BIOLOGICAL DEGRADATION OF EMPTY FRUIT BUNCH WITH BIOSURFACTANTS AND PALM OIL MILL EFFLUENT SLUDGE BY COMPOSTING

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SCHOOL OF CIVIL ENGINEERING
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by

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ABSTRAK

Kompos adalah kaedah rawatan sisa moden yang digunakan untuk rawatan tandan buah kosong, salah satu bahan mentah pepejal utama minyak sawit. Kira-kira 20% tandan buah kosong dihasilkan dalam pengeluaran minyak sawit mentah untuk setiap tan buah segar. Pengkomposan tandan buah kosong menghasilkan kompos tandan buah kosong yang dapat memberi manfaat kepada pertanian. Tujuan kajian ini adalah untuk melihat kualiti kompos tandan buah kosong yang dihasilkan oleh kompos tandan buah kosong dengan biosurfaktan. Prosedur pengkomposan dilakukan di persekitaran makmal menggunakan termos Erlenmeyer 500 ml pada suhu 30ºC dan 50ºC. Sampel kompos terdiri daripada tandan buah kosong, tandan buah kosong dengan sisa buangan minyak kepala sawit dan tandan buah kosong dengan sisa buangan kelapa sawit dan biosurfaktan.Campuran untuk tandan buah kosong dengan sisa buangan minyak kelapa sawit dan biosurfakatan ditetapkan pada nisbah 10:1:1.5 masing-masing. Terdapat beberapa parameter yang perlu dikaji seperti pH, kekonduksian elektrik, pepejal mudah menruap, kandungan kelembapan, nisbah karbon dan nitrogen, fosforus dan aktiviti serat. Untuk menilai kesan suhu yang konsisten terhadap sifat kompos tandan buah kosong, suhu tetap berterusan sepanjang proses untuk 35 hari. Pada 30ºC, kompos tandan buah kosong yang dihasilkan dari kompos tandan buah kosong dengan sisa buangan minyak kelapa sawit dan biosurfaktan menunjukkan prestasi yang lebih baik. Nisbah karbon ke nitrogen kompos tandan buah kosong adalah 5.5, kandungan fosforus adalah 2.19%, kandungan kelembapan adalah 82.02%, dan pH adalah 8.16. Kehadiran biosurfaktan dalam proses pengkomposan dapat menghasilkan kompos yang berkesan dan mengurangkan masa yang diperlukan untuk menstabilkan produk tandan buah kosong semasa proses pengkomposan.

ABSTRACT

Composting is a modern waste treatment method used to treat the empty fruit bunch (EFB), one of the primary feedstock of solid palm oil. About 20% EFB is produced in crude palm oil production for every ton of fresh fruit bunch. EFB composting produces EFB compost that can benefit agriculture. This study aimed to look into the quality of EFB compost produced by composting EFB with biosurfactants. The composting procedure was carried out in a laboratory setting using 500 ml Erlenmeyer flasks at 30ºC and 50ºC. The composting sample consists of EFB, EFB with POME and EFB with POME and biosurfactants. The mixture of EFB: POME: Biosurfactants was prepared in the ratio of 10:1:1.5, respectively. Several parameters need to be examined, such as pH, electrical conductivity, volatile solids, moisture content, C/N ratio, phosphorus, and enzymes activity. To evaluate the effect of consistent temperatures on the properties of EFB compost, temperatures were kept constant throughout the process for 35 days. At 30ºC, the EFB compost created from composting EFB with palm oil mill effluent and biosurfactants performed better. The carbon to nitrogen ratio of the EFB compost was 5.5, the phosphorus content was 2.19%, the moisture content was 82.02%, and the pH was 8.16. The presence of biosurfactants in the composting process can produce adequate compost and reduce the consuming time to stabilize the EFB product during composting.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

ADF	Acid Detergent Fibre
ADL	Acid Detergent Lignin
Al	Aluminium
APG	Alkyl Polyglycoside
C/N	Carbon/Nitrogen
C	Carbon
CO_2	Carbon Dioxide
COD	Carbon Oxygen Demand
EC	Electrical Conductivity
EFB	Empty Fruit Bunch
EQA	Environmental Quality Act
KEGA	Key Economic Growth Activities
Fe	Iron
H+	Hydrogen
MC	Moisture Content
MW	Municipal Waste
N	Nitrogen
NDF	Neutral Detergent Fibre
NH_3	Ammonia
OPDC	Oil Palm Decanter Cake
O_2	Oxygen
P	Phosphorus
POME	Palm Oil Mill Effluent

RE	Renewable Energy
VS	Volatile Solid
μS/cm	Electrical Conductivity Unit

CHAPTER 1 INTRODUCTION

1.1 Overview

This chapter provides an overview of the study context, problem statements, the aims to be accomplished, and the advantages of the planned research project.

1.2 Background

Large amounts of agricultural-based industrial waste are improperly disposed of, resulting in energy, economic, and environmental difficulties. Due to the high organic matter and mineral content of these wastes, they have the potential to be utilised to restore soil fertility (Noor Mohammad, 2012). In Malaysia, the number of biomass wastes is uncountable such as empty fruit bunches (EFB). One way to reduce biomass waste is by composting.

Composting is a microbial process that turns organic matter into a stable product that can be managed, reserved, transported, and practised in the field without causing environmental harm. Composting can be done in countless ways, using a variety of materials, tools, instruments, and scales. Since it has high moisture content and organic content, palm oil mill effluent (POME) sludge can be used in composting EFB, while biodegradable solid waste like empty fruit bunch (EFB) has a high carbon content and adhesive equity that allow air to flow and circulate (Alkarimiah and Suja, 2020).

Furthermore, the use of biosurfactants in composting can deteriorate the surface tension between the liquid and solid and promote the biodegradation of organic matter. Lessen toxicity, greater biodegradability, and thus greater environmental compatibility improved foaming properties (useful in mineral processing), and stable behaviour at intense pH, salinity, and temperature are the characteristics that make biosurfactants commercially promising opportunities to chemically synthesized surfactants (Mukherjee et al., 2006). Hence, this study is focusing on how the use of POME and biosurfactants can improve the composting of EFB.

1.3 Problem Statement

Malaysian oil palm farms cover around 5,64 million hectares of land and have a total output capacity of more than 19,5 million tonnes of crude palm oil (as recorded in 2019). After Indonesia, which accounts for 31% of global palm oil production, Malaysia is the second largest manufacturer and supplier after Indonesia (Zulqarnain et al., 2020). The extraction of palm oil from palm fruits results in a substantial amount of waste in the form of palm kernel shells, empty fruit bunches, and mesocarp fibres, all of which are discarded. It was estimated that more than 80 million tonnes of oil palm biomass were produced throughout the country in 2011 (Zafar, 2020).

Empty fruit bunch (EFB) was the second-biggest donor of Malaysian palm-oil waste in which unsustainable disposals such as landfill dumping, incineration, soil mulching, and boiler fuel were unsustainable. As a result, EFB composting is introduced as one of the handling methods that could profit the agriculture industry due to its effective natural methods of material recovery, ability to cut down greenhouse gas emissions, and economic feasibility (Azhar et al., 2019).

The oil palm industry also has implemented many practices in Malaysia to improve the sustainability of the industry in terms of environmental legislation, agricultural practices, codes of practice, and conservation efforts. The management of biomass waste in consent with environmental regulations, such as the Environmental Quality Act, (EQA) 1974, is one of the main challenges for palm oil millers towards sustainable growth. In the treatment of biomass waste that is generally carried out by most oil palm plantations in Sarawak, composting techniques are technologically easy and relatively inexpensive (Phang and Lau, 2017). Hence, the use of biosurfactants can enhance the compost microenvironment, facilitate infecting dissolution, and speed up the compost reaction phase because biosurfactants are the metabolic product of microorganisms (Shao et al., 2017).

1.4 Research Objectives

i. To examine the effect of biosurfactants in Physicochemical consists of physical, chemical and biological changes in EFB composting.

ii. To determine the enzymatic EFB degradation during composting process in terms of Hemicellulose, Cellulose and Lignin.

1.5 Benefits of The Proposed Research Project

Lessen nitrogen and mineral content of matured EFB compost from composting are the problems faced by an existing composting plant with its long formation. Through the application of biosurfactants to the current EFB composting method, this research aims to resolve these main issues.

i. The benefits of using biosurfactants in composting EFB because biosurfactants are biodegradable, lesser in toxicity, environmentally safe, and display useful surface-active behaviour.

ii. Those properties, combined with their natural origin, raise the suitability of biosurfactants from any applications such as environmental remediation and microbial enhanced oil recovery.

1.6 Scope of Work

The scope of work in this study begins with the identifying of empty fruit bunches and biosurfactants as bulking agents through research. Following that, the mixing ratio of empty fruit bunch, biosurfactants, and POME sludge must be verified by referring to the prior thesis to produce a good result or product in the composting process. Begin the experiment by considering the control parameter, which means that three samples must be examined. Two sample for control are composts EFB only and EFB with POME, while another is EFB with biosurfactants and POME. Perform the experiment in the laboratory to evaluate all parameters.

1.7 Significance Study

The goal of this study is to analyse the effects of regulated temperature and the addition of biosurfactants as a bulking agent on EFB composting in order to understand more about biosurfactant behavior in composting. The project's next goal is to assess the breakdown of lignin, cellulose, and hemicellulose in empty fruit bunch fibre during the composting process. This is due to the high concentrations of lignin, cellulose, and hemicellulose in crude biomass, such as palm oil biomass. Furthermore, understanding degradation can lead to various benefits in manufacturing products such as lignin, which is usually used in carbon fibre production, hemicellulose, which mostly used in ethanol production, and cellulose, which is widely used in the papermaking business.

1.8 Outline of Dissertation

Chapter 1: This chapter provides an overview of the study context, problem statements, the aims to be accomplished, and the advantages of the planned research project.

Chapter 2: A review of the literature was conducted on the palm oil mill industry in Malaysia, the introduction of composting and the mechanisms of composting, as well as the features of biosurfactants used as bulking agents. The factors which affect the composting process, the quality of compost, the application of compost products, and the biomass policy will be discussed.

Chapter 3: Detailed description of the methodology for conducting laboratory-scale composting studies and the methodologies used to analyse various composting parameters.

Chapter 4: The data from the trials will be analysed and the discussion will be conducted appropriately. The results achieved from the EFB, EFB with POME and EFB with POME and biosurfactants at two distinct process-controlled composting temperatures are discussed in this chapter.

Chapter 5: This chapter will wrap up the results of this study. For further work on this study, recommendations will be provided.

CHAPTER 2 LITERATURE REVIEW

2.1 Overview

A review of the literature was conducted on the palm oil mill industry in Malaysia, the introduction of composting and the mechanisms of composting, as well as the features of biosurfactants used as bulking agents. The factors which affect the composting process, the quality of compost, the application of compost products, and the biomass policy will be discussed.

2.2 Palm Oil Mill Industry in Malaysia

Empty fruit bunches (EFB) and POME are the most significant residual fractions from palm oil mills. EFB is produced after palm oil is extracted from fresh fruit bunches, while POME is primarily produced by sterilization and fruit pressing. This process comprises several stages as shown in Figure 2.1. EFB is often permitted to decompose on dumped surfaces, potentially resulting in anaerobic conditions and significant GHG emissions, or it can be burned without energy recovery to minimize bulk before landfilling. (Krishnan et al., 2017).

Oil palm empty fruit bunches (EFB) are a by-product formed by palm oil mills. They are primarily composed of lignocellulosic compounds such as cellulose, hemicellulose, and lignin. Cellulose, in particular, accounts for approximately 37% (dry weight) of the EFB and is a valuable compound that can be used to benefit the palm oil industry (Soom et al., 2009). Figure 2.2 shows the components of EFB and Table 2.1 shows the chemical composition of EFB

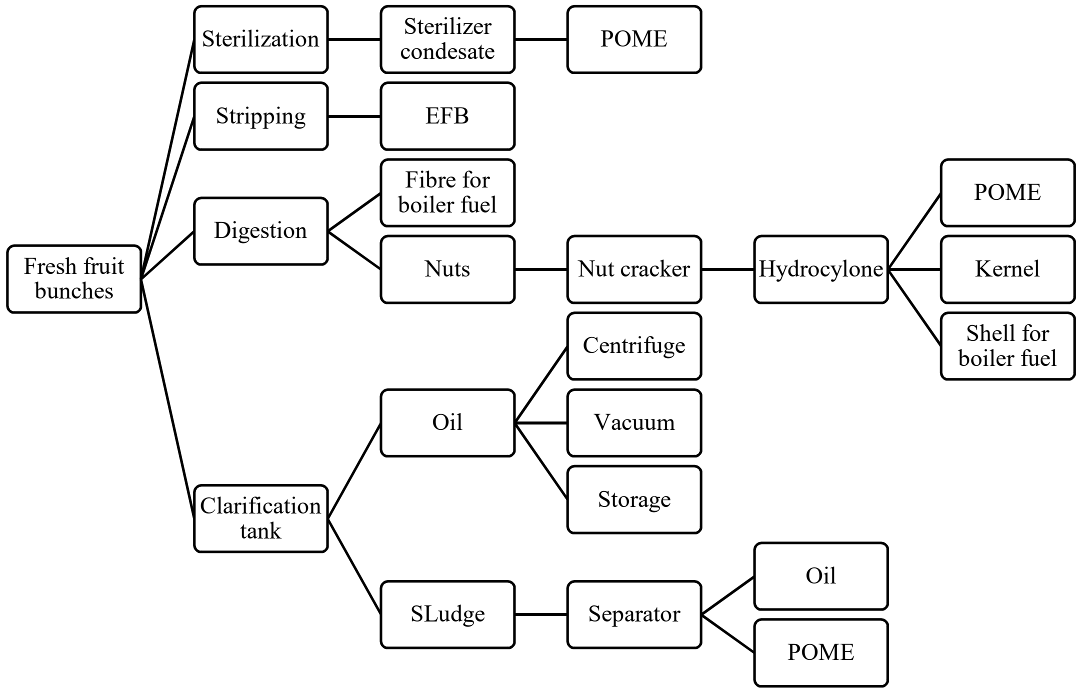

Figure 2.1: Flow Diagram of Palm Oil Extraction Process (Sim and Wei, 2016)

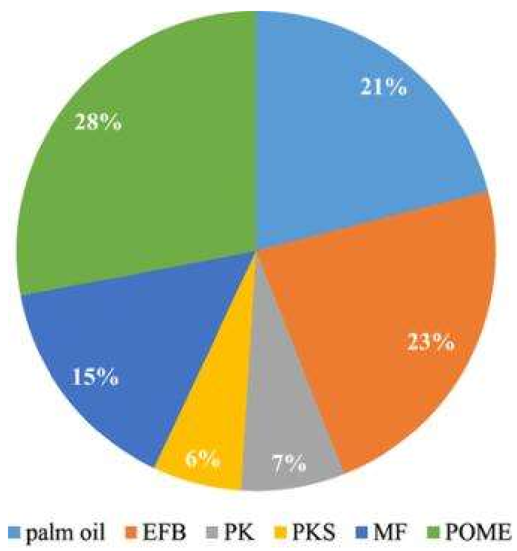

Figure 2.2: Components of Fresh Fruit Bunch (Onoja et al., 2019)

Table 2.1: Chemical Composition of Empty Fruit Bunch (Intasit et al., 2019)

Parameters	Unit	Empty fruit bunch
Cellulose	%	40.13 ± 1.08
Hemicellulose	%	23.24 ± 2.24
Lignin	%	15.64 ± 1.87
Oil	kg/ton	7.33 ± 1.04
Total solid	kg/ton	918.4 ± 5.56
Volatile solid	kg/ton	871.1 ± 2.58
Moisture	kg/ton	88.9 ± 0.661
Ash (550ºC)	kg/ton	0.50 ± 0.001
Carbon (C)	kg/ton	444.87 ± 0.017
Hydrogen (H)	kg/ton	61.81 ± 0.027
Nitrogen (N)	kg/ton	3.93 ± 0.002
Oxygen (O)	kg/ton	408.40 ± 0.267

Oil palm trees as shown in Figure 2.3, which originated in West Africa, were first grown in Malaysia in 1870 as an ornamental plant by the British. Since then, the palm oil sector has developed into a significant commodities crop for Malaysia's socioeconomic development, supporting over two million people and creating job opportunities. In general, oil palms generate two types of oils: palm oil and palm kernel oil, both widely used in the food industry (Zulqarnain et al., 2020).

Figure 2.3: Palm Oil Tree

POME is mostly formed during the palm oil milling process during the sterilization and clarifying of palm oil, which involves the use of a substantial volume of steam and hot water. POME is a viscous brownish liquid as shown in Figure 2.4 with a high concentration of total solids, oil and grease, chemical oxygen demand (COD), and biological oxygen demand (BOD) (Soleimaninanadegani and Manshad, 2014). POME sludge has a large number of soluble chemical compounds that are harmful to the environment. POME has a pH range of 4 to 5 (Alkarimiah and Rahman, 2014) as shown in Table 2.2.

Figure 2.4: A Typical Palm Oil Mill Effluent Sludge

Table 2.2:Characteristics of POME (Cheng et al., 2021)

Parameter	Concentration	Unit
pH	3.4 – 5.5	-
Oil and grease	2234 – 27166	mg/L
Biological oxygen demand	10250 – 76457	mg/L
Chemical oxygen demand	15000 – 100000	mg/L
Total organic carbon	9584 – 38616	mg/L
Total nitrogen	204 – 1708	mg/L
Hemicellulose	2530 – 8433	mg/L
Cellulose	3976 – 14300	mg/L
Lignin	9044 – 15182	mg/L

2.3 Introduction of Composting Process

Composting and vermicomposting are two of the most famous biological stabilisation techniques for solid organic waste by converting it into a safer and stable product that may be used in agricultural applications as a source of nutrients and soil conditioners (Mengistu et al., 2017). Composting is the process of aerobic biological decomposition of organic matter under restrained conditions to produce a stable, hummus-like substance called compost (Graves, 2000).

Compost quality depends on many aspects, including the feedstock material types and components, the design and operation, and the post-processing method for improving composting (Lai, 2014). The primary effect of compost is not to immediately enhance the soil with the elements that are necessary for plant growth and development, such as nitrogen, phosphorus, and potassium, but to improve the soil structure and enable plants to move nutrients, thereby creating a more appropriate soil balance (Sánchez et al., 2017).

Composting under controlled aerobic conditions may improve microbial activity efficiency while limiting undesirable environmental and health effects like odor, rodent control, water, and soil population. Furthermore, the controlled composting process ensures that the decomposed organic product meets the desired quality (Lai, 2014). In general, composting is aimed to cut down odor, lessen the amount of waste, and inactivate pathogens and parasites.

Composting has the following objectives: 1) distracting organic matter from landfills and lowering landfill pressure, leachate content, and odor potential; 2) transform organic matter to stabilized forms; 3) lowering the odor potential of organic matter; 4) lowering the moisture content of urban and industrial sludge; and 5) creating a soil amendment to boost soil fertility (Kazemi, 2017). Figure 2.5 shows the general overview of three composting phases and the degradation processes taking place.

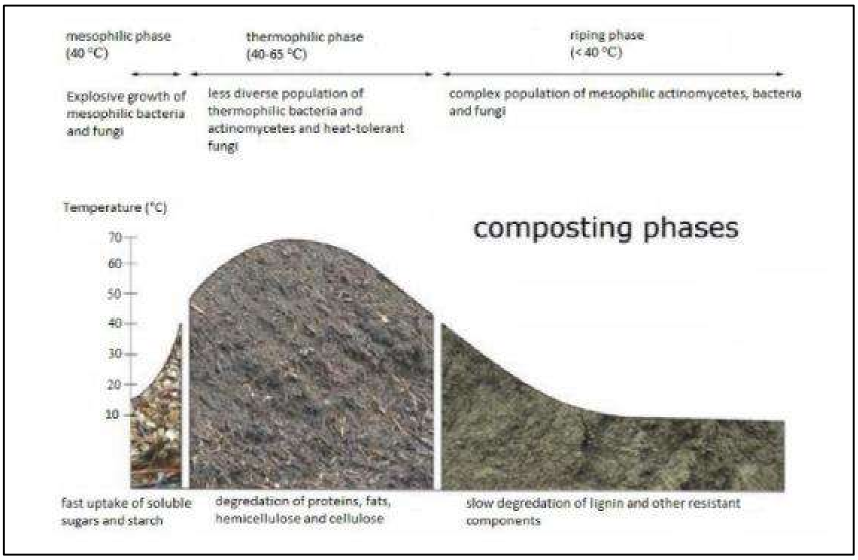

Figure 2.5: General overview of three composting phases and the degradation processes taking place

2.4 Composting of Empty Fruit Bunch with Palm Oil Mill Effluent

Composting EFB alone can have drawbacks such as increased composting time and a low fertilizer value due to the high lignocellulosic content of the compost generated. The addition of POME produces nitrogen that promotes cellulose and hemicellulose degradation in EFB and speeds up the composting process (Krishnan et al., 2017).

According to Adam et al., (2016), adding Oil Palm Decanter Cake (OPDC) as a nitrogen source during composting EFB and POME can enhance the rate of nutrients and accelerate the composting process by lowering the C/N ratio value within 10 weeks.

In a recent study by Zahrim et al., (2017), EFB and palm oil mill effluent (POME) were composted for sixty days under mesophilic conditions in the existence of *Bacillus amyloliquefaciens* D203. During the pre-treatment phase, the EFB was mixed with 1% (w/w) sodium hydroxide and then disclosed to microwave irradiation to achieve the desired results. Because of its decreased organic matter loss, the *Bacillus amyloliquefaciens* D203 strain used as inoculants in EFB-POME composting is not suggested.

The previous study by Desrihastutia et al., (2019) concluded that the particle size of compost material had a significant effect in improving the composting of empty fruit bunches. The EFB size of 1.5 cm had exhibited good performance when compared with EFB sizes of 0.5 cm and 2.5 cm. and also, the addition of bio-sludge from the pulp and paper industry had been used in the EFB composting as nitrogen source and microbial source to enhance the quality of EFB compost.

Meanwhile, Alkarimiah and Suja, (2020) stated that the mixed ratio of fresh EFB, recycled compost and POME sludge plays an important role in achieving optimum composting conditions in terms of C/N ratio and moisture content percentage and good composting process temperature is depending on a mixture of organic matter.

According to the results of the experiment conducted by Victor Baron et al., (2020), a POME to EFB ratio of 1 to 1.5m^3 per tonne was optimal when the EFB moisture content was in the range of 65% to 70%. However, their experimental conditions of the composting process were found to be insufficient for treating the entire POME produced by the mill because the compost was found to be still in a mesophilic state that could not be considered as mature compost due to high C/N ratio and elevated temperature. The summary of composting EFB with POME from the previous study is shown in Table 2.3.

Table 2.3: Summary of Composting EFB with POME from the Previous Study

Mixture	Title	Author
EFB + POME + OPDC	Composting of Empty Fruit Bunch Treated with Palm Oil Mill Effluent and Decanter Cake	(Adam et al., 2016)
EFB + POME	Effect of pre-treatment and inoculant during composting of palm oil empty fruit bunches	(Zahrim et al., 2017)
EFB + Bio-sludge Pulp and Paper	Effect Particle Size of Empty Fruit Bunch and Ratio of Bio-sludge of Pulp and Paper on Biochemical Changes in Composting Process	(Desrihastutia et al., 2019)
EFB + POME Sludge + Recycle Compost	Composting of EFB and POME Using a Step-Feeding Strategy in a Rotary Drum Reactor: The Effect of Active Aeration and Mixing Ratio on Composting Performance	(Alkarimiah and Suja, 2020)
EFB + POME	Waste Reduction and Nutrient Recovery During Co-composting of Empty Fruit Bunches and Palm Oil Mill Effluent	(Victor Baron et al., 2020)

2.5 Biosurfactants as Bulking Agent

Biosurfactants are amphiphilic compounds with hydrophilic and hydrophobic moieties. This composition endows them with surface-active properties, such as the ability to cut down the surface and interfacial tension in aqueous solutions and hydrocarbon mixtures (Jahan et al., 2020).

Nearly any synthetic surfactant can be replaced by biosurfactants and even new physical chemical properties are introduced. Biosurfactants have many advantages compared with chemical surfactants in terms of biodegradability, environmental compatibility, low toxicity, high selectiveness and even activity in extreme temperatures, pH or salinity (Kazemi, 2017). The previous study shows that soft surfactants such as rhamnolipid and Tween 80 could be used for the composting of cellulose-rich waste for the acceleration of the composting process (Shi et al., 2006). Figure 2.6 shows the process of rhamnolipids effects on microorganism characteristics and the degradation of pollutants.

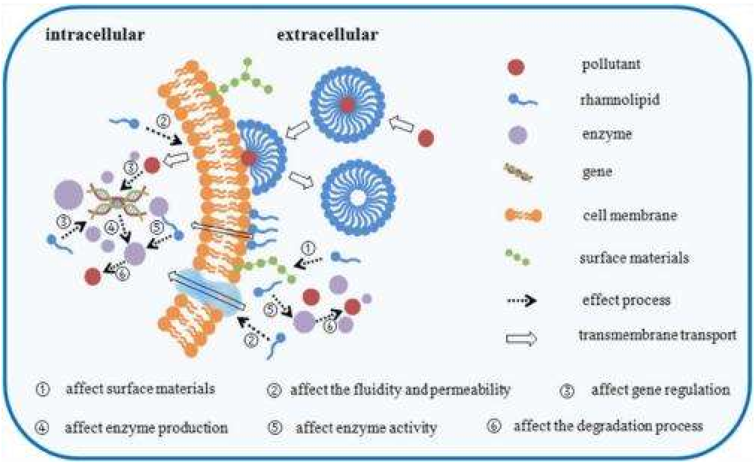

Figure 2.6: The process of rhamnolipids effects on microorganism characteristics and the degradation of pollutants (Shao et al., 2017)

Numerous researchers have attempted to advance the composting process and increase the performance and consistency of composting by adding biosurfactants. The following methods can be used to promote: to begin, biosurfactants may improve the physical-chemical conditions of the composting microenvironment, such as temperature, humidity, oxygen, porosity, and pH, thus enhancing microorganisms development (Shao et al., 2017).

According to Yin et al., (2019), tween-80 had a significant effect on the structure of the bacterial community, increasing the abundance of bacteria that breakdown cellulose and lignin (members of the order *Bacillales*) and their glucose and amino acid metabolism capacity. During the thermophilic phase, rhamnolipid and tween-80 also boosted the number of genes involved in glucose and amino acid metabolism. In addition, the bacterial population exposed to tween-80 possessed the greatest capacity for carbohydrate and amino acid degradation, and it was strongly associated to *Bacillales* metabolism.

Furthermore, the addition of Alkyl Polyglycoside (APG), also known as a 'green surfactant,' enhanced nitrate nitrogen concentrations, accelerated matter breakdown, and improved seed germination indices. The result from the previous study indicates that the addition of APG improves microorganism growth conditions, slightly increasing organic matter breakdown and speeding up the composting process, hence improving the compost quality to a degree (Zhang et al., 2011).

Moreover, Zhang and Sun, (2014) concluded that the combination of 0.15% rhamnolipid and adjustment of the initial compost particle size to 15 mm maximised the effectiveness of two-stage composting and the quality of the compost produced. This optimal combination increased aeration and water permeability, resulting in a more favourable particle size distribution and pH, decreased the C/N ratio, increased microbe numbers and enzyme activity, and thus increased the rate of green waste breakdown. As a result, in only 24 days, green trash was turned into a high-quality, mature compost. The summary of composting with biosurfactants as bulking agent from the previous study is shown in Table 2.4.

Table 2.4: Summary of Composting with Biosurfactants as Bulking Agent from the Previous Study

Mixture	Title	Author
Wheat Straw + Chicken Manure + Rhamnolipid + Tween-80	Effects of rhamnolipid and Tween-80 on cellulase activities and metabolic functions of the bacterial community during chicken manure composting	(Yin et al., 2019)
Cow Manure + Mushroom Residuals + APG	Effects of alkyl polyglycoside (APG) on composting of agricultural wastes	(Zhang et al., 2011)
Fallen Leaves + Branch Cuttings + Rhamnolipid	Effects of rhamnolipid and initial compost particle size on the two-stage composting of green waste	(Zhang and Sun, 2014)

2.6 The Mechanism of Composting Process

Composting is a controlled biological treatment of organic wastes in the solid phase, as opposed to natural rotting. The process of self-heating is triggered by heat generated by increasing microbial metabolic activity on the combination of substrates (Sim and Wei, 2016). The composting process is performed by a diverse population of mainly aerobic microorganisms which break down organic matter to grow and reproduce (Graves, 2000). The phase changes are related to the process temperature, as the temperature of the composting process varies according to microbial activity. Compost can be divided into three widely referred stages, which correspond to process temperature changes: the self-heating phase, thermophilic and cooling, and maturation phases (Lai, 2014).

During composting, oxygen (O_2) is used by microorganisms as shown in Figure 2.7 to feed organic matter. Active composting releases heat, high carbon dioxide (CO_2) amounts, and vapor into the air. Losses in carbon dioxide and water (vapor) will amount to half the weight of initial waste. Composting thus decreases the volume and mass of raw materials, thus making them useful soil conditioners (Shimizu, 2018).

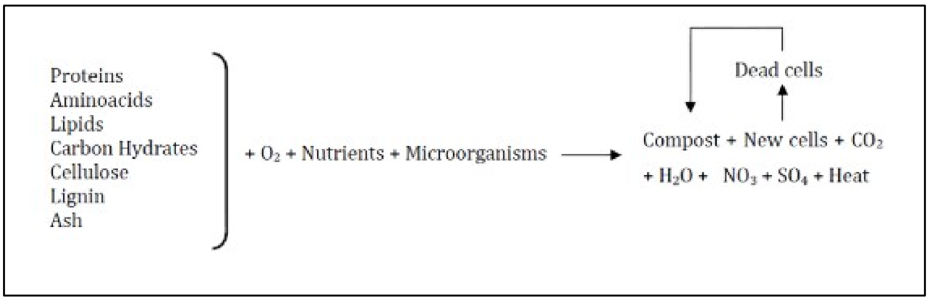

Figure 2.7: Diagram of Composting Process

2.7 Aerobic Composting

The decomposition of organic material in the presence of oxygen is referred to as an "aerobic" process. Aerobic microbes use oxygen to feed on organic matter to produce their cell protoplasm from nutrients (primarily nitrogen, phosphorus, and a small amount of carbon) contained in the compost raw material. Organic matter breaks down more quickly and fully in the presence of readily available oxygen, owing to the energy produced by aerobic respiration (Mehta and Sirari, 2018).

The use of aerobic composting technology to treat organic waste is a viable option. Sludge, as one form of organic waste, is traditionally treated by dehydrating it to less than 80% moisture content and using it for aerobic composting, which can result in issues such as low fermentation ability, strong odour, and a wide surface area (Cai et al., 2019).

2.8 Passive Aeration

Composting in passively aerated windrows or piles that are turned on a regular basis to guarantee enough aeration, water distribution, and appropriate degradation rates is a widely used technique. Passive aeration is facilitated by the heat generated by microbial activity within the compost piles. This decreases the density of the air inside the pile, causing it to rise, resulting in an inflow of air towards the bottom and an outflow at the top of the pile (Poulsen, 2010).

Regular mixing of wastes was performed in a passive aeration reactor with passive aeration, but no external aeration was used (Bhave and Kulkarni, 2019). Passive aeration composting systems usually involve periodic agitation or "turning" of the materials. Although turning materials introduces fresh air, the added air is quickly absorbed by the composting process (Shimizu, 2018).

2.9 Factor Affecting Composting Process

Efficient composting typically needs to be controlled by numerous parameters to prevent distressing problems such as unpleasant smells and dust, as well as to achieve good quality products for a natural composting process (humus) (Sim and Wei, 2016). The decomposition of microorganisms is an essential guarantee of composting ripeness, thus affecting the effect and quality of the compost generated in all its parameters which impact microorganism activities. Composting is a complicated process of a biochemical reaction that can be influenced by many factors such as the carbon-nitrogen ratio, moisture, oxygen and aeration, temperature, pH, the composting raw material size, etc. (Lai, 2014).

2.9.1 pH

pH value is one of the most crucial factors influencing the composting process. Most microorganisms maintain their microbial activities between pH 5.5 and 8.5, according to many studies. Microorganisms have better decomposition abilities in a composting environment when the pH is above 7, and the optimal pH for composting cellulose and protein-rich waste is around 8.0 (Shi et al., 2006).

The biodegradation of organic acids, mineralization of organic compounds, and subsequent release of volatile NH_3 have all been related to an increase in pH during composting (Ogunwande and Osunade, 2011). However, a fall in pH during composting may be connected to ammonia volatilization and microbial nitrification, which produce a greater amount of CO_2 and acids (Rastogi et al., 2020). At maturity, the pH of stabilised composts is found to be nearly neutral, which may be related to the buffering properties of humic compounds (Sim and Wei, 2016).

2.9.2 Volatile Solid

During the decomposition of organic matter in composting processes, the ash content tends to increase (Rawoteea et al., 2017). The increased organic matter loss indicated that aeration by rotating aided in organic decomposition during composting. The presence of refractory decomposable substances such as cellulose and lignin, on the other hand, may account for the relatively low degree of volatile solid loss (Wong et al., 2001).

Dastpak et al., (2020) mentioned that the decrease in volatile solids is considered to be due to CO_2 loss during the composting process, and the significant decreases in volatile solids readings are one of the signs for sludge stability.

2.9.3 Electrical Conductivity

The electrical conductivity (EC) of a compost sample indicates the total salt content (mostly magnesium and calcium ions released into the matrix during microbial mineralization of organic matter fractions contained in the substrates) of the composting substrates in the matrix and consequently the compost's quality as a soil supplement (Rawoteea et al., 2017).

The progressive decline in EC value over time would support the hypothesis that, first, mineralized ions were leached during periodic water showering on the composting mass, and second, as the composting process progressed, humification would inevitably occur, and the resulting humic fractions would have complexed the soluble salts, therefore decreasing the amount of mobile free ions and thereby the EC (Mengistu et al., 2017). In the biodegradation of biomass waste, a higher EC value usually indicates the presence of high nutrient elements or a slower decomposition of the organic matter, resulting in a slower release of mineral salts into the solution (Zaha et al., 2013).

According to Uçaroğlu and Alkan, (2016), the EC values will increase as a result of the creation of organic acids and the release of mineral salts (such as phosphates and ammonium ions) during the decomposition of organic substances. As the composting process advanced, ammonia volatilization and mineral salt precipitation may have resulted in decreased EC values.

Meanwhile, Irvan et al., (2018) stated that the decrease in EC values occurs as a direct result of increasing nutrient concentrations such as nitrates and nitrites, whilst the increase in EC values occurs as a result of the release of mineral salts such as phosphate and ammonia ions during the composting process.

Rawoteea et al., (2017) clearly explained that the initial increase in EC due to the discharge of mineral salts such as ammonium-based compounds following microbial degradation and disintegration of the organic matter components on the substrates. Composting then proceeded with a gradual fall in EC due to the much more likely loss of mineral salts and ions in the produced leachate. The comparison of EC with different composts during the composting process from previous study is shown in Table 2.5.

Table 2.5: Comparison of EC with Different Composts During Composting Process from the Previous Study

Mixture	EC	Author
Vegetable waste + Sewage sludge + Sawdust + Tap water	1970-3040 µS/cm	(Zaha et al., 2013)
Wastewater treatment sludge + corncob/sunflower stalk	3500 µS/cm	(Uçaroğlu and Alkan, 2016)
Shredded vegetable wastes + dry leaves + bagasse + chicken manure + paper.	1835.3 µS/cm	(Rawoteea et al., 2017)
EFB + Activated liquid organic fertilizer	4725 µS/cm	(Irvan et al., 2018)

2.9.4 Moisture Content

Moisture levels have a direct effect on microbial activity, oxygen consumption rate, temperature, and porosity level in composting. Effective composting requires a moisture content of approximately 50–60% (v/w), depending on the composition of the input material (Rastogi et al., 2020). The ideal moisture content for composting is determined by the physicochemical equity and biological characteristics of the materials to be composted. Moisture content influences both microbial activity and physical formation in the composting process and thus has a major impact on organic material biodegradation (Alkarimiah and Suja, 2020).

According to their findings, Desrihastutia et al., (2019) concluded that the minimum moisture content required to increase microbial activity during the composting process was 50%, and a moisture content range of 60-70 percent could provide the highest level of microbial activity. The ideal moisture content in the starting material varies and is dependent on the physical condition and size of the particles, as well as the composting method used; however, moisture content of 60% in the starting material is considered adequate in most cases (Bhave and Kulkarni, 2019).

2.9.5 C/N Ratio

The initial carbon to nitrogen (C/N) ratio influences the speed of microbial activity significantly. Carbon satisfies the energy requirements of the process evolution microorganisms but at the same time, it becomes part of their fundamental structural elements, while nitrogen is integral to proteins, nucleic acids, amino acids, and enzymes that make up 50% of their dry mass and are necessary for cell growth in microbial form (Bhave and Kulkarni, 2019).

Nitrogen is the most important component in herbal nutrition, received the most attention in the formulation of compositions, and is often identified as a restricting factor in microbial growth and activity, particularly in materials with a high C/N content, when plant residues are decomposed. Carbon is an energy source in the oxidation process but also is one of the most likely elements to be lost during the composting process (Kazemi, 2017).

Carbon to nitrogen ratios during composting have an effect on the process and, as a result, the final product. According to previous research, the ideal C/N ratio for composting is between 20-25 and 25-30. However, a C/N ratio of 10-15 is commonly accepted as a value indicating humic acid formation and enhanced compost stability (Alkarimiah and Suja, 2020)

Desrihastutia et al., (2019) asserted that carbon to nitrogen ratio of 27 to 30 was optimal for initiating the composting process, although a carbon to nitrogen ratio of 22 to 44 was universally assumed to be successful. Microbes use roughly 30 parts carbon and one part nitrogen. Following that, Hau et al., (2020) underlined that a decrease in the C/N ratio below 20 revealed an advanced degree of organic stabilisation, indicating a desirable level of maturity in composts. Additionally, the C/N ratio exceeds 50:1, resulting in a sluggish composting process. The comparison of the C/N ratio with different composts during the composting process from previous study is shown in Table 2.6.