COMPOSTING OF FOOD WASTE AND ITS PRODUCT PERFORMANCE ON *Ipomoea aquatica*

BY

NUR SYUHADAH BINTI AHMAD ROSELI

A thesis submitted in fulfilment of the requirement for the degree of Master of Science (Biotechnology)

Kulliyyah of Science
International Islamic University Malaysia

MAY 2020

ABSTRACT

Food waste (FW) is a global issue and their disposal at landfills created another environmental problems. Since FW is biodegradable, they can be treated through composting. The importance of fungi in degrading recalcitrant materials during FW decomposition process has yet to be extensively characterized. While most of the previous studies focused on one type of composting method, the comparison with other methods are scarce. Hence, this study aimed to compare the physicochemical parameters and to identify the fungi associated with FW in conventional and spinning barrel composting method. Physicochemical parameters including temperature, pH, moisture content (MC) and C/N ratio and fungal isolation on potato dextrose agar (PDA) were done in triplicate every three days interval throughout 30 composting days. Physicochemical parameters were analyzed using GraphPad Prism. Different fungal colonies were isolated, subcultured and identified using 18S rRNA gene sequencing. Based on the results, MC in spinning barrel reached the optimum range of 54.61 % on day 30. A total of 7 fungal isolates were found associated with FW. The fungi identified between these two methods are almost similar based on morphological observation and molecular analysis due to source of the FW which comprised identical components such as rice, eggs, chicken and chicken bones, and vegetables remain. The effectiveness of FW compost produced from both methods was combined in appropriate proportions to be tested. FW compost, NPK fertilizer and combination of both were applied on *Ipomoea aquatica* to determine the best fertilization treatment by observing at plant height, leaves number, leaf width, soil pH and nutrient contents in the soil. After five weeks of planting, the combination of NPK fertilizer and FW compost recorded an optimum soil pH and highest nutrients content in the soil which resulted in significant growth on plant; tallest height, highest leaves number and largest leaf width. In short, spinning barrel was found to be superior to conventional composting method in maintaining final optimum MC. Fungal isolates from this study could be further characterized for their functional abilities such as degradation of cellulolytic biomass, proteolytic activity and degradation of chitin. The combined use of NPK fertilizer and FW compost was found to be the best fertilization treatment and could be used to promote the planting of *I. aquatica*.

خلاصة البحث

هدر الغذاء مشكلة عالمية ويسبب التخلص من الأغذية في مقالب القمامة مشاكل بيئية أخرى. وبما أن الغذاء المهدر قابل للتحلل فإنه يمكن تحويله إلى سماد. لم يتم بعد وعلى نطاق واسع وصف أهمية الفطريات في تفكيك المواد المضادة للتفكك أثناء عملية التحلل. ركزت معظم الدراسات السابقة على طريقة واحدة للتسميد، وكانت الدراسات المقارنة للطرق الأخرى محدودة. وبالتالي فقد هدفت هذه الدراسة إلى مقارنة المؤشرات الفيزيائية-الكيميائية لتحديد الفطريات المرتبطة بتحويل الغذاء المهدر إلى سماد بطرق التسميد العادية وطريقة البرميل المقلب. حُسبت المؤشرات الفيزيائية-الكيميائية والتي تضمنت درجة الحرارة، ودرجة الحموضة، ومحتوى الرطوبة، ونسبة C/N والعزل الفطري وذلك على طبق أجار من دكستروز البطاطا ثلاث مرات بفاصل ثلاثة أيام خلال 30 يوم للتسميد، وقد تم تحليل المؤشرات الفيزيائية-الكيميائية باستخدام برنامج جرافباد بريزم. تم عزل مستعمرات فطرية مختلفة، ومن ثم استزراعها ثانويا والتعرف عليها باستخدام التسلسل الجيني لـ S18 من الحمض النووي الريبوزي الريبوسومي. استنادًا إلى النتائج، وصل محتوى الرطوبة في البرميل المقلب إلى النطاق الأمثل وهو 54.61٪ في اليوم 30. تم العثور على 7 معزولات فطرية مرتبطة بفضلات الطعام. تشابهت تقريبا الفطريات التي تم تحديدها بين طريقتي التسميد اعتمادا على الملاحظة المورفولوجية والتحليل الجزيئي وذلك نظرا لمصدر الغذاء المهدر الذي يكون من مكونات مماثلة مثل الأرز والبيض ولحم وعظام الدجاج، وبقايا الخضراوات. تم الجمع بين فعالية السماد المنتج بالطريقتين المختلفتين بكميات مناسبة لفحصها. تم استخدام سماد فضلات الطعام وسماد NPK ومزيج من الاثنين على السبانخ المائية (*Ipomoea aquatica*) لتحديد أفضل علاج للتسميد من خلال ملاحظة ارتفاع النبات، وعدد الأوراق، وعرض الأوراق، ودرجة الحموضة في التربة والمحتوى الغذاء في التربة. بعد خمسة أسابيع سجل مزيج سماد NPK وسماد فضلات الطعام أعلى درجة لحموضة التربة وأعلى محتوى غذائي في التربة مما أعطى النبات نموا كبيرا، وطولا مرتفعا، وأعلى عدد للأوراق، وأكبر عرض ورقي. باختصار، اتضح أن طريقة البرميل المقلب كانت متفوقة على طريقة التسميد التقليدية في الحفاظ على محتوى الرطوبة النهائي المثلى. بالامكان تمييز المزيد من المعزولات الفطرية من هذه الدراسة لقدراتها الوظيفية، مثل تدهور الكتلة الحيوية السلوليتية، ونشاط التحلل البروتيني، وتدهور الكيتين. كان الاستخدام المشترك لسماد NPK وسماد الفضلات الغذائية أفضل علاج تسميدي للتربة وبالامكان استخدامه لتعزيز زراعة السبانخ المائية.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science (Biotechnology)

……..
Abdul Latif Noh
Supervisor

……..
Mohd Faez Sharif
Co-Supervisor

……..
Mohd Hamzah Mohd Nasir
Co-Supervisor

……
Nur Shuhada Mohd Tajudin
Co-Supervisor

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science (Biotechnology)

……..
Zakuan Azizi Shamsul Harumain
Internal Examiner

This thesis was submitted to the Department of Biotechnology and is accepted as a fulfilment of the requirement for the degree of Master of Science (Biotechnology)

……..
Mardiana Mohd Ashaari
Head, Department of
Biotechnology

This thesis was submitted to the Kulliyyah of Science and is accepted as a fulfilment of the requirement for the degree of Master of Science (Biotechnology)

……..
Shahbudin Saad
Dean, Kulliyyah of Science

DECLARATION

I hereby declare that this thesis is the result of my own investigation, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Nur Syuhadah Binti Ahmad Roseli

Signature ..... Date ….....

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

DECLARATION OF COPYRIGHT AND AFFIRMATION OF FAIR USE OF UNPUBLISHED RESEARCH

COMPOSTING OF FOOD WASTE AND ITS PRODUCT PERFORMANCE ON *Ipomoea aquatica*

I declare that the copyright holders of this thesis are jointly owned by the student and IIUM.

Affirmed by Nur Syuhadah Binti Ahmad Roseli

……..…… ..……..

Signature Date

ACKNOWLEDGEMENTS

In the Name of Allah, The Most Gracious and Most Merciful. My deepest gratitude goes to my respected supervisor, Asst Prof Dr Abdul Latif Noh for his time supervising me. Despite his busyness, he always allocates some time for me to discuss about my project and thesis progress. Not forgetting Asst Prof Dr Mohd Faez Sharif, Asst Prof Dr Mohd Hamzah Mohd Nasir and Asst Prof Dr Nur Shuhada Mohd Tajudin for their time spent and assistance provided whenever in need. Special thanks to Asst Prof Dr Mohd Azrul Naim for helping me a lot especially for labworks related to microbes and Chapter 3 and also Asst Prof Dr Suhaila Mohd Omar (supervisor during internship) for the experience I gained from the three-month composting project; that really helps me so much in my current journey. I am so grateful and enjoyed being supervised by this team. I learnt a lot and thanks for the opportunity given for me to learn new things.

Big thanks to Sis Mueizzah, Sis Nurul and other KOS lab assistants for everything they offered especially related to labs. I would like to express my thanks to EBBRU laboratory team; Sis Faizah and Sis Zati Nabilah for helping me with the project and labworks during internship, not to mention Sis Fatin Nazurah (food waste partner), Sis Syahira Illiyin, Sis Nik Sarah and Sis Syakira, Br Hakim (Plant Science) for their time spent answering my questions related to this-and-that labwork things. My thank you also goes to Sis Najatul and Sis Iffah for their help (thanks for being my friends in the lab) and also Dr Asha (UMK) for helping me with the cloning labworks and others. Thanks so much Sisters and Dr, or else I might still struggling to find ways in making sure everything settled on time.

Being chosen as part of PGKOSSS 2017/2018 members, I am more than grateful that I learnt so many things. The most important, I got to know PGKOS students especially Br Hakim, Sr Syafiqa, Sr Fatin Munirah, Sr Amilin, Br Shahrain, Br Qusyairi, Sr Wani, Br Sufi and Sr Erlena. I will surely miss the moments with them and thanks for everything shared (I count the jokes and stories as well). Not forgetting all PG friends especially Sr Hanani Syafiqah and Sr Liyana for their “I’m all ears” and endless support; thanks for always being a good listener.

Special thanks go to my parents, I couldn’t thank them enough for the money and time spent, not to mention their endless support. They told me to keep going no matter what. And Alhamdulillah I am finally here, writing this. To my siblings, you guys know your role, thanks!

Last but not least, to KOS communities and everyone who involves directly or indirectly in my enjoyable journey, thank you so much and may Allah ease yours as well.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

cm	Centimetre
g	Gram
h	Hour
kg	Kilogram
L	Litre
mg	Milligram
mL	Millilitre
ng	Nanogram
µL	Microlitre
%	Percentage
°C	Degree Celsius
±	Plus, Minus
+	Plus
-	Minus
x	Times

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

The human population worldwide is greatly expanding every year. By the year 2050, the global population is estimated to reach 9.3 billion (Bond, M., Meacham, T., Bhunnoo, R. and Benton, 2013). As this growth increased, the need for space for their inhabitants as well as waste produced will also increase. Concerning the need for more spaces to support the population in the future, increased in the waste disposal potentially increased the space management problem as well as hygiene issues if these issues are not properly managed.

Waste can be generally defined as unwanted or unusable material, substances, or by-products from any processes. The waste can be divided into few types such as liquid waste, solid rubbish, organic waste, recycling rubbish and hazardous waste. Liquid wastes are commonly found in households and industries including dirty water, organic liquids, wash water, waste detergents and even rainwater. Solid rubbish can include a variety of items found in the household along with commercial and industrial locations and commonly broken down into few types (plastic waste, paper/card waste, tins and metals and ceramics and glass). Any waste materials that can be converted into products that can be reused is known as recycling rubbish. All types of rubbish that are flammable, toxic, corrosive and reactive are classified as hazardous waste. Organic waste is another common household in which food waste, garden waste, manure and rotten meat are classified into this waste type. Among these, food waste (FW) is

becoming the topic of interest currently as they can contribute to a significant benefit if properly treated and managed.

FW together with yard waste collectively represented nearly 50% of waste stream in Malaysia (Dinie, Samsudin, & Don 2013; Periathamby, Hamid, & Khidzir, 2009). Generally, FW is the one that is discarded due to uneaten, expired or spoiled. The media recently were littered with reports regarding food wastage especially during the festive season. It is reported that nearly 8 tonnes of food material trashed daily by Malaysians can feed at least 6 million people. All the wasted food products are going to be disposed at the landfills untreated, mixed with other types of wastes. As there are a huge amount of wastes generated daily, available spaces for wastes disposal at landfills are getting limited. To overcome this problem, Solid Waste and Public Cleansing Management Corporation (SWCorp) started to implement the solid waste separation in 2015; separation at sources according to the composition of solid waste generated in hoped to reduce the disposal of solid waste at landfills. Segregation at source increases the downstream benefits of FW through the production of biomass in compost.

Composts are a mixture of decayed organic matter that can be used as organic fertilizer. In general, FW is one of the good sources of biomass in compost. The diversity of food types and its derivatives enriches the wide spectrum of nutrient in compost, which is also suitable for the use as organic fertilizer. Due to the unique characteristics of FW, the effectiveness of FW compost can be tested on the growth of plants. Thus, despite being disposed at landfills, FW can be turned into compost and can be used as a very cost-efficient fertilizer in agro farms and landscapes. The conversion of FW or other organic wastes into compost involved a process known as composting.

Composting is a bio-oxidative process involving mineralization of organic matter to carbon dioxide, ammonia, water and partial humification that leads to a stabilized final product free of phytotoxicity and pathogens (Das et al., 2011). This environmental-friendly method seems be one of the effective and efficient ways to overcome the food wastage problem and other related environmental issues. Composting can be done in various methods such as windrow or vessel system. Apart from few composting methods being practiced, this study focused on two composting methods which were conventional and spinning barrel. The latter differed from conventional due to the involvement of aeration. Aeration is one of the factors affecting composting that can help to improve the composting process by increasing aerobic homogenization. Although composting is an environmental-friendly method, but it still has some drawbacks that need to be considered such as duration of the process might be longer depends on the types and amount of waste to be composted as well as leachate and odour problems.

Composting involves various microorganisms to convert the wastes into compost. Fungi and bacteria are the two major groups of microbes involved during the process (Kutzner, 2000; Hultman et al., 2010). As reported, fungi are among the major decomposers of plant polymers, including lignocellulosic materials in any ecosystem and have the ability to decompose a wide variety of materials and compounds (Eida, Nagaoka, Wasaki, & Kouno, 2011). In this FW composting study, the focus was mainly on fungi. This is because FW composition is varied and these varieties of components can be decomposed by fungi, which is known as a degrader of a wide variety of materials and compounds as mentioned.

1.2 PROBLEM STATEMENT

The studies related to composting of various types of wastes were well established. Currently, the serious food wastage problem reported has led to the study of FW composting. Since aeration is among the important physicochemical parameters during composting, this study focused on the comparison between two composting methods that differed in terms of aeration provided from turning applied since there was less publication on that. Despite the importance of fungi during the degradation process, there has been little discussion about their diversity especially in association with FW composting. At the end of FW composting, the FW compost was produced. The research to date tends to focus on the application of other organic wastes especially animal manure as organic fertilizer to grow plants rather than FW compost.

1.3 SIGNIFICANCE OF STUDY

In a study related to composting, it is essential to observe the physicochemical parameters as they reflect the composting progress. In this study, temperature, pH, moisture content (MC) and carbon to nitrogen (C/N) ratio were monitored and compared between two composting methods (conventional and spinning barrel) to observe the most effective method in producing good quality compost by looking at the physicochemical parameters achieved and hence, those method could be further used and improved for a large scale composting study.

For the identification of fungi, both cultivation and non-cultivation approaches were used. Identification of a species is important for further analysis of their functional ability. At the end of this study, fungi associated with FW might be useful to be used as a medium to improve the composting process.

FW compost produced at the end of the process can be further tested and compared with chemical fertilizer for their application and effects on plants growth. As part of this study, the FW compost as well as NPK fertilizer was applied on *Ipomoea aquatica* to observe its vegetative growth. The findings would be beneficial for people to have an idea about the effectiveness of different fertilizers on *I. aquatica.* Theoretically, if the application of FW compost resulted in better growth of *I. aquatica*, all plants under the family Convolvulaceae could be also grown using FW compost as a source of organic fertilizer. Hence, it is hoped that the use of FW compost could return the nutrients to grow *I. aquatica.*

1.4 OBJECTIVES OF STUDY

1. To compare the physicochemical parameters of FW compost between conventional and spinning barrel composting.
2. To identify the fungi associated with FW in conventional and spinning barrel composting.
3. To measure and compare the effect between NPK fertilizer, FW compost and the combination of both NPK fertilizer and FW compost on the vegetative growth of *I. aquatica.*

1.5 HYPOTHESES OF STUDY

1. Spinning barrel composting will record better compost parameters measurement compared to conventional due to turning applied.
2. There will be no difference in fungal species between both composting methods since the source of isolation will be similar which is from FW.

3. The combination of NPK fertilizer and FW compost will result in better growth of *I. aquatica* because of the synergetic effect of nutrients release.

1.6 THESIS OUTLINE

This thesis is divided into five chapters. Chapter 1 introduces the whole idea about this study; the background of this study including the statement of problem, significance of this study and how it leads to the aims of this study to overcome the problem stated.

Chapter 2 describes the literature review on several parts such as the current management of FW in Malaysia. Composting as alternative to FW problems covers the types of composting methods, factors affecting the process and its benefits as well as fungi as degrader during the degradation process. Lastly, the application of fertilizers reviews the benefits and uses of sole inorganic fertilizer, sole organic fertilizer and their combinations on different plants by looking at different growth parameters.

Chapter 3 will be the first part for this study, focuses on objective 1 and 2. This chapter discusses the methodologies of physicochemical parameters during every sampling day and their significance comparison between conventional and spinning barrel composting methods throughout 30 days of composting. FW compost produced from the composting method with optimum physicochemical parameters achieved will be used and tested on *I. aquatica*. In addition, the analysis of fungi associated with FW from the isolation step and up to their identification from both composting methods will be also included in this chapter.

Chapter 4 is the continuity of Chapter 3, focuses on objective 3 and highlights the application of FW compost from composting methods that showed optimum physicochemical parameters reading. In this chapter, four different applications of fertilizer treatments will be used to observe and compare the growth performance of

I. aquatica. The treatments will be no fertilizer as control (T1), inorganic fertilizer which is NPK fertilizer (T2), organic fertilizer which is FW compost (T3) and the combination of inorganic and organic fertilizer (T4).

Chapter 5 concludes the whole thesis findings and suggestions to improve this study.

CHAPTER TWO

LITERATURE REVIEW

2.1 FOOD WASTE (FW) MANAGEMENT IN MALAYSIA

Wastage of food materials, including both raw and processed food is one of the global issues reported, and it is getting serious from year to year. This problem occurs at few countries worldwide including Malaysia. As reported in Global Food Security, FW may be more finely classified as food loss when incurred during early phases of the food supply-chain, and as FW within latter phases (Gustavsson, Cederberg, Sonesson, van Otterdijk, & Meybeck, 2011). The sources of FW are various; they can be leftovers, uneaten food due to expired or spoiled, food materials either processed on non-processed, raw or cooked, and also the ones that being rejected by supermarkets because they do not pass the quality control. All of them are going into the trash in which later on will be brought to landfills and mixed with other types of wastes. This is quite worrying because as populations are greatly expanding every year, so do the wastes that will be generated and disposed at the landfills.

Landfills are places where the collected wastes are compacted before burial. Due to its simplicity and cost-effective, landfilling has become the main method used for solid wastes disposal in Malaysia (Moh & Abd Manaf, 2014). Out of the currently operating landfills, only 14 have been classified as sanitary landfills whereas the remaining are unsanitary (Noor et al. 2013). The uncontrolled amount of wastes generated from day to day by the increasing pattern of population density caused the need for more landfill spaces. Unfortunately, the increasing size of population limits the

available land for this purpose. FW disposal at landfills is another issue and has been reported to cause various environmental related problems such as foul odour, toxic leachate, emission of greenhouse gases and vermin infestation (Lee, Choi, Osako, & Dong, 2007).

Despite having those food wastage problem and their disposal issue, Malaysia does not have a specific method to manage FW (Abdul Hamid, Ahmad, Ibrahim, & Nik Abdul Rahman, 2012). Realizing the importance of waste management and limiting of disposal sites, SWCorp established a new campaign known as solid waste separation at source. Through this campaign that started its implementation on 1st September 2015, the solid waste to be segregated is divided into two types; residual waste (including kitchen waste and FW) and recyclable waste. Among the purposes, solid waste segregation at source aims to reduce the amount of solid waste sent to landfills as well as to prevent disposal of recyclable materials including FW. Although this effort by SWCorp is beneficial to overcome food wastage problems and their disposal at landfills, no serious initiative has been done on FW especially to increase the efficiency of FW decay and its product. Despite being disposed, the variety composition of FW and its unique characteristics are interesting to be studied for further application research.

2.1.1 Characteristics of FW

As mentioned previously, FW has become a topic of interest because if they are properly treated and managed, they will bring significant impact towards environment especially in reducing the amount of FW disposed at landfills. Hence, this helps to overcome odour and leachate problems as well as to increase the downstream application of FW compost as organic fertilizer.

There are few characteristics of FW which make them suitable to be disposed by composting. Chang & Hsu, (2008) stated that FW contains high MC, a high organics-to-ash ratio, and a loose physical structure. Another point is FW consists of high amount of easily degradable organic substances such as sugars, starches, lipids and proteins (Li, Lu, Ren, & He, 2013) which can be degraded by the help of various microbes associated with composting. FW also contains important nutrients and it would be more efficient to re-use them in agriculture (Hossain, von Fragstein und Niemsdorff, & Heß, 2017). The variety components of FW contain various nutrients needed for plants to grow upon its application as fertilizer.

2.2 COMPOSTING

Composting is a biological process carried out by endogenous or inoculated microorganisms and influenced by the physicochemical properties of the decomposing organic matter (Xi et al., 2015). It is a bio-oxidative process involving mineralization of organic matter to carbon dioxide, ammonia, water and partial humification that leads to a stabilized final product free of phytotoxicity and pathogens (Das et al., 2011). Gajalakshmi & Abbasi, (2008) emphasized that recycling of organic residues through composting have been an ancient practice. Few countries worldwide have practiced composting as a way to manage wastes problems. For instance, in 2000, 92% of the households in the Netherlands (16 million people in 6 million households) were involved in a separate collection system for organic waste resulting in 1.57 million tonnes of biowaste being processed into 0.6 million tonnes of compost. (S. Kumar, 2011). He further reviewed that in Switzerland, about 88% of collected organic waste in 2000 which amounted to 641,000 tonnes or 14% of the total MSW was composted.

Currently, apart from the unique characteristics of FW, FW composting has gained considerable attention from researchers due to people greatest concern on the negative impact of food wastage problems towards environment. Further details on the types of composting method, factors affecting the process, microbial community associated with the process and application of the end product (compost) as organic fertilizer are discussed below.

2.2.1 Types of Composting Method

As time passes by, composting process has been modified in line with the advancement of technology; composting of various type of wastes are conducted in large scale using various types of composting methods. There are two categories of composting system (Gajalakshmi & Abbasi, 2008). The first one is the "fully or partially open to air" systems (ranging from the ones used from prehistoric times to the windrow, static pile, and "household" systems used currently). The second category is the "in-vessel" systems including "tunnel" systems, the rotary drum composting system (RDCS) and other "in-vessel" or "reactor" systems of various designs. In the agitated system, the material to be composted is agitated mechanically to introduce oxygen as well as to (and accordingly) control the temperature, and effect mixing of the material compared with static system in which the substrate remains static and air is blown through it (Gajalakshmi & Abbasi, 2008).

While most of previous studies focused on one type of composting method, there is less study on the comparison between two methods of FW composting. In this study, two different methods of composting; conventional and spinning barrel were compared. The latter differed from conventional due to turning applied which indirectly provide aeration to the FW to be composted. The concept of spinning barrel is almost similar to

rotary drum composter; it provides a better aeration since the FW inside the tanks were turned daily, compared to no turning in conventional. Aeration from turning applied to spinning barrel helps to introduce oxygen which can control the temperature (Gajalakshmi & Abbasi, 2008). Alkoaik, (2019) also emphasized that the mixing of compost materials in the rotating bioreactor created uniform temperature distribution of compost. Kalamdhad & Kazmi, (2009) further stated that the consistency and uniformity of the final product can be obtained from rotary drum as it provides agitation, aeration and mixing of the compost. Hence, a comparison between conventional (no turning applied) and spinning barrel (turning applied) was done to observe the most suitable method in producing good quality compost by monitoring the physicochemical parameters achieved throughout composting period.

2.2.2 Factors that Affect Composting

To ensure the composting process occurred effectively, there are several factors need to be considered. Temperature, moisture content (MC), pH level, aeration rate, carbon to nitrogen (C/N) ratio, particle size, and nutrient contents are the main factors that control FW composting process (Adhikari, Barrington, Martinez, & King, 2008; Chang & Hsu, 2008; Kumar, Ou, & Lin, 2010).

2.2.2.1 Temperature

The microbial activity and the occurrence of the composting process can be observed by looking at the temperature pattern (Bernal, Alburquerque, & Moral, 2009). Mesophile phase is where the pile temperature slowly increases from ambient temperature to reach the average temperature of this phase, which is about 40 °C (Azim et al., 2018). During this phase, degradation of fresh matter by microorganisms causes