kehilangan jisim dan pembebasan gas. Purata pengurangan jisim dan kompos terhasil adalah ~67% dan ~27% daripada nilai awalan jisim, masing-masing. Purata penggunaan kuasa sebanyak 6.78 kWj diperhatikan untuk satu kitaran proses pengkomposan. Paras patogen yang rendah dan kandungan nitrogen yang lebih tinggi telah dikesan dalam kompos akhir manakala beberapa nutrien tidak berada dalam julat yang disyorkan. Di antara rawatan, campuran kompos 5%-30% menunjukkan perkembangan pertumbuhan yang paling besar. Keputusan dalam kajian ini menunjukkan bahawa pengkomposan sisa makanan boleh digunakan untuk menggalakkan pertumbuhan bunga melati. Kinetik yang diperolehi adalah penting untuk menentukan biodegradasi sisa dan membangunkan parameter yang berguna untuk kehilangan bahan organik semasa pengkomposan. Berdasarkan analisis kos, kebolehgunaan sistem pengkomposan di UMS adalah berpatutan dari segi ekonomi dan berkemungkinan boleh menjana keuntungan sebanyak RM 14,824.61 setahun.*

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LIST OF ABBREVIATIONS

C/N	-	Carbon to Nitrogen
DL	-	Dry Leaves
EC	-	Electrical Conductivity
EF	-	Modelling Efficiency
FTIR	-	Fourier Transform Infrared Spectroscopy
GI	-	Germination Index
FW	-	Food Waste
MC	-	Moisture Content
MSW	-	Municipal Solid Waste
OM	-	Organic Matter
R^2	-	Coefficient Correlation
RMSE	-	Root Mean Square Error
SEM	-	Scanning Electron Microscope
TOC	-	Total Organic Carbon
WHC	-	Water Holding Capacity

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Globally, around 1.13 million tons of food waste (FW) are discarded daily (T. Chen *et al.*, 2020), which is expected to increase due to population growth (Nguyen *et al.*, 2020). The amounts of MSW generated by Asian urban cities per day are estimated from 760,000 tons in 2016 to 1.8 million tons by 2025 (Aiking & de Boer, 2019). According to SWCorp (2020), there were 38,200 tons of waste generated per day in 2020 and 44.4% of it is food waste in Malaysia and recycling rate less than 30 %. Furthermore, a massive number of MSW is being generated each day and disposed into a landfill with by a recycling and composting rate of less than 5% (Jayashree *et al.*, 2012). Moreover, the recycling rate of biodegradable waste generated in Universiti Malaysia Sabah (UMS) still poor, where the waste mostly ends up in landfill (Sariah *et al.*, 2020).

Food waste accumulation in landfills negatively impacts the environment, economy, and community, such as greenhouse gas (GHG) emissions and groundwater contamination (C. Chen *et al.*, 2020). Therefore, as a prospective preference for waste stabilization and recycling of waste-derived products, biological process such as composting is suggested. Composting technologies are divided into three major phases: mixture preparation, bio-oxidative phase, and maturation phase (Pergola *et al.*, 2018). compost products from solid organic waste, including FW, have also been found to stimulate plant development and increase soil fertility (T. Chen *et al.*, 2020).

Composting is another alternative biological treatment method in which biodegradable organic material is decomposed by microbes in the presence of oxygen into a stabilized material (Garg & Tothill, 2009). Composting is a process highly valued in waste management due to its strength and the possibility of obtaining a valuable product with soil amendment potential (Chia *et al.*, 2020). However, with various technology and amendments or control systems, the quality of the final compost produced can be varied (Lim *et al.*, 2017). It is necessary to vary the compost product to determine the standard quality of compost is achieved. However, due to different composting process technology, the compost product quality may different from one another such as nutrient and phytotoxicity level. Moreover, it is essential to determine which compost dosage is suitable for plant growth. The satisfaction and effectiveness of the composting process are influenced by a number of factors, including the properties of the starting materials, operational conditions, and maturation time (Soto-paz *et al.*, 2019). FW has certain limitations as a biowaste, such as a low C/N ratio, high moisture content, poor porosity, and nutritional deficiencies such as total organic carbon (TOC), total nitrogen (TN), and total phosphorus (TP), all of which influence to compost quality (Fan *et al.*, 2018).

Aeration affects the composting process. Aeration can be provided through turning or convection for a passive aeration system and through blower or air pump for an active aeration system. Optimum turning frequency (TF) provides sufficient ventilation, which controls the compost pile's temperature, excess water, and microbial activity (Z. Liu *et al.*, 2020). Low or excessive turning frequency caused slow biodegradation due to undesired porosity, oxygen availability, and heat loss (J. Wu *et al.*, 2019). Several successful studies had proposed different TF for different composting materials. For example, Zhang *et al.* (2019) evaluated the effect of different TF (every 5, 7, 10 and 15 days) on goat manure combined with Camellia oleifera shell. The results showed that turning every 7 days produced high quality compost in terms of total nutrient and C/N ratio. Another study by Manu *et al.* (2019) investigated the influence of TF (every 5 days) and microbial addition on mixed food waste with garden waste. A similar household-scale study of different TF (every 1, 2, 3 days) with C/N ratio of 20, 25 and 30 using food waste and dry leaves was carried out by (Nguyen *et al.*, 2020). They concluded that the optimum conditions for plant growth were a C/N of 30 and a turning frequency of once every 2 days.

Ragi is widely used in Sabah as a fermentation starter for food or beverage fermentation. Ragi prepared from a mixture of rice flour, spices, and water or sugarcane juice, naturally contains filamentous fungi, bacteria, and yeast (Hiroshi *et al.*, 1997; Kofli & Dayaon, 2010). According to Saono *et al.* (1981), ragi contains molds, yeast and bacteria with amylolytic power; and yeast and bacteria (lactic acid bacteria) with non-amylolytic power. Those with amylolytic power in mold are Amylomyces, Mucor, and Rhizopus. in yeast are Endomycopsis (Saccharomyces) and Candida, and bacteria contain a kind belonging to Bacillus (Ohhira & Toshitaka, 1987). Yeast culture for ragi originating from Sabah, Malaysia, is categorized into species of *Saccharomyces cerevisiae* and *Saccharomycetales sp.* (Nguong *et al.*, 2011). The application of microbial inoculation that contains yeast in composting is commonly used in previous studies (Nakasaki *et al.*, 2013; Poongodi & Damodharan, 2016; Sarkar *et al.*, 2010). However, to the best of our knowledge, there has been no research on the effect of local *Sabah Ragi* on food waste composting.

1.2 Problem Statement

Accelerating the organic matter decomposition during primary fermentation of composting is very challenging. Thus, well-stabilized compost is hard to produce within a short period. In order to establish good quality of the composting material, it is important to look for adequate procedures that allows the best condition for the composting process to take place. Unmatured compost will result in low quality compost and could retard the plant growth due to high level of phytotoxicity. Moreover, Unmanaged biodegradable waste generation in the campus is a pressing problem. Therefore, implementing the composting system in the campus can be a sustainable approach Compost made from food waste can be applied to soil as a soil amendment to reduce the need for chemical fertilisers, enhance soil quality and promote circular economy. The feasibility of the composting system in campus had evaluated by several studies. For instance, Aji *et al.* (2021) had conducted composting feasibility study for UMS KK campus without the addition of *Sabah Ragi*. However, the composting system in terms of its process and economic feasibility are varied depending on the design itself. Thus, process optimization and economic analysis of the composting system in Universiti Malaysia Sabah (UMS) Kota Kinabalu campus was evaluated.