ASSESSMENT ON THE POTENTIAL OF PLASTICS BIODEGRADATION BY TERMITES (DICTYOPTERA: ISOPTERA)

by

AISHA SHAHIRAH BINTI AZLI

A report submitted in fulfillment of the requirements for the degree of
Bachelor of Applied Science (Natural Science Resources) with Honours

FACULTY OF EARTH SCIENCE
UNIVERSITI MALAYSIA KELANTAN

2024

DECLARATION

I declare that this thesis entitled "Assessment on The Potential of Plastics Biodegradation by Termites (Dictyoptera: Isoptera)", is the result of my own research except as cited in the references. The thesis is not being presented concurrently for the candidature of any other degree, nor has it been accepted for any degree.

Signature : ________________

Name : AISHA SHAHIRAH BINTI AZLI

Date : 12 AUGUST 2024

ACKNOWLEDGEMENT

In the name of Allah, The Most Benevolent, and The Most Merciful. Praises to Allah SWT for giving me chances and lend me the strength to complete this thesis successfully.

Without the encouragement and assistance of numerous people, the thesis could not be finished. My supervisor, Dr Norashikin Fauzi, deserves a humble present of gratitude for all of her helpful suggestions, counsel, direction, and encouragement during the entire study. I sincerely value the knowledge I have gained from her assistance during this research. I keep in constant contact with my supervisors despite the many challenges I have in completing my thesis.

My gratitude also been extended to my parents, Azli Abdullah and Zaimah Daud, for their understanding and supports throughout this study. I also want to thank my closest friends and siblings for their support and immense affection. I am grateful for your unwavering support throughout this extremely demanding academic year; without it, I could not have finished my thesis.

I would want to sincerely thank my fellow undergraduate students for providing me with constant encouragement and for helping me persevere through all of the difficulties. Lastly, I want to express my gratitude to each person who took part in my study, whether on purpose or accidentally. I appreciate your willingness and valuable time. May Allah make your journey easier.

Assessment on The Potential of Plastics Biodegradation by Termites (Dictyoptera: Isoptera)

ABSTRACT

This thesis was based on the objectives which indicate to assess the potential of plastics biodegradation among termites and to compare the plastics preferences and biodegradation rates by termites, specifically for polypropylene (PP), polyethylene (PE), polyethylene terephthalate (PET), polystyrene (PS), and polyvinyl chloride (PVC). This study also investigated at the termites' capacity to biodegrade five different kinds of plastic over the course of five days. In order to determine the decrease percentages and evaluate the rates of biodegradation, the initial and end weights of every type of plastic were measured. Plastics such as PP, PE, PET, PS, and PVC were evaluated. The results showed that different plastics biodegraded to differing degrees. With an 84.42% weight reduction, polyvinyl chloride (PVC) had the highest biodegradation rate. Significant degradation was also demonstrated by polyethylene (PE) and polyethylene terephthalate (PET), with reduction rates of 79.52% and 79.35%, respectively. Polypropylene (PP) displayed the lowest biodegradation rate at 58.51%, while polystyrene (PS) demonstrated a moderate reduction rate of 64.04%. According to the study, termites have the ability to biodegrade specific plastics, with PVC being the most vulnerable and PE and PET following closely behind. Even so, the degradation rates of PS and PP were lower. These findings demonstrate the various polymers' susceptibilities to termite biodegradation and imply the potential use of termites in biological waste management plans, especially for more biodegradable plastics like PET, PVC, and PE. It is advised to conduct more research to examine the biochemical processes underlying termite-mediated biodegradation as well as to assess the environmental effects and long-term viability of employing termites to handle plastic waste.

Penilaian Potensi Biodegradasi Plastik oleh Anai-Anai (Dictyoptera: Isoptera)

ABSTRAK

Tesis ini adalah berdasarkan objektif yang menunjukkan untuk menilai potensi biodegradasi plastik di kalangan anai-anai dan untuk membandingkan keutamaan plastik dan kadar biodegradasi oleh anai-anai, khususnya untuk polipropilena (PP), polietilena (PE), polietilena tereftalat (PET), polistirena (PS), dan polivinil klorida (PVC). Kajian ini juga menyiasat keupayaan anai-anai untuk membiodegradasi lima jenis plastik berbeza dalam tempoh lima hari. Untuk menentukan peratusan penurunan dan menilai kadar biodegradasi, berat awal dan akhir setiap jenis plastik telah diukur. Plastik seperti PP, PE, PET, PS, dan PVC telah dinilai. Keputusan menunjukkan bahawa plastik yang berbeza terbiodegradasi kepada darjah yang berbeza. Dengan pengurangan berat sebanyak 84.42%, polivinil klorida (PVC) mempunyai kadar biodegradasi tertinggi. Degradasi yang ketara juga ditunjukkan oleh polietilena (PE) dan polietilena tereftalat (PET), dengan kadar pengurangan masing-masing sebanyak 79.52% dan 79.35%. Polipropilena (PP) menunjukkan kadar biodegradasi terendah pada 58.51%, manakala polistirena (PS) menunjukkan kadar pengurangan sederhana sebanyak 64.04%. Menurut kajian itu, anai-anai mempunyai keupayaan untuk membiodegradasi plastik tertentu, dengan PVC menjadi yang paling terdedah dan PE dan PET mengikuti rapat di belakang. Walaupun begitu, kadar degradasi PS dan PP adalah lebih rendah. Penemuan ini menunjukkan pelbagai polimer yang mudah terdedah kepada biodegradasi anai-anai dan membayangkan potensi penggunaan anai-anai dalam pelan pengurusan sisa biologi, terutamanya untuk lebih banyak plastik terbiodegradasi seperti PET, PVC dan PE. Adalah dinasihatkan untuk menjalankan lebih banyak penyelidikan untuk mengkaji proses biokimia yang mendasari biodegradasi pengantara anai-anai serta menilai kesan alam sekitar dan daya maju jangka panjang menggunakan anai-anai untuk mengendalikan sisa plastik.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

UMK	Universiti Malaysia Kelantan
FSB	Faculty of Earth Science
PE	Polyethylene
PS	Polystyrene
PP	Polypropylene
PVC	Polyvinyl Chloride
PET	Polyethylene Terephthalate
PUR	Polyurethane
MPs	Microplastics
WPC	Wood plastic composite
HDPE	Recycled high-density polyethylene

LIST OF SYMBOLS

%	Percentage
=	Equal
g	Gram
-	Minus

CHAPTER 1

INTRODUCTION

1.1 Background of Study

According to Bollag W B et.al (2000) and Reddy R M (2008), plastics are used as necessary materials in the twenty-first century because of their chemical and physical characteristics. All individual first choice when it comes to raw materials for their use and business is plastic. On an international scale, an estimated 57 million tons of plastic garbage are produced each year. Due to their lack of auto-degradable qualities and slower rate of degradation, plastics generate trash and can release extremely toxic substances that are bad for the environment. As a result, there is a serious risk of environmental pollution from plastic use (Saminathan P et.al, 2014 & Das M P and Kumar S, 2014). Microbes, insects, and the enzymes they are linked with are examples of biotic agents that are important for the decomposition of plastic and the cleanliness of ecosystems. They remove dangerous toxins from the environment by breaking down polymers and their byproducts. Enzymes change plastic polymers into oligomers and speed up the rate at which plastics break down. Fungal species are the best biotic agents or microorganisms for digesting plastic in the process of plastic biodegradation.

According to López-Naranjo E J et.al (2013) and Yang J et.al (2014), plastic or its polymers may potentially be broken down by termites. For termite identification, in addition to morphological identification, molecular identification is typically utilised according to Poonia A and Sharma V (2014). Since termites transform hard plant biomass into soil, they are frequently referred to as ecosystem engineers. In quest of nourishment, termites mostly target moisture-bearing plant materials including cellulose, hemicellulose, and lignocellulose; nevertheless, they will also target non-cellulosic materials like plastics (Kumar A et.al, 2022). Termites that mostly feed on wood attack and break down plastics with their mandibles. Both aerobic and anaerobic processes are involved in microbial decomposition. Degradation of plastic is also influenced by the polymers that were used to synthesize it.

Plastic degradation is any change in the polymer's chemical or physical properties brought on by external elements such heat, light, moisture, chemicals, or biological activity (Kale et al., 2015). The ability of microorganisms, such as some bacteria and fungi, to biodegrade polymers under stress using various exoenzymes has been the subject of recent investigations (Ahmed, 2018). However, the amount of research on insects' capacity to break down plastics is quite limited. Insect pests, including termites may potentially degrade many types of plastic materials. Thus, the current research was created to look into the efficiency of termites to degrade five types of plastics.

1.2 Problem Statement

Human activity creates pollution in nature, and humans are the only ones who can transcend the whole threshold into generating pollution and putting all animals' and plants' health at serious risk. Plastics are one of the primary causes of this issue. The extensive usage of plastic materials results in a significant volume of solid trash, and there are no comprehensive or quick breakdown processes for this solid waste in nature. Additionally, when they degrade, a number of hazardous and poisonous compounds that are bad for the environment are released. Plastic may be treated using a variety of techniques, including photooxidative, thermal, ozone-induced, mechano-chemical, catalytic, and biological deterioration. With the exception of the biodegradation method, all of these techniques are environmentally hazardous.

Microplastic pieces have been discovered in the environment and provide a serious issue for several ecological fields. According to some research, microplastics have been discovered to reach the deep ocean (Bergmann et al. 2020; Cunningham et al. 2020) and the top of the earth (Mount Everest) (Napper et al. 2020). Of all microplastics, fewer than 20% came from water and nearly all from land. Microplastics have an adverse influence on the environment, including the death and harm of aquatic birds, fish, mammals, and reptiles due to plastic aggregation and digestion (Sana et al. 2020).

The environment is gradually overtaken by plastics like polyethylene (PE), polystyrene (PS), polypropylene (PP), polyvinyl chloride (PVC), polyethylene terephthalate (PET), polyurethane (PUR), and other plastic polymers because they are difficult to break down and accumulate. Therefore, the development of new treatments or control technologies is desperately needed. Plastics' ability to biodegrade has drawn a lot of attention because of its safe and environmentally friendly qualities. In vitro environmental microbes and in vivo insect gut microbes are two important types of microorganisms that are involved in the biodegradation of plastics. Significant plastics degrade very slowly in vitro under environmental conditions, sometimes taking months or even years to break down. However, recent research indicates that certain plastics, like PS, PE, and PUR, can break down quickly in some invertebrates, particularly insects, with rates measured in hours. This process of degradation is most likely due to gut microbial-dependent or synergistic bioreactions in animal digestive systems. The main soil insect that can break down plastics with the help of their gut bacteria is the termite. Although termites' guts contain a wide variety of microorganisms, very few of them have the ability to break down plastics. The primary focus of this study is on the possibility of termites biodegrading plastics, as well as the kinds of plastics they prefer to eat and the rate at which they break down.

Therefore, it is becoming more and more important to create techniques for the removal and remediation of waste plastic. One proposed remedy is biodegradation, which might break down plastic trash and possibly allow for the recovery of valuable minerals. Nevertheless, the application of microbial biodegradation as a scalable solution for plastic waste is limited by the present rates of biodegradation, which are sluggish and frequently plastic-specific. To comprehend degradation mechanisms and scale up biodegradation as a sustainable end-of-life fate for plastic waste, it is imperative to identify natural systems that might expedite plastic biodegradation.

1.3 Objectives

The objective of the study as following:

i. To assess the potential of plastics biodegradation among termites.

ii. To compare the plastics preferences and biodegradation rates by termites.

1.4 Scope of Study

The research will be carried out in the Microbiology and Biochemistry Laboratory, Faculty of Earth Science (FSB) of Universiti Malaysia Kelantan (UMK), Jeli campus. The microplastics found in termites are the subject of this study. Termites are usually found in yards and homes with lots of wood, soil, and moisture. They typically like fallen branches and ancient tree stumps. The purpose of this study is also to determine whether termites are capable of decomposing plastic. The study attempts to investigate the type of plastics that were put to the test as well as the ambient temperature and humidity.

1.5 Significant of Study

Investigating the potential ability of organisms particularly microbes to degrade plastic is a captivating field of study. Although it has been demonstrated that some microorganisms may degrade plastics, this usually takes a very long period. Given these issues, it's fascinating to investigate if termites, a common kind of bug, can facilitate the faster and safer breakdown of plastic.

Using termites to decompose plastic is an intriguing concept for research and development. If successful, this method could make disposing of plastic waste safer, quicker, and more environmentally friendly. However, before acting, it's crucial to exercise caution, conduct extensive research, and consider the implications for the environment and morality. In the end, research on termites as plastic biodegraders highlights the significance of addressing our mounting plastic pollution issue.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction of Microplastics

Plastic particles less than 5 mm (as little as 0.3 mm are rarely measured) are known as microplastics, or MPs. Through human use, they become part of the ecosystem. Certain plastics are produced as MPs; yet, when exposed to water and sunlight, larger plastic waste can break down into micro-sized particles. Because MPs have such a wide range in form and shape, it is challenging to quantify and distinguish MPs from natural particles. Microplastic contamination can be caused by disposable plastic, polystyrene foam, synthetic apparel, and plastic bags. There are thirteen varieties of MPs; the most prevalent ones are polystyrene, polypropylene, and polyethylene. MPs fall into two main categories; Synthetic fabrics are the source of microfibers, which are often the most prevalent kind of microplastics. These fibers shed after regular wear and machine washing of clothes, such as fleece coats. The majority of microfibers that are discharged into water have a size of 0.1–0.8 mm. (Hernandez et al. 2017). And the fragments that emerge from the physical shattering of macroplastics. There are a lot of microplastics in drinking water, lakes, and the ocean. From microscopic organisms to humans, microplastics are consumed, inhaled, or absorbed at every stage of the food chain (Coffin and Weisberg 2022).

2.1.1 Properties of microplastics

a) Physical properties

The physical characteristics of microplastics, comprising as their size, shape, surface area, crystallinity, and density, are shown in Figure 1. According to Andrady (2017), changes in these qualities are brought about by several weathering/aging processes that lead to MPs degrading, including oxidation, sun exposure, bio-film growth, and thermal aging (Lambert and Wagner, 2016; Fazey and Ryan, 2016; Rouillon et al., 2016; Luo et al., 2020). According to Lambert and Wagner (2016) and El Hadri et al. (2020), plastic particles are reduced throughout the degradation process to micro- to nano-sized particles and makes it easier for them to enter biotic systems.

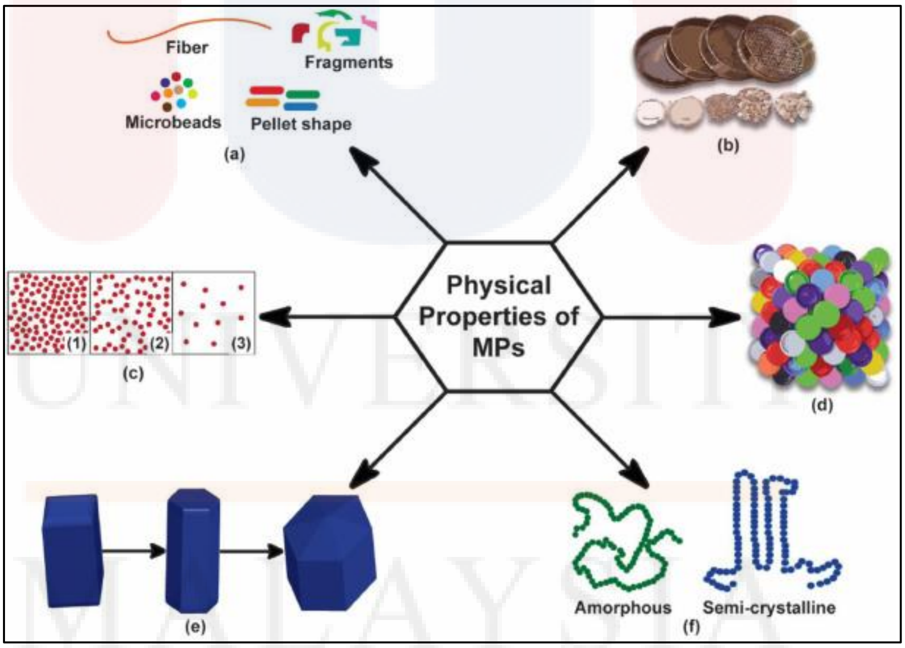


Figure 2.1: Physical properties of Microplastics; (a) Shape, (b) Size, (c) Density, (d) Color, (e) Surface area, and (f) Crystallinity.

b) Chemical properties

According to Burns et al. (2018), Bond et al. (2018), Hidalgo-Ruz et al. (2012), Andrady (2017), polyethylene (PE), polyethylene terephthalate (PET), polyamide (PA), polypropylene (PP), polystyrene (PS), polyvinyl alcohol (PVA), and polyvinyl chloride (PVC) are the most prevalent microplastic polymer types in the aquatic environment. PVC, PS, and PET are amorphous polymers, and PE and PP are semi-crystalline polymers (Crawford and Quinn, 2017). The degree of crystallinity of a polymer directly affects its mechanical properties. The chemical structures of a few typical MP polymers are displayed in Figure 2. 17 MP polymers, including acrylate, biopolymer, low-density polyethylene (LDPE), high-density polyethylene (HDPE), melamine, PP, PS, polyurethane (PUR), PVA, rubber, Teflon, and other unknown polymers, have been discovered by researchers in urban wastewater (Halle et al., 2017; Bayo et al., 2020).

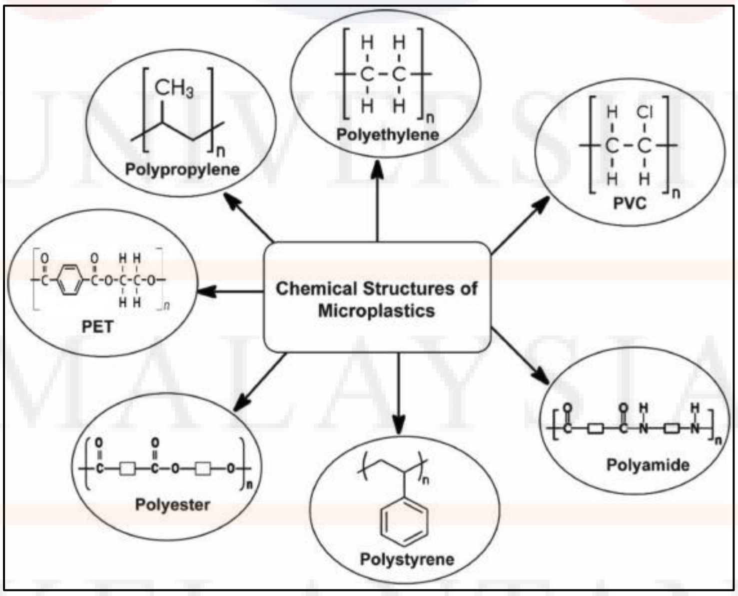


Figure 2.2: Chemical formulas of various typical polymers used in microplastics.

c) Biological properties

Because of their high degree of crystallinity, plastic particles are generally resistant to microbial attack; as a result, plastic biodegradation is difficult (Mueller, 2006). According to recent research, fungus and bacteria among other microorganisms help break down plastic (Jumaah, 2017; Ren et al., 2019). A key element in the biodegradation of plastics is soil quality because several microorganisms that are engaged in the process may require various soil circumstances for optimal growth (Zhang et al., 2021). Furthermore, the process of biodegradation illustrated in Figure 3 is heavily influenced by various factors such as organism types, pretreatment techniques, polymer properties (such as biotic and abiotic environments, mobility, toxicity, crystallinity, molecular weight, kind of functional groups and substituents, and addition of plasticizers or additives). Artham and Doble, 2008).

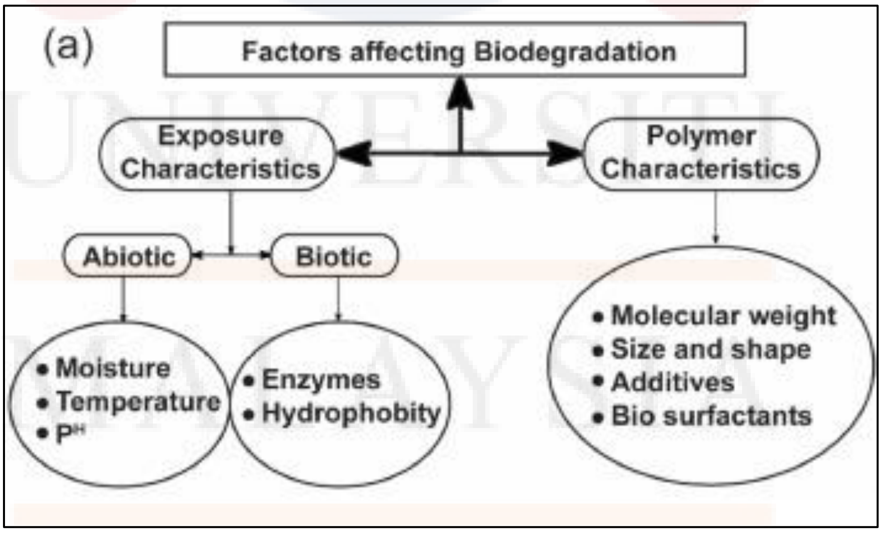


Figure 2.3: Factors that are in charge of influencing how quickly microplastics biodegrade.

2.2 Effects of Microplastic to Ecosystem and Living Biota

Microplastics have an impact on the ecosystem for two primary reasons: (1) they can absorb pollutants on their surfaces due to their small size, which makes it easier for biota to internalise them and cause accumulating within the food chain; and (2) they can absorb contaminations due to their size (Rillig, 2012).

The detrimental impacts of microplastic particles on primary producers must be thoroughly investigated due to their propensity to disrupt any ecological food chain that serves as the foundation of a food web. The first proof of the physical effects of nanosized plastic beads on two algae species—Chlorella spp. and Scenedesmus spp.—was presented by Bhattacharya et al. (2010). Because of the existence of electrostatic attraction, it has been determined that the positively charged propensity of cellulose promotes the adsorption of negatively charged beads on the surface. The form and motility of the algal cells determine the tendency of microplastic particle adsorption, which ultimately causes the creation of reactive oxygen species in the algal species under study.

2.3 Mechanism of plastic degradation by insects

Based on pertinent studies, the process by which insects break down plastics would be broken down into five stages: (1) plastics were physically chewed by mouthparts and enter the intestinal tract; (2) gut microbes adhered to and erode plastic; (3) the plastic was depolymerized into oligomer fragments by oxidation or hydrolysis of enzymes, which were provided by both the host and the gut microbiome; (4) the host provided bioemulsifying agents enhancing the effectiveness of microbial and host enzymes to attack polymers; (5) the bonds of oligomers were broken to form fatty acids; and (6) fatty acids were broken via insect biological metabolism. In order to find effective methods for plastic biodegradation, it was important to take into account how insects' gut microbiota functions (Yang et al., 2015).

2.4 Previous Studies

Year	Author	Previous Studies
2022	Amit Kumar, C. M. Kalleshwaraswamy, Radhika Sharma, Parvati Sharma and Asha Poonia	Biodegradation of Plastic Using Termites and their Gut Microbiota: A Mini Review
2022	Rania Al-Tohamy, Sameh Samir Ali, Meng Zhang, Tamer Elsamahy, Esraa A. Abdelkarim, Haixin Jiao, Sarina Sun and Jianzhong Sun	Environmental and Human Health Impact of Disposable Face Masks During the COVID-19 Pandemic: Wood-Feeding Termites as a Model for Plastic Biodegradation
2019	Nik Athirah Binti Nik Adib	Diversity Of Termites (Order: Blattodea) In Hutan Lipur Bukit Bakar, Machang, Kelantan

2.5 Description of termites

A class of insects known as termites are classified under the Order Isoptera. The term "Isoptera," which translates to "equal wing" in Latin, describes the way the reproductive termite's front sets of wings are arranged (Rahman & Tawatao, 2003). However, evolutionary research of the species of these insects has shown that termites are placed in the same order as cockroaches (Blattodea), according to Inward, Beccaloni, and Eggleton (2007).

2.5.1 Life cycles of termites

Three castes make up termites: workers, soldiers, and reproductive (king and queen) (Collins, 1984). Termites go through partial metamorphosis. When the queen deposits eggs, termites are born. Depending on the size of the colony, the queen might hatch anywhere from hundreds to thousands of eggs every day. When those eggs are about to hatch, they change from being translucent white and weak to being extremely active (Edwards & Mill, 1986). Salivary secretions rich in nutrients were then produced by the reproductive to nourish the larvae. Before these larvae reach their full shape, they often go through several moults. Depending on what the colony requires, they will either become workers or soldiers (Harris, 1957). In addition, external elements like pheromones and hormones have an impact on how termites evolve as a species (Krishna, 1970).

The larvae become the workers before the foundation of the colony is constructed, and later on, a small number of larvae with huge heads and jaws that occasionally have slightly different shapes are discovered. A soldier develops from these larvae (Harris, 1957). Many years later, the colony is still growing, with an increasing number of individuals, a more sophisticated nest structure, and more construction activity (Bignell & Eggleton, 1998). When the larvae with wing buds emerge and become winged termites, the entire developmental cycle is finished (Harris, 1957).

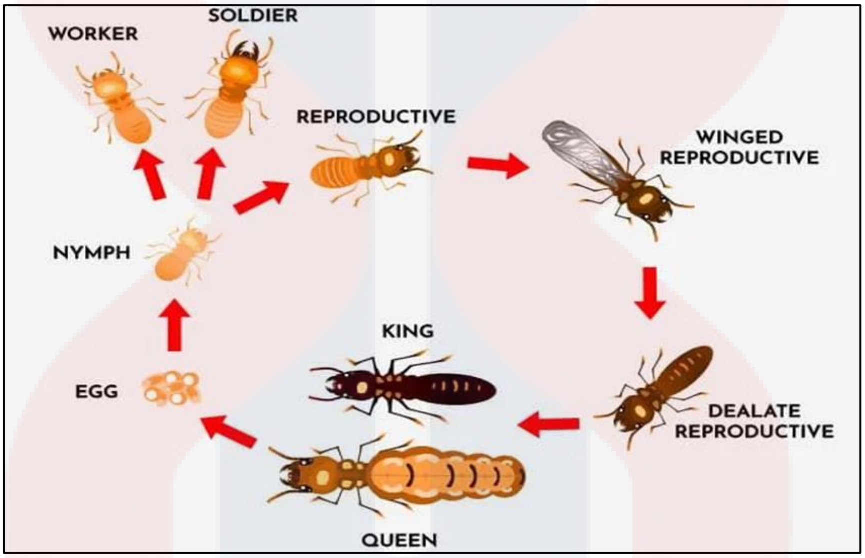


Figure 2.4: The life cycle of termites

2.5.2 Roles and Feeding Guilds of Termites

Termites are a varied collection of creatures with a range of nest-building and feeding practises. Termites' functional differences have significant effects on trophic webs and the cycling of nutrients. Most people who see termites for the first time think of them as pests that consume building wood (Su and Scheffrahn, 2000) or as the animals that create mounds in tropical savannas (Spain et al. 1986, Davies et al. 2016, Martin et al. 2018). As a matter of fact, termites are found in many different types of habitats and exhibit a broad variety of feeding and nesting behaviours. Wood, grass (Poaceae family), litter, manure, dirt, and certain African and Asian species even cultivate fungus as a food source are examples of feeding substrates (Eggleton and Tayasu, 2001). Given that termites are eusocial insects, their nests play a crucial role in termite biology as sites of numerous intracolonial interactions (Noirot and Darlington, 2000). Nevertheless, there is a great deal of variation in termite nest forms.

Certain termite species that feed on wood build their nests inside the structure where they find food; however, many other termite species, including those that feed on wood, create separate nests (Eggleton and Tayasu, 2001). These include belowground nests, aboveground arboreal nests (Noirot and Darlington, 2000), and aboveground epigeal nests, which are typically made of clay. The placement of the nest affects both the kinds of vertebrates that hunt termites and the ecosystem's nutrient distribution in the environment. For example, termites are the food source for aardvarks, Orycteropus afer, in aboveground mounds (Taylor et al., 2002), and slider lizards, Lerista spp., in belowground nests (Greenville and Dickman, 2005). Every termite species has unique nesting and feeding habits that allow them to coexist in a particular area of the ecosystem.

Termites' nesting and feeding habits can be distinguished as distinct functional features that specify their place in the ecosystem and how they interact with other species (McGill et al. 2006). For example, in certain environments, aboveground mounds have a favourable effect on the quantity and quality of plants available to herbivores (Levick et al. 2010, Davies et al. 2016b), while kingfishers have a home in arboreal nests (Hindwood 1959, Kesler and Haig 2005). In forest and savannah ecosystems, termites that feed on wood are essential to the process of wood degradation. They compete with fungi for the wood resource (Cornwell et al. 2009, Ulyshen 2016), and in savannas, they have a similar function to grass-feeding termites (Bodine and Ueckert 1975, Silva et al. 1985, Holt and Coventry 1990).

Furthermore, because termites are ectothermic, the temperature of their surroundings is essential to their survival and can be controlled, for example, by the design of their nest (Noirot and Darlington 2000, Korb 2003). In order to prevent excessive heat loss, we anticipate that underground termite nests should be preferred at lower temperatures, as has been seen in ant observations (Reymond et al. 2013). Lastly, it has been demonstrated that soil characteristics have a significant role in the construction of termite mounds. Since these structures rely on stable fine clay soils (Jouquet et al., 2002), we anticipate that species that create mounds will be more prevalent in regions with a high clay concentration.

2.5.3 Role of Termites Gut Microbiota in Plastic Degradation

Termites primarily rely on the microbial strains in their stomachs to break down hard materials. Thus far, the only microorganisms that can break down plastic are termite gut bacteria and fungus. Compared to bacterial strains, fungal strains have a higher potential to break down plastic polymers. Two distinct bacterial strains with the ability to break down LDPE were found in termites' stomachs. According to Thamil C T (2016), these are *Bacillus cereus* and Lysinibacillus. On the surface of polyethylene materials, like polyethylene bags, these bacterial colonies are stimulated. They are able to grow in both anaerobic and aerobic environments. Gram-positive, rod-shaped facultative anaerobic strains of Bacillus sp. and gram-positive, rod-shaped spore-forming bacteria Lysinibacillus sp. Bacillus species. Possessing the capacity to break down around 24.7% of polyethylene bags in 30 days, whereas Lysinibacillus breaks down 27.8% of polyethylene at the same time. The 16S rRNA gene sequences allowed for the identification of both strains (Thamil C T, 2016). The Kathiresan method (Kathiresan K, 2003) was utilised to assess the bacterial decomposition of polyethylene.

The fungus Xylaria, which exhibits a close exosymbiotic relationship with termites, is found in wood, feeding on the combs and gardens of higher termites (Sharma R, 2021). Additionally useful in the breakdown of plastic polymer sheets, Xylaria sp. utilises plastic sheets as a source of carbon [9]. Both aerobic and anaerobic plastic degradation processes are carried out by Xylaria sp., which produces CO2 and H2O in the former case and CO2, H2O, and methane in the latter (Kumar A et.al, 2020, Laessoe T, 1994 & Rogers J D et.al, 2005).

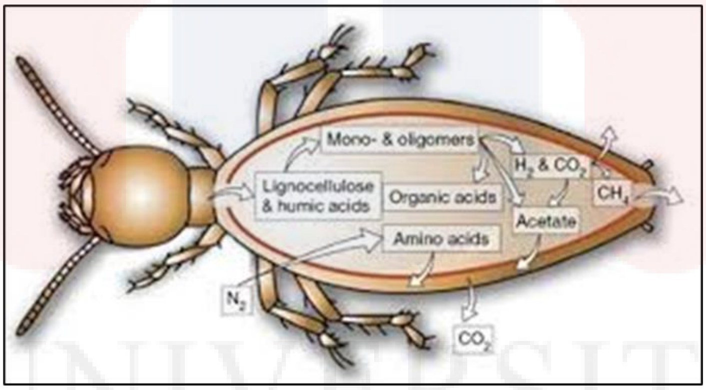


Figure 2.5: The Termite's Guts

2.5.4 Termite's Potential in Plastics Polymer Degradation

It takes some time for plastic polymers to fully decompose naturally. Plastic bags pose a serious threat to the environment because they deplete subterranean water supplies, diminish soil fertility, contaminate soil, water, and air, and harm human and grazing animal health (Kathiresan K, 2003 & Soud S A, 2019).

The primary constituents of plastic polymers, wood plastic composite (WPC) and recycled high-density polyethylene (HDPE), are wood and petrochemical plastics. WPC is made up of 20% thermoplastics derived from fossil fuels and 80% lignocellulose particles. Polypropylene (PP), Polyethylene (PE), and Polyvinyl chloride (PVC) are components of thermoplastics (Singh B & Sharma N, 2008). Wood and recycled high-density polyethylene can both be simply included into WPC construction. WPCs are entirely biodegradable polymers. The WPCs are deteriorated by a variety of living (bacteria, fungi) and non-living (sunlight, moisture, and temperature). Moreover, termites deteriorate recycled high-density polyethylene (HDPE) and WPCs. When wood pulp composites (WPCs) come into touch with high relative humidity or water, their moisture absorption attracts termites and fungi that will destroy them.

For termites to break down their food sources, moisture is necessary. Termites and climatic conditions accelerate the surface characteristics of WPCs. Termites can enter WPCs through a variety of surface fractures that are created when weather acceleration occurs. Termites alter the chemical or physical characteristics of WPCs with their mandibles. The plastics are removed from the surface, and they obtain their food source from the woody materials found inside the WPCs (López-Naranjo E J, 2013).

2.6 Techniques Used for Plastic Degradation Analysis

To study plastic degradation, a number of techniques were used, such as scanning electron microscopy and fourier transform infrared. The rate of evolution of CO2, the intake of O2, modifications to the chemical and physical properties of the polymer, and the pace of organism growth can all be used to monitor the biodegradation of plastics. To evaluate the degradation of plastic, it is advised to carry out several experiments (Mohan K, 2011).

CHAPTER 3

MATERIALS AND METHODS

3.1 Materials

In this study, Table 3.1 shows the following materials and apparatus that were used in this assessment to evaluate the potential of plastics biodegrading by termites:

Table 3.1: Materials and Apparatus

Samplings at Jeli, Kelantan	- Shovel - Hand shovel - Wheelbarrow - Stainless steel bowl - Aluminium foil - Gloves
Laboratory materials and apparatus	- Petri dishes - Spatula - Forceps - Filter-papers - 1g of termites for each petri dish - 1g Polyethylene (PE) - 1g Polypropylene (PP) - 1g Polyethylene Terephthalate (PET) - 1g Polystyrene (PS)

	- 1g Polyvinyl chloride (PVC) - Analytical balances for measuring plastic weights - Gloves (cotton) - Laboratory coat (cotton) - Mask - Tissues paper - Wet tissues - Aluminium foil - Scissors - Plastic grinder

3.2 Methods

3.2.1 Study Area

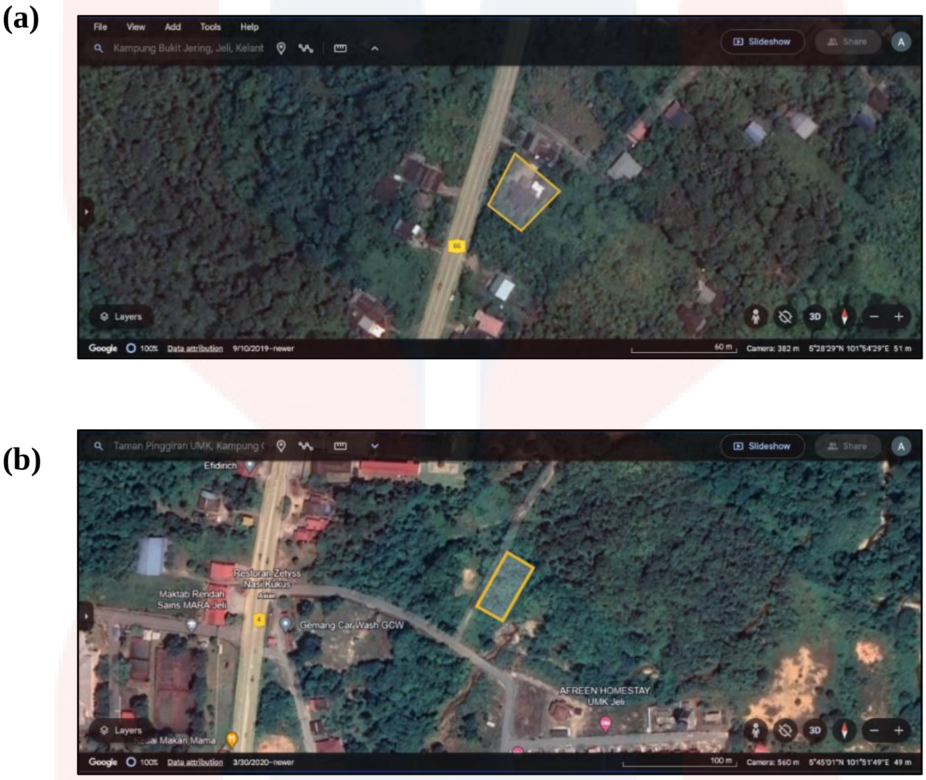


Figure 3.2: (a) Kampung Bukit Jering, Jeli, Kelantan Google Earth Maps, (b) Taman Pinggiran UMK, Kampung Gemang Lama, Jeli, Kelantan Google Earth Maps

The study site to sampling termites was located in Kampung Bukit Jering and Taman Pinggiran UMK, Kampung Gemang Lama, which was situated in the district of Jeli, Kelantan. The coordinates for Kampung Bukit Jering was 5° 28’ 29” N latitude and 101° 54’ 29” E longitude, and Taman Pinggiran UMK, Kampung Gemang Lama was 5° 45’ 01” N latitude and 101° 51’ 49” E longitude. In both areas, there was many nests or mounds and active termite paths which can be used as a sample to this experiment. It taken an hour to drive from UMK Jeli to Kampung Bukit Jering and only five minutes to Kg Gemang Lama by riding a motorcycle.

3.2.2 Collection of samples termites (*Coptotermes gestroi*)

In order to collect the sample, the species of termites has been identified which *Coptotermes gestroi*. The genus Coptotermes was characterized by the presence of a pear-shaped head, narrow at front with a pointed labrum in the soldier caste (Pearce et al., 1993). Mandibles were slender, sharply pointed and slightly incurved without marginal teeth. Most distinctive in the soldier caste was the large fontanelle (opening) at the front of the head which exuded a white defence secretion when the insect was disturbed. Coptotermes have been shown to possess, as for other members of the Rhinotermitidae, sunken pores on their legs which produced a defensive secretion against predators (Bacchus, 1979). These termites were the domestic pest in which easier to found and accessible within the neighbourhood especially wooden houses.

Samples of termites was obtained also by cooperatinge with my course-mate at the area of her aunts’ house and approaching the residents of the area Jeli, Kelantan for termites’ mound. Before approaching to the sampling site, temporary placement for termites was provided, which a stainless-steel bowl was covered with aluminium foil. At sampling site, collecting the samples mostly were found at near damp areas and termites’ mounds. If the termites were found at the area with decaying wood, the wood fragments needed to take as a termites’ food source. To keep the termites from escaping after they have been collected, the sample was placed in a big glass aquarium tank and covered with box and aluminium foil with holes on top. The sample was brought back and tested in the laboratory. The humidity and temperature of sampling site will be recorded, and the surrounding area of sampling site will be photographed.

Figure 3.3: The one of the area termites' samplings

Figure 3.4: Collecting the termites

Figure 3.5: The sample of termites in glass aquarium tank

3.2.3 Preparation of plastics

In order to assess the degree of plastic deterioration caused by termites' activity, it was important to take into consideration different types of plastics. All plastics were differed in terms of its structures, characteristics, and chemical composition, all of which affect how susceptible it was decay through biodegradation.

The initially of preparation of plastics, the researcher was chosen bubble wrapped (PE), waste plastic (PP), mineral watered bottles (PET), polystyrene cups (PS) and book wrappers (PVC) as the main observation of termites consumed these plastics. These plastics had been finely grounded by used a grinder in the lab to be made it into a powder and made sure it was easier for termites to digest. These following was provided some justification regarding why these five typical polymers was included in such this assessment:

i. **Polyethylene (PE):** Products made of polyethylene were widely used in daily life. Pipe, wire, and cable insulation, and food and pharmaceutical packaging film were a few examples. Because polyethylene was one of the most widely utilised polymer materials in daily life, its manufacturing was enormous. Numerous items, such as plastic bags, plastic film, and milk barrels that are appropriate for hollow moulding, injection moulding, and extrusion of other products, could be produced from plastic (Zhong et al., 2018).

Figure 3.6: 1g of PE

ii. **Polypropylene (PP):** PP was the most significant substance for three key reasons. First, PP was ideal for long-term applications due to its excellent qualities, which include low density, high melting temperature, and chemical inertness at a low cost. Second, because polypropylene was such a versatile material, a wide range of mechanical qualities and structural designs are possible. Third, by adding fillers or reinforcing agents and combining PP with other polymers, several morphological configurations of PP were achievable, each of which results in a polymer with better properties (Maddah H.A., 2016).

Figure 3.7: 1g of PP

iii. **Polyethylene Terephthalate (PET):** One of the most popular materials for beverage packaging was polyester plastic called polyethylene terephthalate (PET). PET bottles were more widely produced and used for beverage packaging due to its superior clarity, light weight, gas and water barrier qualities, impact strength, UV resistance and unbreakability (in comparison to glass bottles). PET was known for being recyclable, but it also has biodegradation capability that was worth considering since it offerred performance advantages over other packaging materials like glass bottles, aluminium cans, paperboard cartons, and other polymers (Patnarin Benyathiar et al., 2022).

Figure 3.8: 1g of PET

iv. **Polystyrene (PS):** Styrene was a liquid hydrocarbon that is produced commercially from petroleum and the monomer of polystyrene (PS), a polymer. PS was typically a solid thermoplastic at room temperature, but it could be melted and then resolidified for moulding or extrusion at a higher temperature. PS was an aromatic polymer, while styrene is an aromatic monomer. It is renowned for its resistance to microbial deterioration and is also utilised in packaging and disposable products. Examining the degrading process mediated by termites provides insight into possible approaches to handle waste polystyrene (Koerner et al., 2007).

Figure 3.9: 1g of PS

v. **Polyvinyl Chloride (PVC):** Vinyl chloride monomer was polymerized to create polyvinyl chloride, or PVC for short. Various compounds were frequently added to PVC to give it new qualities (Fischer et al., 2014; Mijangos et al., 2023). According to Ahmad et al. (2023), it provided a wide range of benefits, including low cost, superior mechanical and chemical qualities, solubility in organic solvents, chemical resistance, and thermal stability. For this reason, a wide range of applications and goods, including pipes, PVC billboards, car components, artwork, medical applications, and interior design elements, employed this material extensively (Abreu et al., 2023; Li et al., 2023b; Mijangos et al., 2023). Traffic light, window, and vehicle wrapping were all done with flexible PVC films (Emanuel Ximim Gavim et al., 2023).

Figure 3.10: 1g of PVC

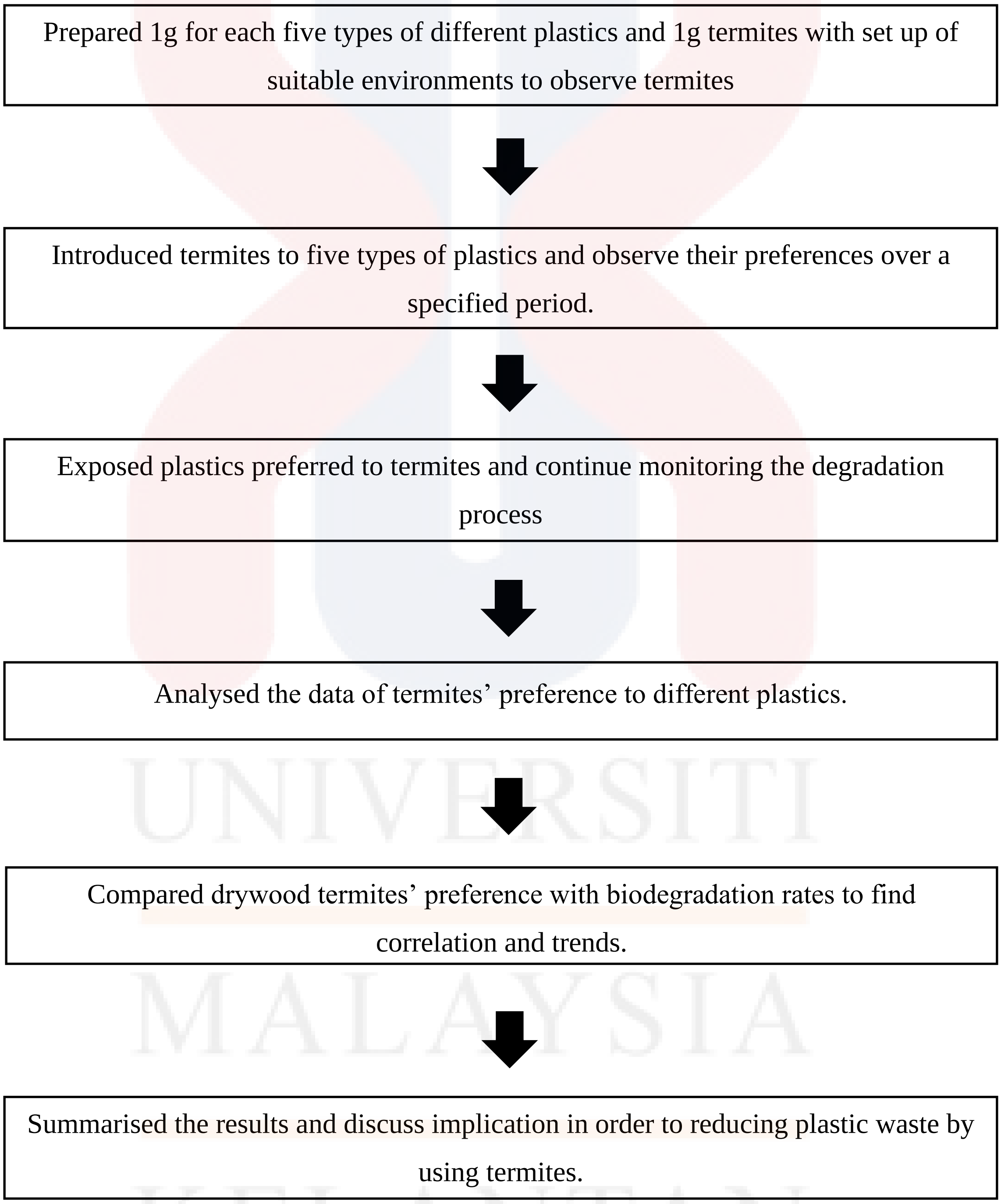
3.2.4 Test optimisation

This experiment was used the optimisation test and conducted in the laboratory. For the beginning, the five type of plastic preferences was provided in which each weighing 1 gram, including PE, PP, PET, PS, and PVC. Each of them was provided in petri dish. Each of petri dish was consisted of 1g termites. In terms of size, shape, and starting weight, had been make sure that plastic samples were all the same. The plastics was exposed in forms appropriate to their everyday use to replicate real-world situations. Regarding to surrounding conditions, the researcher was imitating regulated humidity, light, and temperature to mimic termite habitats like found in nature. The researcher kept an eye on and continuously maintained these circumstances during the experiment.

For the duration of ingestion or decomposition of plastics, the researcher conducted that experiment in 5 days to record the result while the other days available by ensuring termites were able to live for one day and the following day to digest the plastics. On Day 1, experiment was conducted to make termites acclimated to their new environment and adapted with plastics to digest. After that, the observation was made on which plastic was the most frequently consumed by termites. On Day 2 and the following day, the observation was repeated and recorded the data to compare the plastics preferences and biodegradation rates by termites.

3.3 Flow chart of study

Over the course of the six-month study endeavour, numerous significant tasks were completed. First, the title of the study was carefully chosen based on the supervisor's proposal. Next, an informative introduction explaining the background of the research was developed. A complete assessment of pertinent literature publications was carried out to achieve a thorough comprehension of the research matter and to provide a strong basis of information regarding biodegradation, particularly with regard to termites. Subsequently, the observation work by implementing two main objectives: to assess the potential of plastics biodegradation among termites, to compare the plastics preferences and biodegradation rates by termites.



Prepared 1g for each five types of different plastics and 1g termites with set up of suitable environments to observe termites

Introduced termites to five types of plastics and observe their preferences over a specified period.

Exposed plastics preferred to termites and continue monitoring the degradation process

Analysed the data of termites' preference to different plastics.

Compared drywood termites' preference with biodegradation rates to find correlation and trends.

Summarised the results and discuss implication in order to reducing plastic waste by using termites.

Figure 3.11: Flow chart of study

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Potential of plastic biodegradation

To assess the potential for plastic biodegradation among termites and compare plastic preferences and biodegradation rates, the researcher begun by visualising the data presented for each type of plastic over a five-day period. This assisted the researcher to understand the biodegradation trends and preferences.

Table 4.1: The weight of termites' digested plastic

DAY	PP	PE	PET	PS	PVC
1	0.94g	0.83g	0.92g	0.89g	0.77g
2	0.89g	0.77g	0.86g	0.82g	0.64g
3	0.57g	0.64g	0.68g	0.74g	0.31g
4	0.41g	0.39g	0.20g	0.43g	0.29g
5	0.39g	0.17g	0.19g	0.32g	0.12g

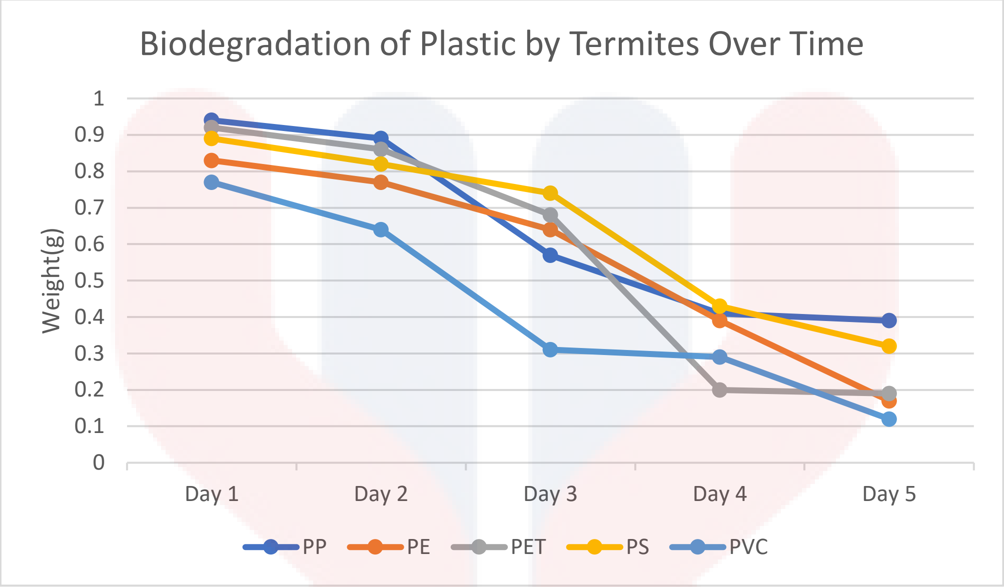


Figure 4.1: Biodegradation of plastics by termites over time

On the beginning of this experiment, 1g of each plastic was placed in each petri dish together with 1g of termites. The weight of the petri dish (x) has been measured, i.e. PP plastic was x=37.51g, PE was x=39.64g, PET was x=35.65g, PS was x=37.27g, and PVC was x=36.65 g. To find the weight of termites' digested plastic (g), the weight of plastic powder by day added with the weight of termites that 1g, plus with the weight of petri dish according to the type of plastic (y), which was (y-x) and it was tabulated as in the Table 4.1 above.

4.2 Biodegradation Analysis

Table 4.2: The data of biodegradation rates

The type of plastics	Biodegradation rates (%)
PP	58.51
PE	79.52
PET	79.35
PS	64.04
PVC	84.42

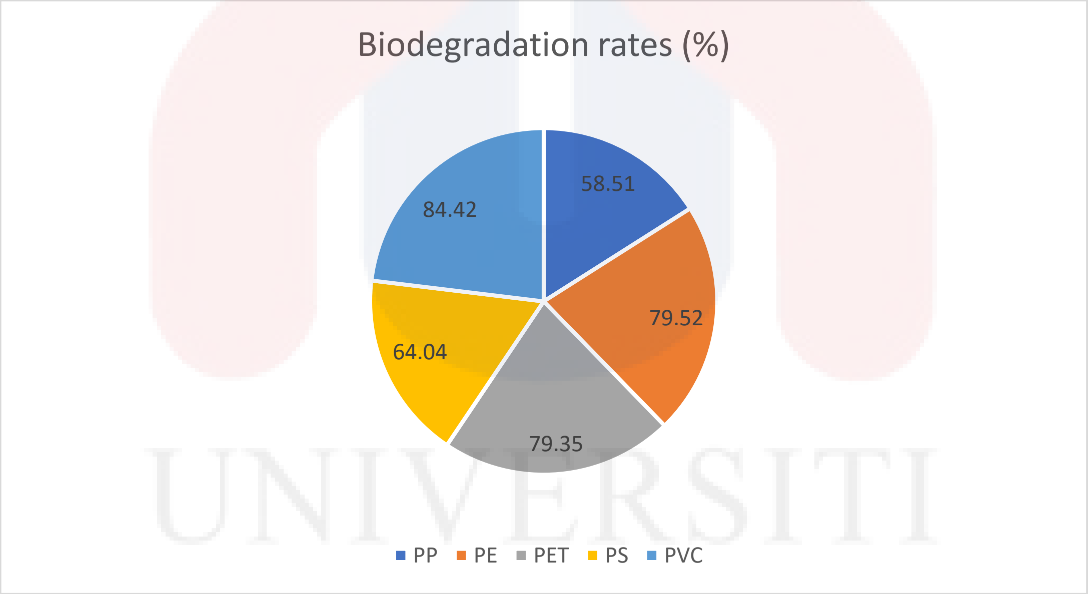


Figure 4.2: Biodegradation rates analysis

The biodegradation analysis of Polypropylene (PP) shown a significant reduction in weight over the five days, indicating that termites were capable of degrading this type of plastic which 58.51%. The initial weight of PP was 0.94g and the final weight of PP was 0.39g. However, compared to other plastics, the reduction rate was relatively lower, suggesting that PP was less susceptible to termite biodegradation.

Polyethylene (PE) exhibited a high reduction rate of 79.52%. For the initial weight of PE was 0.83g and the final weight of PE was 0.17g. This significant decrease highlights PE as one of the more degradable plastics by termites, demonstrating their potential to break down this material efficiently over a short period.

Polyethylene Terephthalate (PET) also shown a high biodegradation rate of 79.35%. The initial weight of PET was 0.92g. The final weight of PET was 0.19g. This indicated that termites can effectively degrade PET, similar to PE, making it another favorable candidate for biodegradation studies using termite activity.

The biodegradation of Polystyrene (PS) resulted in a reduction rate of 64.04%. The initial weight of PS was 0.89g. The final weight of PS was 0.32g. Although reduction rate was substantial, it was lower than that of PE and PET. This suggested that while termites can degrade PS, it is not as efficiently degraded as some other plastics.

Polyvinyl Chloride (PVC) shown the highest reduction rate at 84.42% which the initial weight was 0.77g and final weight was 0.12g. This remarkable degradation indicated that termites had a strong potential to break down PVC, making it the most susceptible plastic to termite biodegradation among those tested.

The highest degradation was PVC while the lowest degradation was PP. PVC shown the highest reduction in weight, suggesting termites degraded this plastic most effectively while PP shown the lowest reduction in weight, indicating it was least preferred or most resistant to termite degradation.

These findings demonstrate how different plastics are more or less susceptible to termite biodegradation. Since termites can break down PVC, PE, and PET more quickly than other materials, it makes sense to use termites to handle biological waste. On the other hand, because of their slower rates of degradation, PP and PS might need extra or different techniques for proper biodegradation.

$$\textbf{Reduction (\%)} = \left(\frac{\boldsymbol{Initial\,Weight - Final\,Weight}}{\boldsymbol{Initial\,Weight}}\right)\boldsymbol{\times 100}$$

Initial Weight: The weight of the material at the beginning of the observation period.

Final Weight: The weight of the material at the end of the observation period.

(Source: Chowdhury et al., 2022)

4.3 Challenges

The first challenge was speed and efficiency. The biodegradation process was relatively slow and inefficient, requiring large amounts of time and termites. The second on was plastic types. Not all types of plastics were equally susceptible to biodegradation by termites. Some plastics were required additional processing or modification. Next, scalability. Large-scale biodegradation of plastics by termites was challenging due to the need for controlled environments and adequate food sources.

One of the most significant issues was the variability of the plastics being examined. Each variety of plastic had a unique chemical structure and composition, which affected its biodegradability. Understanding the particular variables that made some plastics more prone to termite deterioration necessitates extensive chemical investigation. Furthermore, the physical qualities of plastics, such as density, thickness, and surface area, influenced how termites interact with and degrade them. Standardising these factors across different polymers was necessary for comparative studies, however it had been too difficult due to the inherent variances between these materials.

In addition, maintaining consistent and controlled experimental conditions was crucial in obtaining accurate results. Environmental elements such as temperature, humidity, and soil type would have a substantial impact on termite activity and biodegradation. Any changes to these settings would bias the data, making it difficult to draw reliable conclusions. Furthermore, different termite species demonstrated diverse skills and efficiency in decomposing polymers. Identifying and selecting the proper termite species for the study was crucial yet difficult, considering the diversity of termite species and their different ecological responsibilities.

Controlled experimental conditions was the one part of the challenges. Maintaining consistent and regulated experimental settings was crucial for achieving accurate results. Temperature, humidity, and soil type may all have a major impact on termite activity and biodegradation rates. Any modification in these settings could have thrown off the results, making it difficult to draw reliable conclusions. Furthermore, different termite species may have demonstrated varying capabilities and efficiencies in decomposing polymers. Identifying and selecting the proper termite species for the study was crucial yet difficult, considering the diversity of termite species and their varied ecological responsibilities.

Accurate monitoring and quantification of plastic breakdown were important to this work. Precise weight measurements of the polymers before and after the experiment were required to calculate the reduction rates appropriately. Minor weight measurement errors could have a substantial impact on the results, leading to inaccurate conclusions about biodegradation potential. Furthermore, detecting and quantifying the results of plastic decomposition by termites could be difficult. Some byproducts may have been volatile or present in trace amounts, making them difficult to detect and test precisely.

The next challenge was the duration of studies. The process of biodegradation was intrinsically time dependent. Long-term studies may be necessary to fully understand the biodegradation capability of plastics because short-term studies may not have fully captured the extent of plastic degradation. Long-term research, however, had demanded significant financial resources as well as prolonged time commitments. It had taken a lot of work to continuously monitor the degrading process over time. Although these techniques had their own set of difficulties, the development of automated or semi-automatic techniques to monitor changes in plastic weight and condition had been valuable.

The last but not least, the challenge of this study was impacts on the environment and ecosystem. It was essential to evaluate the ecological and environmental effects of plastic biodegradation in order to make sure that no toxic compounds were produced throughout the process. Ecotoxicological investigations were difficult and resource-intensive, yet they were required to assess the possible environmental dangers connected to degraded plastic wastes. It was also crucial to comprehend how soil health and the larger ecosystem were impacted by plastic degradation. The possible advantages and disadvantages of employing termites to manage plastic garbage must be thoroughly examined through extended ecological research.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, PVC showed the greatest degradation, whilst PP showed the least. While PP showed the lowest weight drop, showing it was least preferred or most resistant to termite degradation, PVC showed the highest weight reduction, suggesting termites dissolved this material most successfully. The results obtained show the varying susceptibilities of several polymers to termite biodegradation. Using termites to treat biological waste makes sense because they can decompose PVC, PE, and PET more quickly than other materials. However, due to their slower rates of degradation, PP and PS may require additional or alternative methods in order to properly biodegrade.

5.2 Recommendations

Conducting a long-term study of the potential of plastics biodegradation by termites to understand the full biodegradation potential and environmental impact that would be useful to the future generations as well as the other researchers. Here we are expecting outcomes including comprehensive data on the long-term biodegradation rates and efficiency of termites on various plastics, and insights into the environmental conditions that optimize plastic degradation by termites. And the last one is understanding of the potential environmental risks and benefits, including effects on soil health and ecosystem dynamics.

REFERENCES

Abel, A., Kloas, W., Zarfl, C., Hempel, S., & Rillig, M. C. (2018). Microplastics as an emerging threat to terrestrial ecosystems. *Global Change Biology*, *24*(4), 1405–1416. https://doi.org/10.1111/gcb.14020

Anbumani, S., & Kakkar, P. (2018). Ecotoxicological effects of microplastics on biota: a review. *Environmental Science and Pollution Research*, *25*(15), 14373–14396. https://doi.org/10.1007/s11356-018-1999-x

Asifa Ashrafy, Afroza Akter Liza, Md. Nazrul Islam, Billah, M., Shaikh Tareq Arafat, Md. Moshiur Rahman, & Syed Mahbubur Rahman. (2023). Microplastics Pollution: A Brief Review of Its Source and Abundance in Different Aquatic Ecosystems. *Journal of Hazardous Materials Advances*, *9*, 100215–100215. https://doi.org/10.1016/j.hazadv.2022.100215

Bahl, S., Dolma, J., Singh, J., & Sehgal, S. (2021). Biodegradation of plastics: A state of the art review. *Materials Today: Proceedings*, *39*, 31–34. https://doi.org/10.1016/j.matpr.2020.06.096

Brandon, A. (2020). *UNDERSTANDING NATURAL PLASTIC BIODEGRADATION: A CASE STUDY OF TENEBRIO MOLITOR.* https://stacks.stanford.edu/file/druid:cs239bh3255/Brandon_AnjaMalawi_Dissertation-augmented.pdf

Bulak, P., Kinga Proc, Pytlak, A., Andrzej Puszka, Gawdzik, B., & Bieganowski, A. (2021). Biodegradation of Different Types of Plastics by Tenebrio molitor Insect. *Polymers*, *13*(20), 3508–3508. https://doi.org/10.3390/polym13203508

Chowdhury, M., Hossain, N., Tauhidul Islam Noman, Hasan, A., Alam Shafiul, & Kashem Mohammod Abul. (2022). Biodegradable, physical and microbial analysis of tamarind seed starch infused eco-friendly bioplastics by different percentage of Arjuna powder. Results in Engineering, 13, 100387–100387. https://doi.org/10.1016/j.rineng.2022.100387

Coptotermes (termites). (2022). CABI Compendium. https://doi.org/10.1079/cabicompendium.15279

Cox, K., Covernton, G. A., Davies, H. L., Dower, J. F., Juanes, F., & Dudas, S. E. (2019). Human consumption of microplastics. *Environmental Science & Technology*, *53*(12), 7068–7074. https://doi.org/10.1021/acs.est.9b01517

Dey, S., Taraka Veerendra, P.S.S. Anjaneya Babu, & Kundeti Nagarjuna. (2023). *Degradation of Plastics Waste and Its Effects on Biological Ecosystems: A Scientific Analysis and...*ResearchGate; Springer Nature. https://www.researchgate.net/publication/370780965_Degradation_of_Plasti cs_Waste_and_Its_Effects_on_Biological_Ecosystems_A_Scientific_Analysis_and_Comprehensive_Review

Enhanced Bioavailability and Microbial Biodegradation of Polystyrene in an Enrichment Derived from the Gut Microbiome of Tenebrio molitor (Mealworm Larvae). (2021). Environmental Science & Technology. https://pubs.acs.org/doi/abs/10.1021/acs.est.0c04952

Galal, N., & Khattab, A. M. (2023). Plastics Biodegradation and Biofragmentation. *Springer EBooks*, 571–600. https://doi.org/10.1007/978-3-031-09710-2_22

Hodson, M., Duffus-Hodson, C., Clark, A., Prendergast-Miller, M., & Thorpe, K. (2017). Plastic Bag Derived-Microplastics as a Vector for Metal Exposure in Terrestrial Invertebrates.. Environmental science & technology, 51 8, 4714-4721 . https://doi.org/10.1021/acs.est.7b00635.

Jumaah, O. S. (2017). Screening Of Plastic Degrading Bacteria from Dumped Soil Area. *IOSR Journal of Environmental Science, Toxicology and Food Technology*, *11*(05), 93–98. https://doi.org/10.9790/2402-1105029398

Koerner, G. R., Hsuan, Y. G., & Koerner, R. M. (2007). The durability of geosynthetics. *Elsevier EBooks*, 36–65. https://doi.org/10.1533/9781845692490.1.36

Kumar, A., Kalleshwaraswamy, C. M., Sharma, R., Sharma, P., & Poonia, A. (2022). Biodegradation of Plastic Using Termites and their Gut Microbiota: A Mini Review. *IOP Conference Series*, *1057*(1), 012016–012016. https://doi.org/10.1088/1755-1315/1057/1/012016

Maddah, H. A. (2016). *Polypropylene as a Promising Plastic: A Review*. ResearchGate. https://www.researchgate.net/publication/290439450_Polypropylene_as_a_Promising_Plastic_A_Review

Nosova, A. O., & Uspenskaya, M. V. (2023). Ecotoxicological effects and detection features of polyvinyl chloride microplastics in soils: A review. *Environmental Advances*, *13*, 100437–100437. https://doi.org/10.1016/j.envadv.2023.100437

Patnarin Benyathiar, Kumar, P., Carpenter, G. S., Brace, J. G., & Dharmendra Kumar Mishra. (2022). Polyethylene Terephthalate (PET) Bottle-to-Bottle Recycling for the Beverage Industry: A Review. *Polymers*, *14*(12), 2366–2366. https://doi.org/10.3390/polym14122366

Rania Al-Tohamy, Ali, S. S., Zhang, M., Tamer Elsamahy, Abdelkarim, E. A., Jiao, H., Sun, S., & Sun, J. (2022). Environmental and Human Health Impact of Disposable Face Masks During the COVID-19 Pandemic: Wood-Feeding Termites as a Model for Plastic Biodegradation. *Applied Biochemistry and*

Biotechnology, *195*(3), 2093–2113. https://doi.org/10.1007/s12010-022-04216-9

Raudhah, N., Nirwandy, I., & Noordin, M. (2020). Understanding the Issue of Plastic Waste Pollution in Malaysia: A Case for Human Security. *Journal of Media and Information Warfare*, *13*(1), 105–140. https://jmiw.uitm.edu.my/images/Journal/Vol123Paper4.pdf

Tamer Elsamahy, Sun, J., Elsilk, S. E., & Ali, S. S. (2023). Biodegradation of low-density polyethylene plastic waste by a constructed tri-culture yeast consortium from wood-feeding termite: Degradation mechanism and pathway. *Journal of Hazardous Materials*, *448*, 130944–130944. https://doi.org/10.1016/j.jhazmat.2023.130944

Tsunoda, K., Rosenblat, G., & Koji Dohi. (2010). Laboratory evaluation of the resistance of plastics to the subterranean termite Coptotermes formosanus (Blattodea: Rhinotermitidae). *International Biodeterioration & Biodegradation*, *64*(3), 232–237. https://doi.org/10.1016/j.ibiod.2009.12.008

Turney, S. (2022). *Pearson Correlation Coefficient (r) | Guide & Examples*. Scribbr. https://www.scribbr.com/statistics/pearson-correlation-coefficient/

Wijas, B., Lim, S., & Cornwell, W. K. (2021). Continental-scale shifts in termite diversity and nesting and feeding strategies. Ecography, 2022(1). https://doi.org/10.1111/ecog.05902

Yang, X., Wen, P., Yang, Y., Jia, P., Li, W., & Pei, D. (2023). Plastic biodegradation by in vitro environmental microorganisms and in vivo gut microorganisms of insects. *Frontiers in Microbiology*, *13*. https://doi.org/10.3389/fmicb.2022.1001750

Yutaka Tokiwa, Calabia, B. P., Ugwu, C. U., & Sei-ichi Aiba. (2009). Biodegradability of Plastics. *International Journal of Molecular Sciences*, *10*(9), 3722–3742. https://doi.org/10.3390/ijms10093722

Zhong, X., Zhao, X., Qian, Y., & Zou, Y. (2018). *Polyethylene plastic production process*. ResearchGate; PiscoMed Publishing Pte. Ltd. https://www.researchgate.net/publication/335656841_Polyethylene_plastic_production_process

APPENDIX

Sample of termites

A colony of termites (*Coptotermes gestroi*)

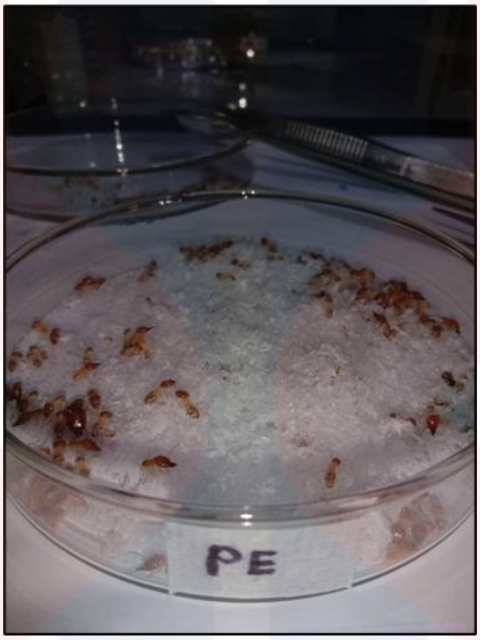
Scattering of termites (*Coptotermes gestroi*)

The discovery of termites' colony

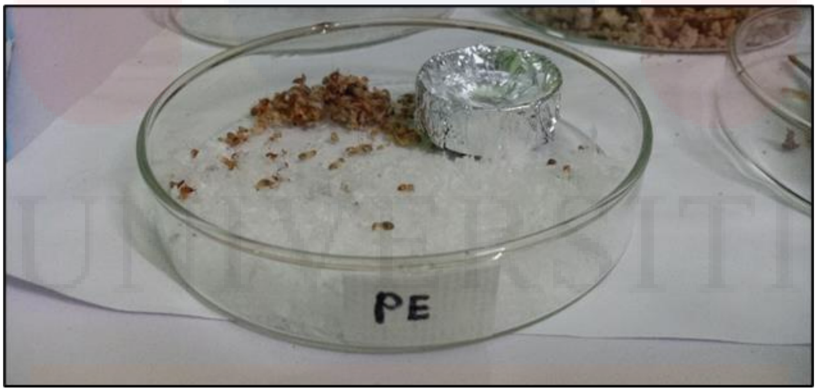
Wooden walls worn out by termites

The signs of the presence of termites

The figures of termites digested the plastic

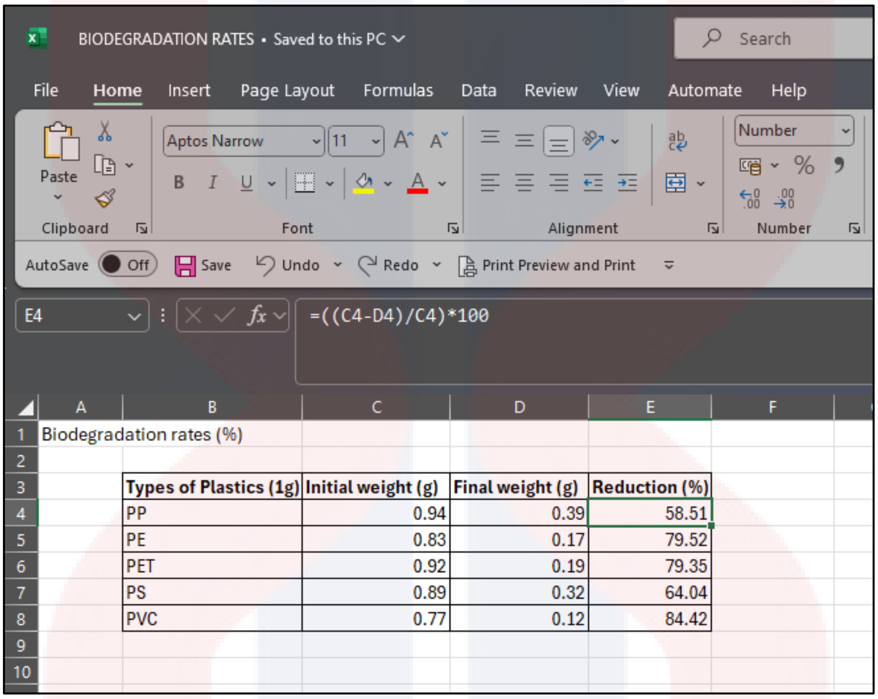


The preparation of termites in petri dish



The adaption of termites to the environmental conditions

The calculation of biodegradation rates by used Excel



=((C4-D4)/C4)*100

Biodegradation rates (%)

Types of Plastics (1g)	Initial weight (g)	Final weight (g)	Reduction (%)
PP	0.94	0.39	58.51
PE	0.83	0.17	79.52
PET	0.92	0.19	79.35
PS	0.89	0.32	64.04
PVC	0.77	0.12	84.42

Biodegradation rates’ calculation