

**PRODUCTION OF COMPOST FROM DISPOSING SOLID WASTES IN
BATU TANNERY, AKAKI KALITY WOREDA 05, ETHIOPIA**



Tigist Woldeyesus Reji

A Thesis Submitted to the Department of Applied Chemistry,

College of Applied Natural Science

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Applied
Chemistry (in Industrial Chemistry)

Office of Graduate Studies

Adama Science and Technology University

Dec, 2025

Adama, Ethiopia

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Advisor: Gemechu Deressa (Ph.D)

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Declaration

I hereby declare that this Master Thesis entitled “Production of Compost from Disposing Solid Wastes in Batu Tannery, Akaki Kality Woreda 05, Ethiopia” is my original work. That is, have not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly recognized by proper citations.

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I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled “Production of Compost from Disposing Solid Wastes in Batu Tannery, Akaki Kality Woreda 05, Ethiopia” prepared under my guidance by Tigist Woldeyesus Reji, submitted in partial fulfillment of the requirements for the degree of Mater of Science in Applied Chemistry (Specialization in Industrial Chemistry). Therefore, I recommend the submission of the revised version of the thesis to the department following the applicable procedures.

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I, the advisor of the thesis entitled “Production of Compost from Disposing Solid Wastes in Batu Tannery, Akaki Kality Woreda 05, Ethiopia” and developed by Tigist Woldeyesus Reji, hereby certify that the recommendations and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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We, the undersigned, members of the Board of Examiners of the thesis by Tigist Woldeyesus Reji, have read and evaluated the thesis entitled “Production of Compost from Disposing Solid Wastes in Batu Tannery, Akaki Kality Woreda 05, Ethiopia” and examined the candidate during the open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirements of the degree of Master of Science in Applied Chemistry (Industrial Chemistry)

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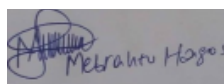
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LIST OF ABBREVIATION

WS	Wood Shavings
FS	Fine Saw Dust
WBS	Wet Blue Shaving
STW	Solid Tannery Waste
SWM	Solid Waste Management
SWGR	Solid Waste Generation Rate
LFW	Limed Fleshing Waste
TOC	Total organic carbon
ARG	Antibiotic Resistance Genes
SCG	Spent Coffee Grounds
SLC	Standard Institution of Sri Lanka
APHA	American Public Health Association
WSH	Wet Salted Hide
LPMOS	Lytic Polysaccharide Monooxygenases
CSA	Central Statistics Agency
UNDEP	United Nation Development of European Program
FEPA	Federal Ethiopian Environmental Protection Authority
GHG	Green House Gas

Abstract

Tanning industries generate significant amount of liming fleshing waste which needs alternative and proper treatment. This study was developed to utilization of liming fleshing waste (LFW) in combination with sawdust (SD), Spent Coffee Grounds (SCGS) as compost manure. The samples of the Three wastes were formed and combined in ratios (SD /SCGS/LFW) 1:1:1(Trial 1) 2:2:1(Trial2),SD/SCGS/LFW(8:1:1(Trial3),SD/SCGS/LFW(4:1:1(Trial4),SD/SCGS/LFW(3:1:1(Trial5) and Control(SD/SCGS(2:1)Trial 6.and to estimate tannery solid waste generation rate. The process was carried out using a plastic package. The 12 weeks of composting were done both in aerobic and anaerobic conditions. To maximize the process of composting, the mixture was rotated after every one week to keep the aeration. Physicochemical analysis was done on samples collected on 0, 30, 45, 60, 75, and 90 days. The average physicochemical findings of the matured compost are within the permissible limits provided by most countries' guidelines. Compost obtained after 90 days composting was the result; In general, the average range of the trial composts are pH(7.33-7.54) with low levels of electrical conductivity (1.73- 1.89) $\mu\text{S}/\text{cm}$, Ash content(6.82-9.61)% Moisture content(34.17- 35.54) and low levels of nitrogen (0.81-1.16)%, total Carbon Content((10.54 Although a germination index of 128.63, 50.14, 90.84, 102.47and 160.32% which represented the compost maturity, it was odorless, stable and earth smelling.

Keywords: *limed fleshing waste, tannery solid waste, composting, germination index, Compost maturity*

CHAPTER ONE

1. INTRODUCTION

1.1 Background of the Study

The leather industry is very important in many economies, processing rawhide and animal skins into various finished leather products. Leather production is accompanied by the generation of substantial solid, liquid, and gaseous wastes, all of which can be very injurious to the environment and human health if not disposed of properly (Alejandra et al., 2024). Specifically, tanneries, like Batu Tannery in Ethiopia, produce significant amounts of solid waste during the stages of leather processing. These studies estimate that about 250 kg of solid waste is produced for every 1000 Kg of rawhide being processed (Shaikh et al., 2017). These wastes include keratin wastes (2–5%), rawhide skin trimmings (5–7%), buffing wastes (25–35%), and leather-thinning fleshing wastes (45–50%) (Kanagaraj et al., 2015). In fact, Addis Ababa and the surrounding regions contain nearly a third of the country's tanneries, which generate polluting waste and expose the surrounding population to healthcare risks (Faye & Sibali, 2025).

Organic matter, including proteins, fats, and carbohydrates, is rich in tannery solid wastes, which can decompose rapidly. Once these wastes are discharged into water bodies, dissolved oxygen might be depressed, which could harm the aquatic ecosystems and encourage anaerobic microbial activity that releases toxic gases such as hydrogen sulfide and ammonia (Islam et al., 2023). In addition, tannery wastes may contain heavy metals, chlorinated phenols, and hexavalent chromium, all of which are persistent in the environment, can contaminate soil, water, and air, and hence may pose long-term risks to both terrestrial and aquatic ecosystems (Jin et al., 2023). Therefore, if not treated appropriately and disposed of, tannery solid wastes may lead to severe environmental pollution and public health problems.

These challenges call for appropriate waste management practices. Recycling, reuse, reduction, and revalorization of TSW (tannery solid wastes) into value-added products have been some of the practical and sustainable approaches. For example, tannery wastes can be valorized into biofuels, renewable energy, building materials, fertilizers, biodegradable packaging, and other commercial products (Verma & Sharma, 2023). Wet blue shavings, one of the major solid wastes

generated from tanneries, can be mixed with sand and cement to form construction blocks-an environmentally friendly building block alternative to conventional burnt clay bricks (Us et al., 2022). Similarly, pyrolysis of tannery wastes can produce biochar that can be used for improving the structure of soil, increasing nutrient availability, and eventually enhancing crop productivity (Younas & Nazir, 2021). Among these, composting has emerged as a significantly effective and sustainable approach for limed fleshing waste management. Composting not only reduces the volume of solid waste but also remodels it into nutrient-rich soil amendment, which contributes toward environmental sustainability and the concept of a circular economy (Hashem et al., 2023).

Limed fleshing waste (LFW) is a waste product produced during the liming process in leather production, whereby hides are treated in an alkaline solution to remove hair, epidermis, interfibrillar proteins, and fats and to blow up leather fibers. Liming normally involves chemicals like hydrated lime, $\text{Ca}(\text{OH})_2$, and sodium sulfide, Na_2S , or sodium hydrosulfide, NaHS . These chemicals are needed to ensure the quality of leather and are mostly recyclable; if treated accordingly, they have minimal risks to the environment (Covington & Wise, 2019). Nevertheless, the generation of LFW has been an environmental problem due to its high organic content, which leads to putrefaction and the creation of odors. Composting of LFW is a feasible way to transform hazardous wastes into safe, useful products and reduce environmental pollution. The incorporation of bulking agents improves the efficiency and quality of compost produced from tannery wastes. Composting bulking agents can improve the physical structure of the feedstock, establish and retain optimal moisture contents, allow for appropriate aeration, and reduce the initial C/N ratio to a level that enhances microbial decomposition (Manga et al., 2022). Commonly used bulking agents include wood shavings, fine sawdust, wood chips, wheat straw, cow dung, chicken manure, coffee husks, and rice husks (Ejileugha et al., 2023). Sawdust, which is generated during wood processing, is one successful bulking agent, given its high carbon content, economic feasibility, and ability to maintain the C/N ratio during composting. It also enables the formation of open spaces in the compost matrix, thus enhancing aeration and microbial activities in it (Kebibeche et al., 2019)

Aside from sawdust, spent coffee grounds (SCG) have also been identified as an effective bulking agent. Coffee grounds are highly organically nutritious, and their utilization in compost

produces higher-quality fertilizers (Shayene et al., 2023). SCGs exhibit low risk for heavy metal contamination and have been reused as soil amendments in improving soil fertility and supporting sustainable agriculture accordingly to a study illustrated by Cervera-Mata *et al.*, 2019. In complementing LFW with a bulking agent like sawdust and SCGs, the resulting compost could achieve a balanced nutrient content with improved texture and increased suitability for agricultural purposes.

Given the environmental hazards associated with tannery solid wastes and the potential of composting as an effective diversion strategy, this research aims to assess compost production from solid wastes generated at Batu Tannery. Specifically, the main objective of the study is to evaluate the physicochemical quality of an agricultural fertilizer produced through the composting of limed fleshing waste (LFW) with other organic amendments. The study focuses on co-composting LFW with selected organic additives to investigate the physicochemical characteristics of the matured compost and its suitability for agricultural application as a fertilizer. This approach not only addresses the challenges of tannery solid waste management but also contributes to sustainable waste management, improves soil fertility, and supports the implementation of circular economy principles within the leather industry.

1.2 Statement of the Problem

Tannery waste from companies that produce leather is one of the most polluting types of industrial waste. A portion of the solid waste produced by the company includes chromium (Cr), a hazardous heavy metal that is known to contaminate plants, soil, groundwater, and have a cancerous effect on people's health. When polluted soils are used for crop production, Cr and other heavy metals have the potential to be hazardous to humans, animals, and crops. As such, this anthropogenic interference could have negative effects on the community. The study found that the following factors contributed to the case company's low solid waste management (SWM) performance: an improperly designed collection route system and schedule; insufficient and broken operation equipment; poor site conditions for the final dump; and littering the area around the skips, which encouraged illegal dumping. Reusing tannery fleshing wastes is a crucial part of managing waste in the tanning industry and sustainably producing leather. There are

different techniques for converting waste into value-added products among these available processes; composting is considered the best approach (Mottalib et al., 2023).

The current state of composting as a waste management practice in Ethiopia faces several challenges. The existing waste management system in Ethiopia is characterized by sporadic and inconsistent waste collection, low coverage, technical frailties, and a lack of enforcement of laws, which impact the composting process. Chemical fertilizers are pricy and bad for the fertility of the soil. Furthermore, less than 40% of farmers use fertilizers, primarily due to high prices two to three times higher than global market rates. The nation's tanneries and timber businesses are expanding, and both generate large amounts of garbage. These wastes, especially the tannery waste is frequently disposed of carelessly, which pollutes the environment and gives off foul odors (Gebrekidan et al., 2024). The wastes (sawdust, spent coffee grounds, and tannery wastes) are plentiful in regions where tanning, coffee houses, and woodworking operations predominate, which present a waste disposal challenge. The wastes can, however, be transformed into beneficial goods. The goal of the current project was to create compost using sawdust, tannery waste, and spent coffee grounds as a bulking agent. In order to address the fertilizer issues, soil structure problems, and recycling organic wastes, such as tannery wastes, has become imperative. Composting enhances soil fertility, permeability to water, and structure. In addition to improving plant health, organic amendments can raise yields.

1.3 Objectives of the Study

1.3.1 General Objective:

The overall goal of this research was to produce organic composts using solid wastes generated from tannery industries of Ethiopia by minimizing the disposal of the solid wastes in the environment and reducing their negative impact.

1.3.2 Specific Objectives:

- To design and develop a method for preparing composts using the waste.
- To produce organic composts using the solid wastes of tanneries.
- To characterize, the prepared compost using various state- of- the- art techniques.
- To determine the physicochemical parameters of the compost, such as pH, temperature,

moisture content, organic carbon, Nitrogen content, Ash content, Electrical conductivity, and carbon to nitrogen ratio, to get a suitable compost.

- To develop optimizing procedure for compost mixture ratios using solid tannery wastes

1.4 Significance of the Study

The data obtained from the tannery waste generation rate gives some guideline information to the municipal and other solid waste management personnel and environmental protection agencies about the current situation of SWGR of tanneries, and also improves solid waste management practices. Excessive fleshing waste is generated during the leather liming process, and these wastes are polluting the environment adversely. The sustainability of leather processing industries will be under threat unless the LFW is managed or utilized properly. Hence, this study is of great importance by providing alternative ways to manage the liming fleshing waste dumped in the landfill, and it also offers the practical choice of using this trash as a starting point for making organic compost. This approach has the potential to not only reduce waste in the leather industry but also contribute to a more environmentally-friendly and the baseline data of this study will be used by other researchers for further study.

1.5 Scope of the Study

The goals of this inquiry were to characterize the LFW, determine the Batu Tannery's solid waste generation rate, and create a workable plan for turning the fleshing waste produced by the leather industry into compost. Additionally, the production of high- quality compost can be utilized in local agriculture and landscaping projects, promoting healthier ecosystems and improving the overall aesthetics of the surroundings. These social benefits not only enhance the quality of life for individuals within the community but also propose proper solid waste management options, mainly focusing on composting for society.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Leather Manufacturing Processes

Tanning is a general term for the numerous processing steps involved in converting animal hides or skins into finished leather. Cured hides and skins arriving at a tannery are trimmed to remove long shanks and unwanted materials for leather making before the tanning process. Leather-making processes in a tannery can be classified into four main categories: Storage and beam house operations, tanning operations, post-tanning operations, and finishing operations (Rai et al., 2025). The proportions of tannery waste from different processes include skin trimming (5-7%), fleshing (50-60%), chrome shaving, splits, and buffing dust (35-40%), and hairs (2-5%), etc. Due to the production of massive volumes of solid waste and wastewater, leather solid waste (LSW) from the leather processing sector raises serious environmental issues (Modelling, 2023).

2.2 Types of Wastes Generated in the Leather Making Process

The leather industry is globally recognized as a major producer of waste. Solid waste is the most challenging type produced by the sector to manage because of its distinct size and characteristics (Basaran *et al.*, 2019). Solid waste from the industry included skin trimmings, hair, flesh, shaving scraps, and buffing dust. Only 20% of the raw material is converted into a finished product; the rest 80% is discarded as solid and liquid wastes during leather processing (Wan et al., 2020). The release of a high amount of poorly controlled solid tannery waste (STW) into the environment is extremely harmful to it, as it endangers human and animal lives, polluting soil, surface, and underground water sources. STW is made of proteinaceous untanned and tanned waste that must be treated to enable it to be disposed of in an environmentally responsible manner (Kanagaraj *et al.*, 2015).

In Ethiopia, a major challenge to agricultural production and economic expansion is soil erosion and fertility degradation. It was estimated that, on average, about two billion tons of soil were removed during the year in the whole of the country. Consequently, to ensure agricultural production, reduce soil erosion, and preserve the equilibrium of soil fertility. Using environmentally friendly compost and putting composting technology into practice are essential. Concerns over land degradation, the danger to ecosystems posed by either improper or excessive

use of inorganic fertilizers, air pollution, and soil health are growing. Composting and other organic recycling techniques have gained renewed attention worldwide due to biodiversity and cleanliness (Wassie, 2020).

Over time, some strategies have been developed for the reduction and recycling of solid waste to produce biofuels (biodiesel and briquettes), renewable energy (biogas and biohydrogen), fertilizers, construction materials, commercial products (adsorbents, animal feeds, proteins, fats, and enzymes), and biodegradable packaging and non-packaging. The reduction of waste has emerged as a concern in order to maintain compliance and ensure the future of the leather industry (Vasileiadou, 2024). Composting has not been widely used for the use of limed fleshing until recently. Composting is now the best method available for managing solid waste, particularly organic solid waste, out of all the possibilities. Organic matter is broken down by a variety of microorganisms into a simpler, nutrient-rich product that is applied as a soil conditioner. The process is usually diverse in species and is due to the decomposition of the organic waste elements in a natural biological way. These organic wastes could be used to restore soils and provide a good source of fertilizer. The makeup is not the same in the quality and stability of composts produced out of different organic wastes, and additionally, these rely on the makeup of the raw materials utilized to produce compost (Hashem et al., 2023). Tannery solid wastes can be categorized based on different criteria, based on their process stage during which the waste is generated, they can be divided into three main groups: -

2.2.1 Untanned Solid Tannery Wastes (USTW)

The untanned solid wastes that predominantly consists the trimming of the rawhide and excess portions after the liming and fleshing operation. The chemical composition of such solid wastes is also different based on the types and quality of the raw hides/skin, and also the process conditions. The key components of these wastes are fats and proteins (10.5%). The content of moisture may be up to 60, i.e., high-water content. The above solid wastes lack chromium compounds (Awulachew, 2021).

2.2.2 Tanned Solid Tannery Waste (TSTW)

TSTW are generated in the operations conducted during or after the proper tanning process, i.e., leather trimmings, splits, shavings, and dust. These types of waste are as biologically stable as

the leather itself, as they contain the same tanning agent compounds in their inner structure (Famielec, 2020).

2.2.3 Tannery Sludge (TS)

Tannery sludge is produced during the treatment of process wastewater. It contains organic matter released from hides or leather during tanning operations, along with excess chemicals used at various stages of the tanning process (Famielec, 2020).

2.3. Waste Disposal Management/Solid Waste Management

Solid waste management encompasses the following activities: solid waste gathering, distribution, storage, recycling, and disposal. All of these processes need to be legally, socially, and environmentally acceptable in order to guarantee public health and protect the environment [FDRE, Proclamation No. 513/2007]. It is a complex process because it involves many technologies and disciplines. These include technologies associated with the generation (including source reduction), on-site handling and storage, collection, transfer and transportation, processing, and disposal of solid wastes. All of these processes have to be carried out within existing legal, social, and environmental guidelines that protect public health and the environment and are aesthetically and economically acceptable. The objective of solid waste management is to reduce the quantity of solid waste disposed of on land by recovery of materials and energy from solid waste (Hirpe, 2021).

2.3.1 Leather Industry Waste Management Practice

To ensure a successful and appropriate comprehensive solid waste management plan, there are several concepts related to waste management. One of the most commonly exercised concepts in waste management is the waste pyramid. Reduce, reuse, and recycle are the 3Rs that are mentioned in the waste management system. Ethiopia's solid waste management practices are currently quite inadequate. Along with municipal solid garbage, tanneries dispose of their solid waste in open dumping sites; some even burn it alongside additional dry solid waste (Kanagaraj et al., 2015).



Figure 1: Solid waste management practices in the leather tanning industry: (a) accumulation of leather scraps in open bins, (b) close-up of chrome-tanned "wet blue" shavings, and (c) workers handling the open burning of solid waste without protective equipment (Basak et al., 2020).

2.4 Utilization and Valorization of Tannery Solid Wastes

2.4.1 Preparation of Value-Added Chemicals

Tannery fleshing waste is rich in fats, oils, and proteins, which makes it a valuable raw material for the production of various value-added chemicals. The lipid fraction of fleshing waste can be extracted and converted into biodiesel through transesterification processes. Previous studies have reported that biodiesel produced from tannery fleshing waste mainly consists of fatty acid methyl esters (FAMES), particularly oleic and palmitic acids, which impart favorable fuel properties and good oxidative stability (Sandhya *et al.*, 2016). Beyond biodiesel production, fleshing waste can also serve as a source for the recovery of fatty acids, glycerol, and industrial greases. These recovered products find wide applications in soap manufacturing, lubricants, cosmetics, and other chemical industries. Overall, the valorization of fleshing waste for chemical

production not only minimizes the environmental impacts associated with its disposal but also promotes resource recovery and supports circular economy principles within the leather industry (Chojnacka *et al.*, 2021).

2.4.2 Production of Leather Fat Liquors

Leather fat liquors are essential processing agents used during post-tanning operations to improve the softness, flexibility, and durability of leather. Fleshing waste, due to its high fat content, serves as a cost-effective and sustainable source for producing fat liquors. The extracted fats from fleshing waste can be chemically modified through sulfonation or sulfation to produce emulsifiable fat liquors suitable for leather processing (Limed *et al.*, 2017).

2.4.3 Production of Regenerated Leather Composites

Regenerated leather composites are produced by reprocessing leather waste materials, including fleshing waste, chrome shavings, and trimmings, into usable composite products. These materials are mechanically or chemically processed into fine fibers or powders and then combined with binders such as natural latex, polyurethane, or biodegradable polymers to form composite sheets (Hang *et al.*, 2021).

2.4.4 Utilization of Fleshing Waste as Microbial Growth Substrates

Fleshing waste can serve as an excellent substrate for microbial growth due to its high content of proteins, fats, and moisture. These nutrients support the growth of various microorganisms, including bacteria and fungi, which can be exploited for the production of enzymes, biofertilizers, and biofuels. Several studies have reported the successful use of fleshing waste in fermentation processes to produce industrial enzymes such as proteases and lipases. These enzymes are widely used in detergents, leather processing, pharmaceuticals, and the food industries. Additionally, anaerobic digestion of fleshing waste has been shown to generate biogas, contributing to renewable energy production while simultaneously reducing organic pollution (Chatterjee *et al.*, 2023).

2.5 Composting

Fleshing waste has been utilized to produce compost. Proper composting processes can break

down the organic materials and pathogens in the waste, turning it into a nutrient-rich soil conditioner (Chatterjee et al., 2023).

2.6 An Overview of Composting Practice in Ethiopia

Ethiopia is found among the least developed nations, and its economy relies mostly on agriculture. The countryside is presently dealing with several environmental issues brought on either directly or indirectly by human activity, including increased exploitation of natural resources, rapid population expansion, and agricultural practices. Land degradation and environmental contamination are among the difficulties (Birhanu et al., 2024). According to UNEDP (1995), the goal of an ecologically friendly farming system is to help society overcome the issues associated with chemical-based farming systems. There is little fertilizer use in the nation. In Ethiopia, only 30 to 40 percent of smallholder farmers apply fertilizer, and those that do apply an average of only 37 to 40 kilograms per hectare (ha), which is much less than what is advised (Spielman, Alemu, and Kelemwork 2013). Thus, a misalignment between the government's goals and the actual demand for fertilizer under the current regulations, infrastructure, and institutions is implied by the developing issue with carry-over stockpiles. Therefore, the main fertilizers utilized in Ethiopian cereal production are inorganic fertilizers such as diammonium phosphate (DAP: 18% N, 46% P₂O₅) and UREA (46% N) (Dabessa Iticha *et al.*, 2021).

A Central Statistical Agency report (CSA, 2004 and 2021) states that 87% to 84.37% of the nation's total inorganic fertilizer application is made up of grains. Also, it contributes 3.7 to 3.44%, 2.7 to 4.98%, 1.6 to 0.75%, and 1.9 to 2.32% vegetables, pulses, oilseed, and root crops, respectively. However, in Ethiopia, some of the most common inputs used to improve crop production are not only inorganic fertilizers but also organic fertilizers, improved crop varieties, and agronomic techniques. For more than forty years, urea and DAP have dominated Ethiopian fertilization. Their use started in the 1960s during the "Freedom from Hunger" campaign, which highlighted the importance of phosphorus (P) and nitrogen (N) for crop production, especially for cereals like wheat and teff (Desta & Gezahegn, 2023). The price and availability of fertilizers pose a challenge to a large number of farmers. Farmers have been discouraged from using fertilizers effectively because their prices have been increasing. One issue that concerns the long-term viability and environmental impacts, including soil erosion and water pollution due to

runoffs, is the reliance on chemical fertilizers. This has given rise to debates concerning the need to have a blend of the traditional practices with better agronomic practices and organic manure (Abebe et al., 2022)

The composition of different wastes, the advantages of composting, and the difficulties faced by farmers are all highlighted in various studies.

In Ethiopia, household solid waste is predominantly organic, accounting for approximately 76–84% of the total waste generated, and a substantial proportion of this fraction has high potential for composting. The use of composted organic waste as an alternative or supplement to mineral fertilizers has been shown to improve soil fertility and enhance crop productivity (Obsa et al., 2022). Previous studies have demonstrated that composting food waste mixed with cattle manure significantly improves soil properties and maize yields, with the most effective results achieved at a 50:50 food waste-to-manure ratio, indicating efficient waste management and environmental safety (Wolka & Melaku, 2015). In addition, vermicomposting, which utilizes earthworms to biologically convert organic waste into nutrient-rich organic fertilizer, has proven to be an efficient and sustainable waste treatment method (Geleta & Daka, 2024). Furthermore, the application of composted tannery waste has shown considerable economic and environmental benefits for Ethiopian agriculture by improving soil properties and increasing crop yields; for example, long-term application of composted tannery sludge resulted in a maximum cowpea yield of 8.3 Mg ha⁻¹ after six years. In line with these findings, the Ethiopian government has launched several initiatives to promote the balanced use of organic and chemical fertilizers, encouraging composting, organic farming practices, and the integration of conventional fertilizers with modern sustainable agricultural approaches.

2.7 Comparison between the Financial and Environmental Advantages of Chemical Fertilizer and Compost

2.7.1 Compost's economic and environmental benefits

The production of landfill gases (LGs) is one of the primary contributors to the greenhouse gases (GHG) that produce global warming and ozone holes because landfill gases are the result of anaerobic and aerobic organic material breakdown. Composting is one of the simplest methods of diminishing the amount of methane emissions since it keeps the organic part of the waste

stream out of landfills. Composting eliminates greenhouse gases; compared to treatments with mineral fertilizers only, compost treatments produce much less nitrous oxide (Kjeldsen et al., 2024). Although composting emits CO₂, it is now seen to be an impartial process due to photosynthesis, which takes out carbon dioxide so as to make organic matter in the atmosphere (Zerssa et al., 2021). In general, composting is not a lucrative enterprise. However, when incorporated into a comprehensive solid waste management program, composting can have significantly more financial benefits. The market value of compost, the reduction in waste disposal costs, and other beneficial environmental effects are the benefits of composting. However, the negatives are the expenses of production, marketing, raw materials, and hidden environmental costs. Governments can save money by lowering the amount of waste that needs to be collected, transported, and disposed of, especially when emerging nations produce significantly more organic materials. The extent of these savings will be determined by the extent to which the waste management system incorporates the use of composting programs, which include elimination of temporary disposal sites, re-direction of the collection trucks, and re-direction of labor (Ansar et al., 2025).

2.7.2 Economic and Environmental Advantages of Chemical Fertilizers

- **Emissions During Production of Urea**

Urea application releases nitrous oxide (N₂O), a GHG 298× more potent than CO₂. In 2001/02, nitrogen fertilizers contributed 35,6000 tCO₂e in N₂O emissions. Agricultural soils account for 8.75% of Ethiopian agricultural GHG emissions, partly from urea breakdown. Excess urea causes nitrogen runoff, contaminating water sources and causing eutrophication. It degrades soil pH and microbial diversity, reducing long-term fertility. (Abebe et al., 2022)

- **Emissions during transportation**

It is reported that transportation emissions are counted in the total carbon footprint of urea, but take a small proportion relative to the emissions of production. In the world, the transport sector contributes about 2-3 percent of the overall GHG of synthetic nitrogen fertilizers as a whole, including urea (Menegat *et al.*, 2022).

- **Emissions during application:**

Hydrolysis of urea in soil causes a temporary inhibition of the NOB, which leads to an increase in nitrite concentration and NOB, thus making nitrite levels and the emission of nitrous oxide (N₂O) to increase, particularly in the first 36 hours of application. This temporary inhibition results in N₂O emission rates up to 10 times those of the ammonium fertilizers. Although the use of fertilizers is increasing, with price and supply limitations, only 36% or fewer farmers use urea at the most appropriate rates frequently. The manufacturing of fertilizers consumes a substantial amount of energy and causes a significant amount of greenhouse gas emissions, which suggests that the production of fertilizer contributes to approximately 1.2 percent of the global energy consumption and 1.2 percent of the overall greenhouse effect (Y. Jiang *et al.*, 2024).

2.8 Advantage of Traditional Composting Over the New Innovation Composting

Cost-Effectiveness

The traditional methods of composting can be applied by a single person and small-scale farmers due to their minimal infrastructure and resource demands. This is in contrast to high-tech composting systems that might require significant investment in machinery and technology, and hence, a simple compost heap or bin can be installed with the help of garden implements and organic waste; there is less cost associated with the initial investment (Z. Liu *et al.*, 2022).

Simplicity and Ease of Use

The traditional composting processes, such as direct composting and vermicomposting, are relatively simple to operate and do not involve any technical skills or experience. This renders them suitable amongst many users, even those who have minimal knowledge of waste management (Ayilara *et al.*, 2020).

Ecological Benefits

Traditional composting is in line with the natural processes whereby the organic waste is repurposed into the soil. This method can maintain the ecological balance of the soil, thereby

preserving it and promoting sustainable agriculture by replenishing nutrients to the soil (Shimelis *et al.*, 2024).

Nutrient-Rich End Product

The compost that is formed by the old way is normally high in nutrients and good microorganisms that enhance the health of the soil. Unlike other modern composting methods, this natural fertilizer enhances soil fertility and growth of plants without chances of chemical residues like in other systems (Jensen 2023).

2.9 Compost: Definition, Benefits, and Limitations

2.9.1 Definition of Compost

The process of decomposing organic matter, caused by the activity of a community of living things, such as earthworms, bacteria, fungi, actinomycetes, and maggots are known as composting. Some organic resources that would otherwise be considered waste products are recycled through this to form a soil conditioner. Olowoake *et al.* 2018 argue that compost contains a high concentration of nutrients that enhance the growth of plants. Compost is used to add mass to the soil structure instead of fertilizer, or, simply put, organic manure. Likely, adding sufficient levels of nitrogen, phosphorus, and potassium to the compost will result in the production of fertilizer of the highest quality. It is utilized in gardening, landscaping, organic farming, and horticulture (Shimelis *et al.*, 2024).

2.9.2 Advantage of Compost

Compost has been shown to increase the amount of carbon-based matter in the soil, enhance the capacity for water absorption of soil that has low water permeability, increase the proportion of space between soil particles, and ultimately increase the soil's ability to hold water. Since the humus retains nitrogen, it prevents the mixing of nitrogen with the groundwater. Plants that have been cultivated on soil rich in humus have the capacity to be healthier and resistant to adverse effects and diseases. To produce high quality compost, a massive quantity of organic matter is mixed with a minimum amount of non-organic material. This therefore implies a reduction in

chemical and agricultural inputs. Additionally, the application of compost helps restore soil structure, minimize soil erosion, and improve water permeability (Ho *et al.*, 2022)

2.9.3 Disadvantages of Compost

The primary drawbacks of composting are as follows: Composting on a large-scale method, such as windrow and aerated static pile composting require large spaces. It is not only likely to attract insects, but it can also be a source of pathogens to the soil. It emits greenhouse gases when it is composted, and it wastes nearly fifty percent of the available nitrogen. Composting should be conducted in a place that will not cause any adverse impacts on the environment, such as the rainwater overflowing (Chataut *et al.*, 2023). According to Ayilara *et al.* (2020), odor control may take place, and depending on the type of initial materials utilized, odor can be produced at the beginning of the composting process. Additionally, the mineralization time lasts longer.

2.10 Types and Methods of Composting

2.10.1 Types of Composting

Composting can be divided into two major categories: aerobic and anaerobic composting.

Aerobic Composting

During aerobic composting, organic wastes decompose in the presence of oxygen to generate ammonia, carbon dioxide, water, and heat as byproducts. Organic matter tends to lose its form when it is exposed to oxygen, and the main cause of such a situation is the energy that is produced during aerobic respiration. Any significant change prevents the process of deterioration. The composting process will be more efficient in cases when the ratio of carbon to nitrogen and moisture is adequate for the kind of compost used. When oxygen is utilized, aerobic bacteria break down organic materials that contain nutrients in the compost's raw material to create their cell protoplasm. Because the right amount of carbohydrates and amino acids is present, mesophilic organisms, which thrive in temperatures between 20 and 45 °C, tend to develop quickly (Zhang *et al.*, 2023).

Anaerobic Composting

Composting under anaerobic conditions entails the decomposition of organic matter in the absence of oxygen to yield methane (CH₄), ammonia (NH₃), and low levels of other organic acids and gases. Among the traditional methods of composting animal manure and human sewage sludge, anaerobic composting is becoming a common practice in the management of part of municipal solid wastes and green wastes (Ye *et al.*, 2023).

2.10.2 Method of Composting

Composting systems have a number of methods. All those composting systems that manage to be satisfactorily managed will share some attributes, including an adequate number of microbes capable of breaking down organic materials, adequate oxygen, the optimal quantity of moisture, nutrients required by microorganisms (C: N ratio), and the necessary volume of materials to grow and develop the microbial population enough to break down natural waste Argun *et al.*, 2017. Both community-scale and farm-scale composting systems employ a variety of techniques.

Static Composting

The term "static pile" refers to a prepared compost mound that has been left untouched state, where aeration is only possible in a pile that has a substantial amount of the bulking ingredients and a high porosity percentage (over 60). The pile is capable of supporting a certain level of aerobic activity even at high temperatures, provided that it is porous enough. A static pile can only perform as intended with the presence of sufficient airflow. This is a strong greenhouse gas known as methane that is produced in the lack of oxygen, hence leading to the anaerobic decomposition of materials. An evaluation of the progress of the pile can be conducted by looking at it (Z. Liu *et al.*, 2020).

Composting in a Container or Enclosed

This cutting-edge technology is drawing interest from composters and researchers alike. This is a sophisticated composting method. The apparatus is contained within a tank or other vessel, so that the emission of noxious gases and odors has an exhaust aperture where they are filtered through biofilters installed in the exhaust unit. The aeration is given either through aeration pumps or simply by closing the container to give a constant rate of air flow. This is because the

system is fully surrounded, moisture is retained adequately indoors, and the quantity of water required is minimal. The optimal moisture content that is easily conserved is between 40 and 60 percent. By preventing heat loss, a thermophilic habitat that supports aerobic thermophilic bacterial species can be produced. In the meantime, the outside nature does not have much influence on the interior environment. In a vessel, there is no need to compost in a particular place based on the local weather (Manyapu *et al.*, 2017).

Bin Composting

In essence, any technique that makes use of an open or closed container is composting in a bin. It is the most widely used home composting method, which is used to cut down on trash. This option is primarily used for yard wastes, smaller amounts of compost, and small-scale composting. It is a free of tension technique that gardeners can use and is ideal for a variety of sustainable agricultural plots. Bins are often covered and can be constructed of concrete, wood, or plastic. They may or may not include forced aeration (Vaverková *et al.*, 2014).

Windrow Composting

Composting in a bin is an activity that involves the utilization of a closed or open container. It is the method of domestic recycling that is used most often to reduce the amount of trash. Yard wastes, small quantities of compost, and small-scale composting are mostly handled using the alternative option. It is a free-from-tension method that gardeners can employ and is best suited to various sustainable farming plots. Bins may be covered and may be made out of concrete, wood, or plastic (Makan & Fadili, 2020).

Vermicomposting

One type of composting that is not thermophilic is vermicomposting, which involves the production of a peat-like product mixture using decomposed organic residues through the use of multiple species of earthworms. As many as possible, *Eurdilus eugeniae*, *Eisenia foetida*, and *Lumbricus rubellus* are the most commonly used earthworms (Ebrahimi *et al.*, 2019). Mengistu

et al. (2017) explain that it incorporates the stability and bio-oxidation of organic matter through the combined efforts of bacteria and earthworms. The worms mix up the vital hormones and enzymes with the contents of their bellies after eating the organic materials. Their waste is also released in the form of worm casting that is easily absorbed by the plants, and it has essential plant nutrients. As a result, it creates a large and dynamic population of microbiological diversity in the soil, unlike composts produced in heat processing (Lirikum *et al.*, 2022).

2.11 Factors Influencing the Composting Process

The type of waste to be processed, the composting method, the environment, microbes, nutrition (carbon and nitrogen), oxygen, and moisture are only a few of the variables that can affect the rate and speed of composting, as they do in any biological process. Temperature, pH, volume, and particle size/surface area are additional variables that impact how quickly composting occurs. Efficient compost maturity requires regular monitoring and management of these elements.

Temperature

Temperature is an important pointer to the extent to which the composting process is going and the extent to which the oxygen is actually being utilized. In the case of viruses, parasites, and weed seeds, a temperature between 35 °C and 55 °C is best. Temperature changes also largely affect the activity of the helpful composting microorganisms, resulting in immature and ineffective composts. Hence, temperature is such an essential element of an effective composting process that can be regulated through turning and aeration of the compost (Jain *et al.*, 2019).

Moisture

The optimum range of moisture is 40 and 60%. In the case where the moisture content of the heap is greater, the water could enter all the pores, leading to the formation of anaerobic conditions and the decomposition of the organic matter. In the other case, microbial activity is reduced in case the process becomes too slow. The sort of elements utilized will determine the moisture content; fibrous material needs to be from 50 to 60 percent (Van Der Wurff *et al.*, 2016).

pH

The manure holds a wide variety of microorganisms that thrive in conditions that are significantly less than neutral to acidic. This takes place in the pH range between 5.5 and 8. Microbes respond to it in different ways. The almost neutral pH range of 6.0 to 7.5 is preferred by bacteria, although fungi can withstand a pH range of 5.0 to 8.0. In addition to determining microbial activity, pH also serves as a process advancement indicator. Early disintegration stages result in the production of organic acids, which promote fungal development and the cellulose and lignin breakdown process. Due to the activity of acid-forming bacteria, the pH level begins to decrease during the mesophilic phase. Upon completion of this acidification phase, the pH rises to 8.0, and ultimately, it reaches 8.5. Although a significant drop in pH could lead to anaerobic conditions, higher values could result in nitrogen loss due to ammonia volatilization. The compost establishes itself in a pH range of 6 to 8 in the later stages of the composting process (Jain *et al.*, 2019).

Oxygen

The process of composting is aerobic. Oxygen is one of the key limitations of aerobic composting. One of the factors that affects the oxygen level is the nature of the material, its texture, moisture level, number of tosses, and forced ventilation. The presence of oxygen has a direct influence on the growth of aerobic microorganisms. A pile of compost that is of slightly lower oxygen concentration can inhibit the growth of aerobic microorganisms and slow down the decomposition of the raw organic matter. Effective aeration also reduces the levels of heat, water vapor, and other gases captured in the heap. Based on this, the proper composting process should be well aerated, and this can be done through constant rotation of the compost pile and monitoring the size of the raw materials used in the compost (Ho *et al.*, 2022).

Carbon to Nitrogen (C: N) Ratio

Among the primary components of organic matter are carbon and nitrogen. One of the primary factors influencing the compost's quality is the C: N ratio. They must have a balanced C: N ratio of 25 to 35 to be regarded as acceptable. Greater C: N ratios impede the process since the amount of degradable carbon on which the bacteria can utilize is greater, and very low C: N ratios reflect

the presence of excessive nitrogen in the process, which is potentially not used in the process and converts into ammonia. (Macias-Corral *et al.*, 2019). Thus, to attain a stable content of both components, low C: N ratios may require the provision of additional material. Well-balanced compost demands the successful blending of wastes of differing C: N ratios. Limbs, sawdust, dry hay, straw, and leaves are a few instances of natural resources with a high C: N ratio (Anwar *et al.*, 2015). Young vegetables, animal feces, and slaughterhouse residues have low C: N ratios. Anwar *et al.* 2015 state that there are studies that indicate that the maturity of large quality compost may fluctuate within the C: N ratios of 14 to 40.

Microbial population

In composting, a diverse community of bacteria, fungi, and actinomycetes completes the aerobic digestion of organic materials. Microbes can break down more complex compounds such as hemicellulose, lignin, and starch. Most readily biodegradable substances are more common in the later phases of composting, when most of these substances have already been consumed. Hyphae are observable, and they are stringy cell structures commonly developed by Fungi. Later in the composting process, when more durable materials like hemicellulose, lignin, and pectin are breaking down, the fungus becomes increasingly significant (Biyada *et al.*, 2020).

2.12 Stages of Composting

According to temperature, which is closely correlated with the biological activity during the composting process, there are four main phases of composting. These stages are

2.12.1 Initial Phase or Psychrophilic Stage

Psychrophilic bacteria are the most active at about 13 °C, the average temperature in the early composting processes. They start decomposing the easily degradable organic compounds, including simple sugars and proteins, into simpler compounds. LPMOS, which is an enzyme produced by psychrophilic bacteria, and this enzyme aids in the breakdown of intricate carbohydrate structures like cellulose and hemicellulose. The processes enhance the breakdown of organic matter faster and add to the initial heating of the compost pile (G. Jiang *et al.*, 2021).

2.12.2 Rising Temperature Phase or Mesophilic Stage

The mesophilic stage in the composting process occurs at temperatures between 20 and 45 °C. During this stage, mesophilic microorganisms rapidly break down the soluble, readily degradable compounds in the compost. Temperature increases and the production of organic acids due to metabolic activities lower pH (Hem *et al.*, 2021).

2.12.3 High Temperature Phase or Thermophilic Stage

Thermophiles like warm temperatures of above 40 °C with a range of 45-65 °C. Thermophiles can break down more complex organic substances such as proteins, fats, cellulose, and hemicellulose during the high temperature of the thermophilic stage. Thermophiles have a greater selection of enzymes, such as cellulases, hemicelluloses, pectinases and proteases, which enable them to decompose an array of polymeric materials (Finore *et al.*, 2023).

2.12.4 Curing Phase or Cooling Stage

When the readily available food sources for the thermophilic microorganisms become depleted, the temperature of the compost pile starts to decline. As the temperature declines, the compost is recolonized by mesophilic microorganisms that degrade the residual sugars, cellulose, and hemicellulose, leading to the formation of human-like substances. (Rastogi *et al.*, 2020).

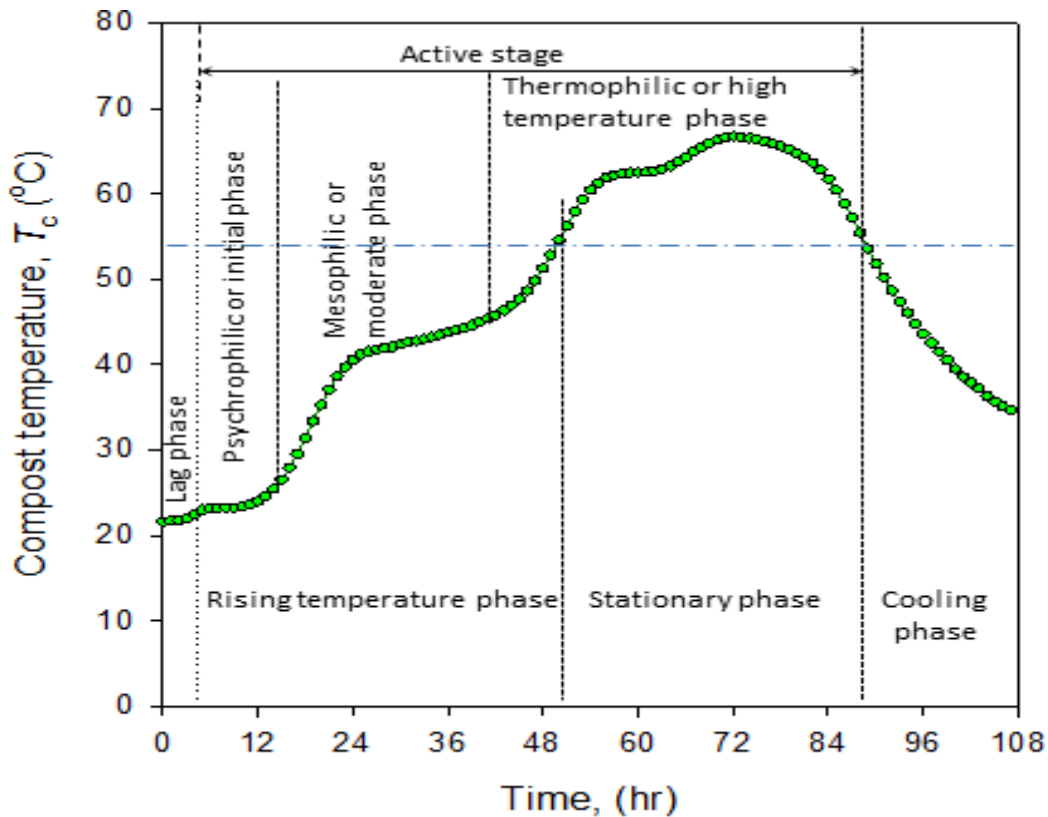


Figure 2: Stages of Composting (Alkoaik et al., 2018)

2.13 Function of Bulking Agents in The Compost Process

The bulking agents that are most frequently employed in composting include wood shavings (WS), fine sawdust (FS), sawdust, spent coffee grounds, brewery waste, wheat straw, rice husk, cow dung, chicken manure, dry leaves, and vegetable /fruit scraps. While wheat straw has a high water-holding porosity that can improve CH_4 generation and decrease NH_3 emission, wood chips have been demonstrated to have a favorable impact on volume density, porosity, and C/N ratio (Finore et al., 2023). Sawdust has been shown to improve manure composting's ability to remove antibiotics and antibiotic resistance genes (ARGs). Spent coffee grounds (SCG) are roasted and ground coffee beans that have been depleted of some of their water-soluble compounds. They are the solid leftovers from preparing coffee beverages and can be found in a variety of places, including cafeterias, restaurants, coffee shops, and home garbage (Franca & Oliveira,

2022). The process of making coffee products results in the generation of solid waste, such as wasted coffee grounds, or SCGs. SCGs are now present in the primary incineration and sanitary landfill treatment processes, which squander resources and pollute the environment (Q. Liu *et al.*, 2022).

Spent coffee grounds are an excellent source of nutrients for composting and soil amendment, based on the search results. During the composting process, minerals including calcium, magnesium, phosphorus, and potassium are released from the coffee grounds (Bomfim *et al.*, 2022). Spent coffee grounds (SCG) can be successfully composted and used as a carbon source in the composting process (Li *et al.*, 2023). Large volumes of organic components, such as fatty acids, lignin, cellulose, hemicellulose, and other polysaccharides, are present in spent coffee grounds (SCG), which can be used to create products with additional value. Consequently, research has been done on producing biodiesel from coffee residue (Mata *et al.*, 2018). It is advised to combine coffee grounds and limed fleshing with other composting materials in a ratio of 25% spent coffee grounds to 75% other compost materials when composting with them (Pavlis, 2023).

Composting with bulking agents offers several important advantages that enhance both process efficiency and compost quality. The inclusion of bulking materials improves compost production by increasing process efficiency and promoting effective organic matter degradation through the creation of favorable conditions for microbial activity. Bulking agents also help maintain an optimal carbon-to-nitrogen (C/N) ratio, which is essential for efficient decomposition. In addition, they improve airflow and prevent compaction within the composting mass, thereby supporting aerobic decomposition, reducing the likelihood of anaerobic conditions, and minimizing odor-related problems. Furthermore, bulking agents contribute to the stability and maturity of the compost, resulting in a high-quality final product suitable for use as a fertilizer or soil amendment. Overall, composting with bulking agents represents a practical and sustainable waste management strategy, particularly for agricultural and industrial wastes (Sayara *et al.*, 2020).

Table 1: Brown & Green used for composting

HOW TO COMPOST	
Brown materials	Green materials
Leaves	Fruit and vegetables peels
Pine needles	Coffee grounds
Twigs branches	Tea bags
Straw	Grass clippings
Napkins	Egg shells
Paper	Weeds
Used paper coffee filters	Rest of bread
Wood chips	Animal manure ,Cow dung
Cardboard	Poultry litter

Spent coffee grounds offer multiple benefits when used in the composting of limed fleshing waste. They contribute essential nutrients, particularly nitrogen and minerals such as calcium, magnesium, phosphorus, and potassium, which support microbial activity and plant growth. Spent coffee grounds also improve compost structure and help balance the carbon-to-nitrogen ratio, enhancing nutrient and water availability. Although slightly acidic in their raw form, composting neutralizes their pH, making the final product suitable for agricultural use. In addition, they can deter slugs and snails, reducing plant damage, while their composting diverts organic waste from landfills and supports sustainable waste management practices.

The scent of spent coffee grounds is pleasant and can help mask bad smells in the compost pile. Spent Coffee grounds absorb a lot of water and don't smell because of their small particle size and texture. Composting liming has been demonstrated to have a lower heavy metal level when using SCG. SCGs have been shown to be useful in lowering the concentrations of heavy metals in soil and water. They can also be utilized as a composting material and soil amendment. The microbial activity in composting lime can be positively impacted by used coffee grounds. Their high nitrogen level can aid in accelerating the composting process, and their strong nitrogen content assists the bacteria that break down waste (Bomfim *et al.*, 2022).

The bioavailable heavy metal content dropped in soils treated with SCG, suggesting that the treatment is successful in lowering heavy metal contamination. Due to its ability to successfully lower heavy metal concentrations without producing phytotoxicity, SCG is a promising remediation solution for heavy metal- contaminated soil and water. Examined whether heavy

metals such as As, Pb, Mn, Zn, Fe, etc. were present in the liming wastewater produced when the keratinous structure of wool and hair was dissolved. Heavy metals are included in the lime fleshing wastes as a result of the partial breakdown of keratinous materials during the hair dissolving liming process. Heavy metals in the forms of Cr, Cu, Zn, Pb, and Cd may have an impact on the finished compost's physicochemical characteristics (Kim et al., 2014).

When combined with other organic waste materials, coffee by-products can also be used in composting to assist in lower gaseous emissions like methane (CH₄). Consequently, combining coffee grounds with liming can be a good way to aid in the decomposition process and enhance the final product's quality when composting. Most results indicate that final compost produced from the limed fleshing waste, the nutrient NPKS was detected by standard methods. However, in order to use the compost for other purposes like soil fertility and agriculture, it must be checked for heavy metal concentration (Ruiz *et al.*, 2021).

2.14 Annual Solid Generation Rate from Tanneries in Ethiopia

Ethiopia, a nation in eastern Africa with an abundance of livestock, has the potential to serve as a foundation for the tanning industry due to its plentiful supply of raw materials (skin and hide). On the other hand, the availability of raw materials suggests favorable conditions for the growth of the footwear, clothing, and products industries. Waste creation is unavoidable wherever there are enterprises that process leather. The annual solid waste generation rate from tanneries in Ethiopia varies depending on the type of animal hides processed. For example, in Ethiopian tanneries, approximately 530kg of solid waste is generated during hide processing (Abajihad, Z.,2012). Additionally, the annual skin removal rate in Ethiopia is nearly 10% for cattle, 38% for goats, and 33% for sheep, leading to significant amounts of solid waste being produced. Furthermore, a study conducted on the Sheba Leather Industry in Wukro, Ethiopia, found that the company generates a total of 5,190 tons of solid waste every year. This waste includes various types of solid waste such as de-dusted salt, raw trimming, hairs, fleshing waste, pickle trimming, and chrome shaving waste, crust leather trimming waste, buffing dust waste, and finished leather trimming waste (Tegadye, D. G., Ram, C., & Alebel, K., 2023). In general, the solid wastes generated during leather processing are significant since the leather industry makes use of only 20 -25 % of the raw material in the finished leather, 75 -80 % end up as waste in the environment (Framis, C.P.,2018).

2.15 Environmental and Health Impacts of Leather Wastes

2.15.1 Environmental Effect

Wastewater and solid wastes are the main environmental problems associated with tanneries. About 20% of the material used to turn hides into leather is wasted as solid waste. This waste is made up of hair, soluble proteins, leather scraps, curing salts, and fleshing (animal fats, collagen fibers, meat, etc.). The enormous volume, intense color, high sediment load, hazardous metals, chemicals, physiologically oxidizable elements, and copious amounts of putrefying suspended matter are all present in the tanneries' effluents. Tannery solid waste is typically disposed of inappropriately both inside and outside the factory. The brightly colored effluents not only have an unsightly appearance, but they also reduce a water body's ability to purify itself by blocking out sunlight. Effluents from tanneries with low pH levels corrode the water-carrying infrastructure. All-natural life in the impacted water might be destroyed by the large pH fluctuations and high BOD values brought on by tannery effluents (Faye & Sibali, 2025).

Many types of life are extremely poisonous to hydrogen sulfide, which is created when sulfides are present in the effluent. Chromium, another hazardous substance that should be taken very seriously, which is found in tannery effluents, is known to cause perforations and bronchogenic cancer in humans who are exposed to it regularly. It is possible that chicken feed made from solid waste from tanneries that contains high protein will directly introduce chromium into the food chain. Tanneries and leather goods large volumes of solid waste, such as leather shavings and trimmings, are produced by manufacturing facilities and are burned in brick kilns for inexpensive fuel. This leads to air pollution and the release of chromium into the environment. Premiere agricultural land is being directly poisoned by tanneries, and it has been discovered that this is affecting the soil's quality and crop productivity. Additionally, it has been documented that the careless release of industrial effluents into open spaces near factories or directly into water bodies causes skin illnesses in people (Rambabu et al., 2023).

2.15.1 Health Effect

The environment and people who work in the tanning industry are both at risk from several hazards. Because worker protections are either insufficient or nonexistent, labor in the tannery itself is dangerous. Scarily real risks include drowning, being boiled alive, or being buried in

lime. Other risks include slips and falls on inadequately drained floors, exposure to acids, bases, tanning liquor, solvents, disinfectants, and other noxious chemicals, and injuries from heavy machinery or folding knives. Working with chromium is still the riskiest aspect of modern tanning. Chromium, depending on how it is absorbed, can cause a wide range of illnesses in people. Chromium is a lung irritant and carcinogen that can be breathed. It can harm the upper respiratory system, restrict airways, and raise the risk of sinus, nasal, or lung cancer. When raw and tanned leathers are ground, smoothed, and polished, small particle dust containing chromium is typically absorbed in this manner. Increased incidence of upper respiratory tract polyps, pharyngitis, asthma, bronchitis, and lymph node and hilar area enlargement have all been related to chromium (Hamja et al., 2025).

2.16 Remedial Strategies for Sustainable Leather Waste Management in Ethiopia

The Ethiopian leather industry faces significant challenges in handling solid waste, much of which is currently discharged into the environment without adequate treatment, leading to pollution and public health risks. A comprehensive strategy incorporating technical, governmental, educational, and infrastructure elements is necessary for effective treatments.

2.16.1 Technological Innovations

Advanced waste treatment technologies such as pyrolysis, gasification, and anaerobic digestion should be explored to improve the management of leather industry waste by converting it into useful energy and value-added by-products. The installation of chromium recovery and recycling systems in tanning operations is also essential to minimize environmental contamination from tanning effluents and to enable the reuse of recovered chromium within the tanning process. In addition, the adoption of enzyme-based processes for tanning and waste treatment could significantly reduce reliance on hazardous chemicals while enhancing the biodegradability of leather waste materials (Tegadye *et al.*, 2023). Further research and investment in innovative recycling approaches are required to develop new pathways for reusing leather waste, including the production of bio-based materials, composites, and other value-added products. Moreover, studies focused on sustainable leather product development that generate less waste and are more amenable to recycling should be encouraged to support environmentally responsible growth of the leather industry (Belay *et al.*, 2008).

2.16.2 Circular Economy Approach

The adoption of circular economy practices within the leather industry should be promoted to ensure that waste materials are systematically reintegrated into the production cycle or transformed into new materials and products, thereby reducing resource consumption and waste generation. In addition, the application of life cycle assessment (LCA) methodologies is essential to comprehensively evaluate and minimize the environmental impacts of leather production across all stages, from raw material sourcing through processing and final waste disposal (Hirpe & Yeom, 2021).

2.16.3 Sustainable Waste Management Practices

Composting facilities specifically designed to process organic leather wastes in combination with other biodegradable materials should be developed to effectively control pH imbalance and odor emissions. In addition, waste-to-energy technologies should be explored as a viable option for converting non-recyclable leather waste into energy, thereby reducing the overall volume of waste while contributing to renewable energy generation (Hirpe & Yeom, 2021).

2.16.4 Regulatory Framework

Strengthening regulatory frameworks is essential to ensure that leather processing industries comply with established environmental standards for waste management. This should be complemented by the provision of financial incentives, such as tax reductions, subsidies, or grants, to encourage tanneries to adopt sustainable waste management practices and cleaner production technologies, thereby improving environmental performance and regulatory compliance (Men & Menbere, 2019).

2.17 Chemical and Biological Reaction During Composting

A number of chemical and biological reactions take place during the composting of sawdust, coffee grounds, and lime-treated fleshing wastes. Humus is the result of these activities, which break down complex organic compounds into simpler ones. The main chemical processes and reactions that occur are listed below.

2.17.1 Decomposition of Organic Matter

Coffee grounds, sawdust, and limed fleshing waste are examples of organic materials that decompose aerobically through the action of bacteria. The carbon in organic materials is converted by bacteria into carbon dioxide (CO₂), which releases heat. This heat helps maintain the optimal temperature range for microbial activity (Compo, 2023)



2.17.2 Hydrolysis

Complex organic materials found in sawdust, such as cellulose and lignin, are hydrolyzed into simpler sugars and acids with the assistance of enzymes made by microbes.

2.17.3 Nitrogen Transformations

Ammonification

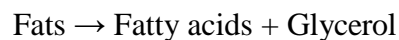
Proteins → Amino acids → NH₃ Nitrification -in aerobic conditions:



(The Chemistry Behind Composting – the Pipette pen, 2021)

2.17.4 Fatty Acid Composition

- Limed fleshing wastes are rich in fats and fatty acids, primarily oleic and palmitic acids.



- Collagen and Protein Breakdown



- Bacteria and enzymes (proteases and lipases) break down collagen and other proteins, as well as fats in the fleshing wastes (Arabiyyat, A. R., 2014).

2.17.5 pH changes

When composting starts, organic acids are produced; this brings the pH down to about 5.5. This acidic environment helps kill pathogens and encourages the growth of fungi and actinomycetes that break down tough materials like lignin and cellulose. The pH increases during the

composting process, occasionally rising over neutral pH, although it typically returns to the slightly acidic range of 6.5 to 7.5. (Chemistry of Composting | Planet Natural, 2023).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Chemicals and Apparatus

All chemicals and reagents used in this study were of analytical grade. Standard laboratory apparatus and instruments, including a pH meter, electrical conductivity (EC) meter, Kjeldahl digestion and distillation units, muffle furnace, hot air oven, analytical balance, mercury-in-glass thermometer, orbital shaker, and desiccator, were used for sample preparation and analysis.

3.2 Description of the Study Area

3.2.1 Site Selection

The experimental work was carried out at the Leather and Leather Products Industry Development and Research Center (LLPIDRC), Addis Ababa, Ethiopia.

3.2.2 Description of Batu tannery

The privately held Batu Tannery PLC is involved in the processing of cowhide, goat hide, and sheepskin. The tannery, which specializes in cow hides at the moment, is renowned for its high quality and ability to produce finished leather goods for both domestic and foreign markets, including shoe uppers, gloves, purses, luggage, clothing, and belts. Approximately half of the tannery's completed leather goods were formerly exported to overseas markets. The local shoe and bag manufacturing enterprises, which then export the shoes and bags, receive the remaining 50% of the product.

3.3 Collection and Preparation of Sample

3.3.1 Limed Fleshing Waste

Limed fleshing waste was obtained from Batu Tannery PLC, located on the East bank of the Tinishu ("Little") Akaki River in the Kality area of Addis Ababa, Ethiopia, north of the Ring Road (8°55'54"N 38°45'29"E). The fleshing waste was collected directly from the fleshing machine before it was dumped. Approximately, 8 Kg of fresh fleshing wastes was collected and

washed repeatedly for five days to remove the sulphide and reduce its high alkalinity. After washing, the sample was packed in an opaque plastic bag and stored prior to physicochemical analysis and composting.

3.3.2 Sawdust

Sawdust (SD) was collected from a local wood workshop located in the Asko area of Addis Ababa, Ethiopia. A 10-kilogram sample of raw sawdust was allowed to air dry at room temperature for two days, followed by sun drying for an additional three days to reduced moisture content. The dried sawdust was then packed in clean plastic bags to prevent contamination and stored at room temperature until further use.

3.3.3 Spent Coffee Grounds

Spent coffee grounds (SCGS), specifically from Abyssinian coffee, were collected from the cafeteria of leather and leather products industry and development research center located at akaki kality subcity of Addis Ababa, Ethiopia. Approximately 1 kg was collected, air-dried, and stored in sealed containers prior to composting.

3.4 Determination of Raw Hide Weight and Waste Generation

3.4.1 Weight of Wet Salted Hide

The mass of one piece of wet salted hide was needed to determine the waste produced (Kg/Kg) from raw hide. Ten pieces of wet salted skin were randomly chosen from multiple batch that were ready for soaking in order to determine the weight of each piece. The average weight was then calculated (see Appendix 1).

3.4.2 Estimation of Tannery Solid Waste Generation Rate

The material balance technique was applied for the estimation of the solid waste generation rate of Batu tannery. i.e., 10 batch of saturated salted hides were received from various leather processing stages, and they were weighted before and after the operations, and the generated waste was calculated as follows: -

$$\text{Waste generated (kg/kg) of raw hide} = \frac{\text{Weight before} - \text{Weight after operation}}{\text{Average of a piece of hide}} \quad 3.1$$

3.5 Experimental Design and Composting Treatments

Liming fleshing waste (LFW), spent coffee grounds (SCGs), and sawdust (SD) were used as bulking agents to improve the structure of the composting feedstock. Figure 4 presents these materials, with Plates Ia–Ic showing liming fleshing waste, spent coffee grounds, and sawdust, respectively.

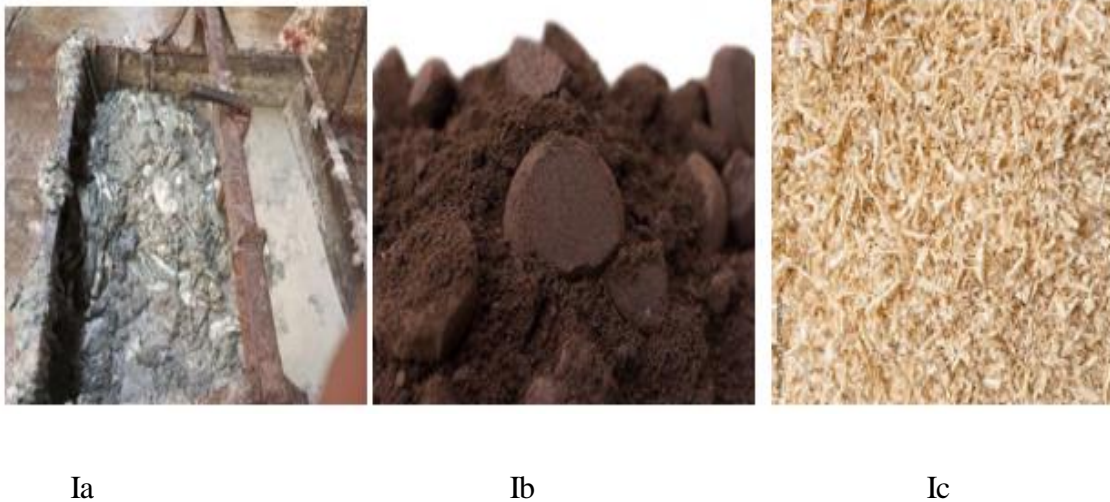


Figure 3: Raw material for composting preparation

The composting feedstock consisted of limed fleshing waste (LFW), spent coffee grounds (SCGS), and sawdust (SD) as bulking agents, with ash and dry leaves used as facilitators. Five treatments and one control were prepared on a dry weight basis

Table 2: Initial Composition of Composting Mixtures

Composting mixture			
Mixture	SD((% W/W,))	SCGS((% W/W,))	LFW((% W/W,))
1.T1(1:1:1)	250	250	250
2.T2(2:2:1)	500	500	250
3.T3(8:1:1)	200	25	25
4.T4(4:1:1)	166.5	41.75	41.75
5.T5(3:1:1)	150	50	50
6.CONTROL(2:1)	166.75	83.25	-

3.6 Characterization of bulking agents and Composting Limed Fleshing

The physicochemical characteristics of Limed fleshing waste, spent coffee grounds, sawdust, and compost samples, pH, Moisture content, Temperature, Electrical conductivity (EC), Nitrogen content, Ash content, & Organic Carbon measurements were done.

3.6.1 pH Determination

To find the pH of the manure and bulking agents, 5 grams of the sample were soaked in 100 milliliters of distilled water, then left in an orbital shaking device for 16 to 24 hours. The pH was then directly measured using the standard procedures of SLC 13, 1996.

3.6.2 Determination of Moisture Content

The oven-dry method was used to determine the moisture content. The well-mixed sample and ten grams (10g) of bulking agents were carefully weighed in a clean, dried crucible (W_i). Until a consistent weight was reached, the crucible was placed in an oven set to 105 °C. For half an hour, the crucible was placed in the desiccator to cool. It was chilled and then weighed once more (W_f). Weight loss after drying in an oven at 105 °C to a steady state using the standard method of SLC 3, 1996, was used to calculate the moisture content.

$$\text{Moisture \%} = \frac{W_i - W_f}{W_i} * 100 \quad 3.2$$

Where W_i - Initial weight of crucible + weight of sample before drying, W_f –final weight of crucible + weight of sample after drying

3.6.3 Determination of Electrical Conductivity

The electrical conductivity of the compost and bulking agents was determined using an electrical conductivity (EC) meter. A water-to-sample ratio of 1:5 (on a dry weight basis) was maintained to ensure accurate measurements. The conductivity cell was carefully cleaned with distilled water before testing. The conductivity measurement was then taken straight from the EC meter after it had been submerged in the sample solution. The results were expressed in $\mu\text{s}/\text{cm}$ (Kargas *et al.*, 2020).

3.6.4 Determination of Temperature

The samples' temperature was determined using a mercury-in-glass thermometer. The thermometer was then submerged in the sample, and a reading was obtained. The temperature of the sample, expressed in degrees Celsius, was considered to be the mercury level. Throughout the course of the composting process, the temperature of the blends was regularly measured within five days, and data were documented. After around two minutes of the thermometer being in the sample, the reading was obtained (Umar *et al.*, 2017). From the Quality, Testing, and Laboratory Desk at the Leather and Leather Products Research Center, the ambient temperature was recorded.

3.6.5 Determination of Nitrogen Content

The nitrogen content of the bulking agents and compost samples was determined using the Kjeldahl method (SLC 7, 1996). A 3 g portion of each sample was accurately weighed into a digestion tube and moistened with distilled water. Then, 20 mL of concentrated H₂SO₄ and 5 g of (Potassium sulfite, Copper Sulphate, Selenium powder in the ratio 50:10:1) were added. The digestion flask containing the mixture was heated initially at 80 °C, followed by an increase in temperature to 350 °C. Digestion continued until the solution volume was reduced to approximately 3-4 mL. After digestion, the flask was allowed to cool, and the digest was quantitatively transferred to a 100 mL volumetric flask and diluted to the mark with distilled water. After that, a 10 mL sample of the digest was put into a Kjeldahl distillation device. After adding 130 milliliters of 40% NaOH, the liquid was distilled. In a 250 mL conical flask, the distillate was taken out over 20 mL of 20% boric acid with three drops of a blended indicator for five minutes. The presence of nitrogen was indicated by the appearance of a light blue color. Finally, 200 mL of the distillate was titrated with 0.5 N HCl until the color changed from light blue to gray and quickly shifted to pink, marking the end point of the titration.

$$\text{Total Nitrogen (TN)\%} = \frac{S-B*0.7003*100}{\text{Weight of Sample}} \quad 3.3$$

Where S =Volume of acid against sample, B = Volume of acid used against Blank, 0.7003 = Conversion factor

3.6.6 Determination of Ash Content

5g of the bulking agents and compost was weighed using a crucible, and it was put in the muffle furnace for 3 hours at 600⁰C and after ignition, the samples were placed in a desiccator, and the weight of the samples was measured after half an hour. The percentage ash content was calculated according to SLC 6, 1996, as follows:

$$\text{Ash Content} = \frac{M_1}{M_0} * 100 \quad 3.4$$

Where M₁ is the mass of the sample after ignition, and M₀ is the mass of the original sample

3.6.7 Determination of Organic Carbon

The Walkley-Black (1934) moist oxidation method was used to quantify the amount of organic carbon. A conical flask with a 500 ml capacity was filled with 2g of the sample. 10 milliliters of 1N K₂Cr₂O₇ and twenty milliliters of concentrated sulfuric acid were added. After giving the flask a gentle spin, it was left to settle for half an hour on a porcelain sheet. Ten milliliters of H₃PO₄ were gradually added, along with 200 ml of pure water. Ferrous concentration was used to reverse titrate the excess dichromate ion in the combination until the solution turned green, at which point the volume used for the titration was recorded. A few drops of diphenylamine marker were then added. Concurrently, a blank sample was run (Gerenfes *et al.*, 2022).

Using equation 3.4, the sample's organic carbon content was determined.

$$\text{Organic Carbon (\%)} = \frac{10*(B-S)*0.39*mcf}{B*W} \quad 3.5$$

Where B= ml of ferrous ammonium solution used for blank S= ml of ferrous ammonium solution used for Sample mcf= moisture correction factor, W=Weight of sample (g), and 0.39 = conversion factor (A correction factor for a purported 70% oxidized carbon is included)

3.6.8 Determination of Carbon to Nitrogen (C: N) Ratio

The individual measurements of organic carbon (OC) and total nitrogen (TN) were used to calculate the C: N ratio (Mengistu *et al.*, 2017).

3.7 Phytotoxicity Test (Germination Index)

When assessing the quality of compost, phytotoxicity is a significant factor. Low-quality composts can produce phytotoxic compounds; they can hinder plant growth and development and harm seed germination (Selim *et al.*, 2012). The germination index (GI) is the most widely used technique for determining the phytotoxicity of compost due to its affordability, short duration, and compatibility with all substrates. Plant seed germination rate and root elongation can be used to calculate GI; a value of less than 50% indicates high phytotoxicity of compost products, a value of more than 80% indicates mature compost, and a value greater than 100% indicates phyto-stimulant effect (Siles-Castellano *et al.*, 2020). Extracts were prepared from the compost by mixing 10 g of air-dried compost in distilled water in the ratio of 1:10 (w/v). The mixture was shaken for 30 min, then filtered using Whatman No. 4 filter paper to generate compost extract, which was then used in seed germination tests. In these tests, I used wheat seed Bread Wheat (*Triticum aestivum L*), namely lemu taken from Ethiopian Institute of Agricultural Research (EIAR). 10ml of compost extract was applied to filter paper in a Petri dish, and 5 Wheat seeds were then placed on the filter paper. All experiments were run in replicates. The Petri dishes were sealed with tape to minimize water loss while allowing air penetration, and then were incubated in the dark. The seed germination percentage and root length of the plants in the extracts were determine a control experiment was also set up using distilled water. After 7 days of incubation, germinated seeds were counted and root length measured (Tibu *et al.* 2019). The germination index (GI) of the treatment was evaluated based on the following formula:

$$GI\% = \frac{\% \text{ Seed germination} * \text{Root length of treatment}}{\% \text{ Seed germination} * \text{Root length pf control}} * 100 \quad 3.6$$

Where GI is the germination index

3.8 Compost Monitoring

The compost was churned once a week to attain aerobic conditions during the twelve-week composting process, and water was sprayed at a moisture level of 40% and higher, per (McKenzie *et al.* 2022).

3.8.1 Sample Collection during Composting

For physicochemical examination, organic matter (LFW/SCGS/SD) was gathered in the composting container at various intervals of 0, 30, 45, 60, 75, and 90 days and systematically mixed (Hashem *et al.*, 2023).



Figure 4: Compost Sample Collection

3.8.2 Compost Sampling and Analysis

Samples were taken from a fraction of the composting combination of each ratio in order to evaluate the compost's various chemical and physical changes. Polythene bags containing the samples were sealed and transferred to the Leather and Leather Industry Development and Research Center laboratory for physicochemical analysis as detailed in this study's Section 3.5.

3.8.3 Determination of Qualities of Compost Produced

As stated in section 3.5, (Ameen *et al.* 2016) focused on determining the chemical and physical characteristics of compost, specifically focusing on nitrogen, pH, organic matter, amount of moisture, C: N ratio, and electrical conductivity. Additional attributes are the compost's physical characteristics, such as its color, look, and smell, which were utilized to confirm the compost manure's stability and maturity (Hammed, 2015)

3.9 Statistical Analysis

Origin Pro 2022 and Microsoft Excel software were used to make graphs.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 Result

Limed fleshing wastes were composted for ninety days, from March 3, 2025, to July 02, 2025, using sawdust and used coffee grounds. First, the source material was characterized in order to change characteristics that significantly affect the composting process. Furthermore, in order to better understand the ongoing process and compare the results with those of prior research in that area, as well as with global norms, multiple criteria were used to characterize mature compost and processed compost.

4.1.1 Physico-Chemical Characterization of Feedstock's

The major physicochemical properties of the Saw Dust (SD), Spent Grounds Coffee (SCGS), and Limed Fleshing Waste (LFW) are presented in Table 2. With an organic carbon content of 55.4%, total N₂ of 0.58%, and a C: N ratio of 95.21, the sawdust (SD) had an acidic pH of 5.75. The moisture content, ash content, and electrical conductivity value were (9.0), (1.85), and (0.42), respectively. The Spent Grounds Coffee (SCGS) was moderately acidic (pH 6.51), containing 43.3 % organic carbon, 1.69% N₂, and a 25.3 % C: N ratio. The moisture content, ash content, and electrical conductivity value were (12.44%), (1.46%), and (0.66 μS/cm) respectively. The results revealed that the Limed Fleshing Waste (LFW) had a pH of 7.8, which is moderately alkaline, with organic carbon (32.76%), N₂ (6.77%), and a C: N ratio of 4.84. The moisture content, Ash content, and Electrical conductivity value were (68.4%), (5.5%), and (3.0 μS/cm), respectively. The minimum value found in fleshing waste is justified because those wastes are generated by the removal of a hypodermis layer, which has a great amount of fat but is poor in protein (ABAJEHAD,2012).

Table 3: Mean physicochemical values of Saw Dust (SD), Spent Grounds Coffee (SCGS), and Limed Fleshing Waste (LFW).

Feed stock	pH	Moisture (%)	Ash (%)	EC ($\mu\text{S/cm}$)	C (%)	N (%)	C/N	Color
SD	5.75	9.00	1.85	0.42	55.40	0.58	95.21	Yellow
SCGs	6.51	12.44	1.46	0.66	43.32	1.69	25.30	Brown
LFW	7.80	68.43	5.47	3.11	32.76	6.77	4.84	Whitish gray

4.1.2 pH Determination during Composting Trials

pH is a key indicator of compost maturity, microbial activity, and nutrient availability, and it directly influences overall compost quality. In the initial stages of composting, pH levels can fluctuate widely. (Sadiku, 2023). Figure 13 shows the evaluation of the pH of the composts. In the mesophilic stage of this study for pH is 6.75, 6.35, 6.46, 6.51, 6.55, & 6.12 in treatment T 1, T2, T3, T4, T5 and T6 respectively. This indicate the action of microorganisms that produce acid causes the pH level to start dropping. This agreed with the finding of Abdul-Halim et al. (2019) who recorded the same range of initial pH values. However, after the 45 days i.e during the thermophilic stage, pH values in the mixtures significantly increased. pH is 8.17, 7.82, 8.13, 8.10, 8.05, & 6.50 in treatment T 1, T2, T3, T4, T5 and T6 respectively. T1-T5 pH values are alkaline except T6. This indicates that Microbial activity producing alkaline compounds as the result of volatilization (Manu *et al.*, 2019). The pH changes in mixtures T1 and T5 followed a similar pattern. After then, pH values in all the mixtures were then decreased. Wang et al. (2021), at the end of the experiment, organic acid change to organic matter. Mature compost derived from anaerobic processes showed pH values between 7.2 and 7.4, indicating a neutral to slightly alkaline environment (Fadela *et al.*, 2024).

Table 4: pH variation of different composting treatments during the composting period

Treatment	Day 0	Day 30	Day 45	Day 60	Day 75	Day 90
(1:1:1)	6.75	7.43	8.17	7.66	7.61	7.53
(2:2:1)	6.35	7.51	7.82	7.73	7.63	7.34
(8:1:1)	6.46	7.35	8.13	7.72	7.45	7.38
(4:1:1)	6.52	7.22	8.10	7.70	7.44	7.33
(3:1:1)	6.55	7.50	8.07	7.59	7.53	7.48
2:1(Control)	6.13	6.45	6.50	6.21	6.15	6.09

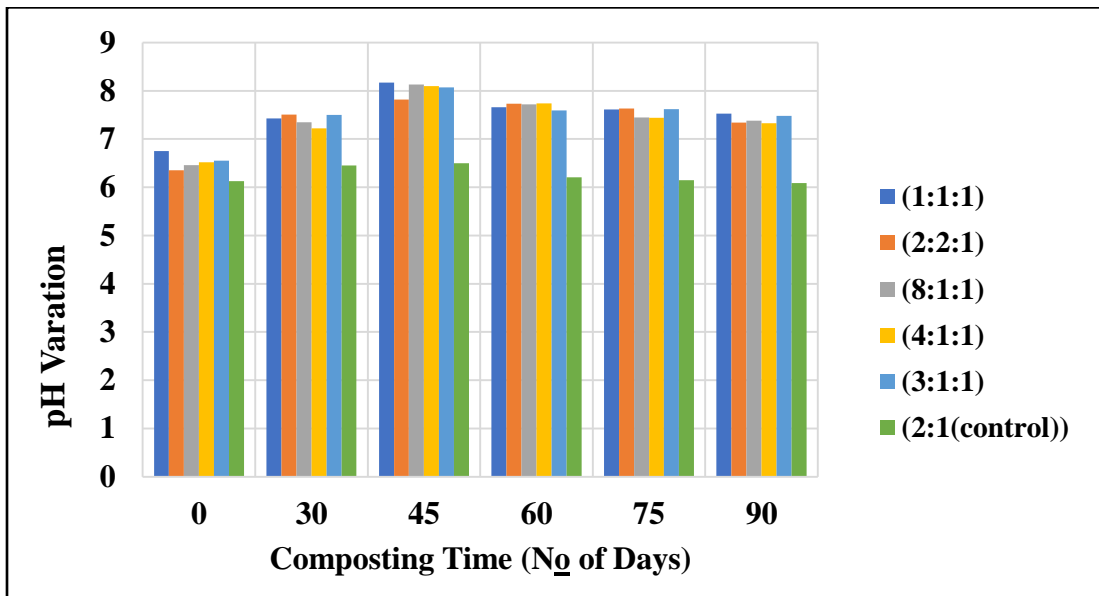


Figure 5: pH variation during composting time

4.1.3 Moisture Content Determination during Composting Trials

Moisture is important for the activity of microbes because it increases the rate of metabolism. (Hemidat *et al.*, 2018). The activity of microbes is minimum when low moisture is provided (Tiquia *et al.*, 1996). The reduction in the value of moisture content at the end of composting is a positive sign of decomposition and it gives mature compost (Epstein *et al.*, 1995).The moisture

content of each treatment group 1:1:1 (T1), 2:2:1 (T2), 8:1:1 (T3), 4:1:1 (T4), 3:1:1 (T5), and Control(2:1) was measured at 0, 30, 45, 60, 75, and 90 days. The Figure 14 below illustrates the average moisture content for each group across the composting period. The moisture content at the initial stage of composting process is optimized and its value should not increase from 50-60%.

All trials show a steady decrease in moisture content over the 90-day composting period, reflecting natural drying and decomposition. The higher sawdust ratio treatments (2:2:1(44.29%), 8:1:1 (43.77%)) better at retaining moisture in the early stages. Variance and standard deviation are highest in T2 and T3, indicating greater fluctuations in moisture content likely due to higher initial water content and more active microbial decomposition. The moisture percentage was decrease with increase in time interval. This can be attributed to active microbial activities and the turning frequency of the compost (Cao *et al.*, 2020). The value of moisture percentage of all trials was recorded the range of 32.73-35.54. The moisture is inversely proportional to the temperature and the microbe activity (Makan *et al.*, 2012).

The moisture content obtained in this study was SD (9.0%), SCGS (12.44%), &LFW (68.43%), as mentioned in Table 4. The LFW had high moisture content than the two feedstocks due to the beam house process stage involving wet processing. Microorganisms can only use organic molecules if they are dissolved in water; hence, the LFW facilitates microbial activity in the compost pile.

Table 5: Moisture Variation of different composting treatments during the composting periods

Treatment	Day 0 (%)	Day 30 (%)	Day 45 (%)	Day 60 (%)	Day 75 (%)	Day 90 (%)
(1:1:1)	41.45	40.47	38.72	36.81	35.07	34.66
(2:2:1)	44.29	43.24	41.28	40.37	38.53	35.51
(8:1:1)	43.77	41.29	39.01	38.06	37.15	35.54
(4:1:1)	43.33	40.59	38.43	37.35	36.69	34.83
(3:1:1)	39.66	38.90	37.42	36.43	35.11	34.17
2:1(Control)	40.54	39.79	38.66	36.56	34.49	32.73

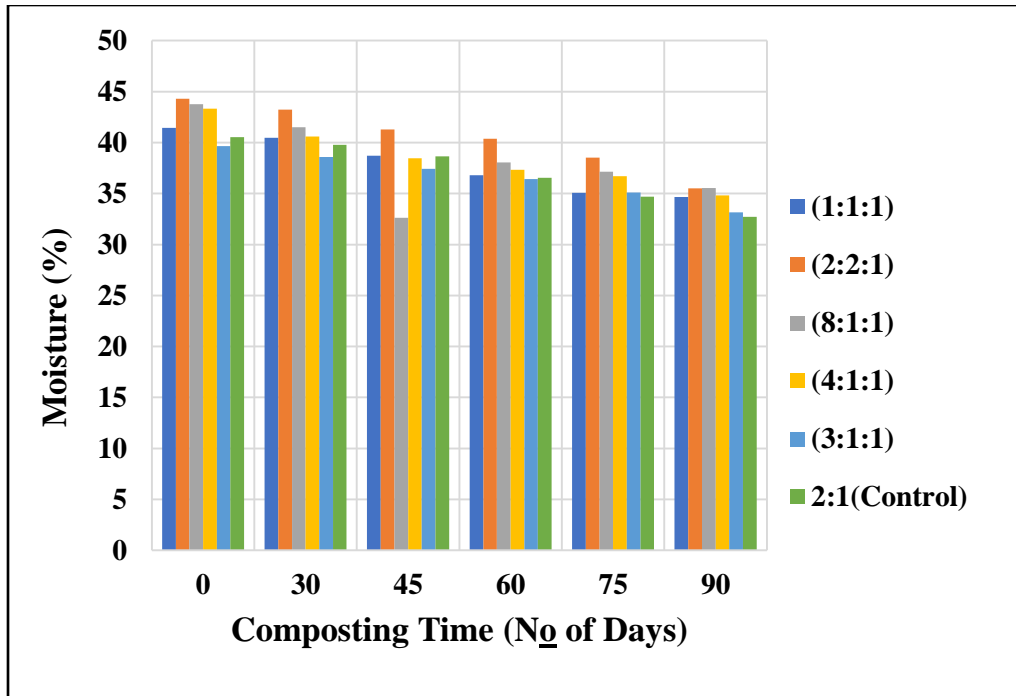


Figure 6: Moisture content variation during composting time

4.1.4 Temperature Evolution during Composting Trials

Temperature fluctuations occurred during the composting process. Temperatures ranged from 19.2 to 22.7 degrees Celsius at the start of the zero-day composting process, and they rose significantly to 32.6 to 34.8 degrees Celsius for T1 (1:1:1) and T2 (2:2:1) after 30 days, as illustrated in Figure 8. The temperature in each treatment gradually dropped throughout the course of the composting process, culminating in the termination of the composting process after ninety days. Day 30 saw the lowest temperature (26.4 °C) at T5 (3:1:1) and the maximum temperature (38.1 °C) at T2 (2:2:1). At day 45, temperature of 28.9 °C & 39.3 °C was recorded in composted mixtures T4 & T2, respectively. At day 60, the temperature (30.2 °C) was observed at T2 (2:2:1). At day of 75, the temperature (20.1 °C) was observed at T2 (2:2:1). Upon completion of composting at day of 90; T2 (2:2:1) had 20.6 °C, while T3 (80% SD) had 20.5 °C (Figure .8). Every trial in this investigation eventually reaches the ambient temperature range, indicating compost stabilization. Additionally, composting matured during the wet season of June to July 2025, when outdoor temperatures were not very high. This may be the reason why temperatures above 25 °C were not reached.

Table 6: Shows the recorded temperatures of the compost pile and the surrounding air.

S/No	Date	Ambient Temp (°C)	Treatment Temperature (°C)					Control
			T1 (1:1:1)	T2 (2:2:1)	T3 (80% SD)	T4 (75% SD)	T5 (60% SD)	
1	03/03/25	19.6	21.2	22.4	20.2	19.2	18.8	18.6
2	07/03/25	20.3	21.5	22.7	19.6	20.1	19.5	18.2
3	10/03/25	20.0	21.8	22.3	20.2	19.8	19.3	18.5
4	14/03/25	21.2	21.6	22.5	20.8	20.4	20.0	18.5
5	17/03/25	23.3	32.2	34.7	25.2	25.4	23.8	20.5
6	21/03/25	22.0	32.4	35.2	24.8	25.6	23.5	20.8
7	24/03/25	20.3	32.0	33.2	24.1	23.4	23.3	23.6
8	28/03/25	19.8	27.7	30.6	21.9	20.7	20.6	18.7
9	31/03/25	21.2	27.4	29.8	21.6	19.8	21.3	19.4
10	04/04/25	22.4	27.3	30.2	21.5	20.7	20.8	19.2
11	07/04/25	21.3	27.5	30.4	21.3	20.4	20.9	18.8
12	11/04/25	21.5	32.6	34.8	25.6	26.4	24.2	21.2
13	14/04/25	20.6	32.8	35.4	25.3	26.3	24.8	21.5
14	18/04/25	20.8	36.3	38.1	28.4	27.6	26.4	22.3
15	21/04/25	22.6	37.4	39.2	28.9	27.9	26.8	22.8
16	25/04/25	24.1	37.8	39.6	29.2	28.4	27.6	23.1
17	28/04/25	23.4	36.5	38.4	29.4	28.6	27.4	22.6
18	02/05/25	21.7	38.7	39.3	30.1	29.5	28.9	23.2
19	09/05/25	22.2	39.4	40.3	30.3	30.2	29.3	23.5
20	12/05/25	19.8	40.2	40.5	31.4	30.4	29.6	23.1
21	16/05/25	21.5	38.7	39.1	30.8	30.6	29.2	23.2
22	19/05/25	21.5	32.4	33.7	24.4	23.9	23.5	20.3
23	23/05/25	22.4	32.6	33.5	24.8	24.5	23.0	20.5
24	26/05/25	21.7	32.3	34.2	24.7	23.6	23.2	20.8
25	30/05/25	20.2	27.7	30.6	21.9	20.7	21.7	18.7
26	02/06/25	20.6	27.4	29.8	21.5	19.8	20.6	19.4
27	06/06/25	19.8	27.3	30.2	21.6	20.4	20.8	19.2
28	09/06/25	20.5	20.3	21.6	20.5	19.3	20.5	18.3
29	13/06/25	22.3	20.1	21.8	20.8	19.5	20.4	18.7
30	16/06/25	21.8	20.3	21.0	20.4	19.6	20.3	18.2
31	20/06/25	20.7	20.4	20.6	20.7	19.4	20.6	18.8
32	23/06/25	22.6	20.2	21.5	20.6	19.3	20.1	18.5
33	27/06/25	20.5	20.3	20.4	20.3	19.4	20.1	18.4
34	02/07/25	20.0	20.1	20.1	20.6	20.2	19.6	20.7

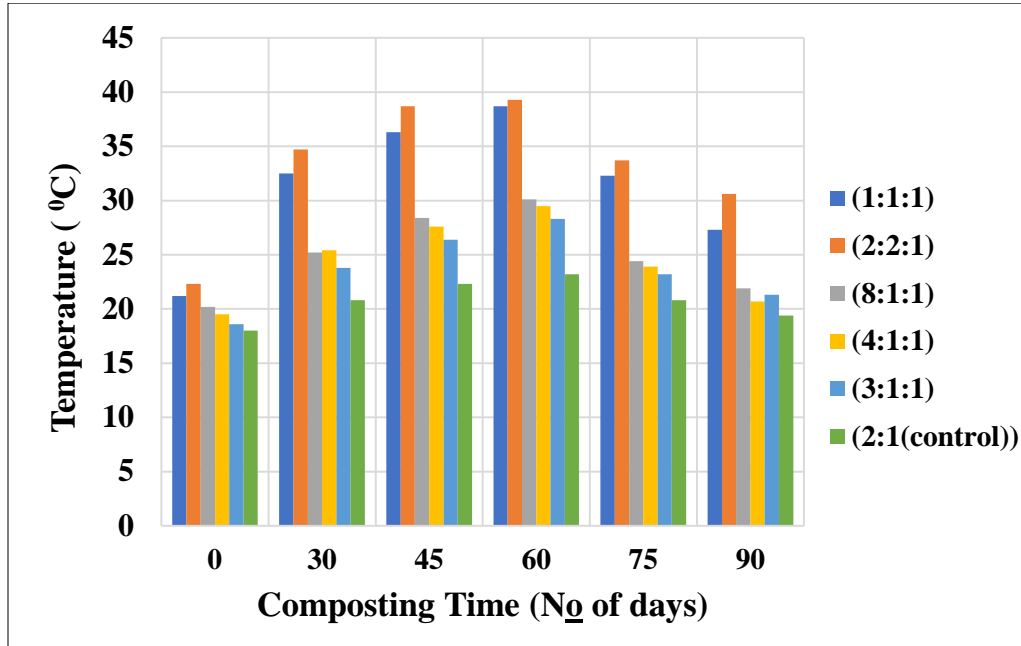


Figure 7: Mean values of Temperature during the composting period

4.1.5 Ash Content Variation

In the initial stages, microbial activity starts to break down the compost's organic materials. However, the ash content does not change significantly during this phase because the inorganic minerals remain unaffected by biological decomposition. (L. Fialho *et al.*, 2009). All compost treatments show a progressive increase in ash content over 90 days, indicating continuous degradation of organic matter shown in Figure.9. In the initial stage. The highest ash content (4.99 ± 0.04) was noted at T1 (1:1:1), showing optimal composting performance, suitable for mineral-rich compost. The highest ash content was recorded in T1 (1:1:1), which may be due to an equal proportion of feed stocks, balanced C/N ratio, and efficient breakdown of organic materials. The SD-based mixtures (8:1:1, 4:1:1) may have suboptimal nutrient ratios, slowing microbial metabolism and delaying decomposition due to lignin resistance. As decomposition progresses, the organic fraction of the materials decreases, while the relative proportion of inorganic minerals (ash) increases. This occurs as a result of organic matter being broken down into water, carbon dioxide, and other volatile substances while the mineral components are left behind. At the end of the composting process, a greater concentration of inorganic minerals is

left behind because the majority of the organic matter has broken down. The proportion of ash in the overall compost will be larger than initially. The compost's ash concentration varied from 4.46 ± 0.05 to $9.45 \pm 0.03\%$, with 1:1:1(T1) having the highest ash content of $9.45 \pm 0.03\%$. The least value ($4.46 \pm 0.05\%$) for ash was observed at Control.T1 (1:1:1) & T5 (3:1:1) show the highest decomposition rates, reaching near-max values by 90 days in the case of a good balanced microbial action. It provides a balanced carbon-to- nitrogen ratio, promoting microbial growth and efficient breakdown. All treatment results are within the limit of Herity (L.2003).

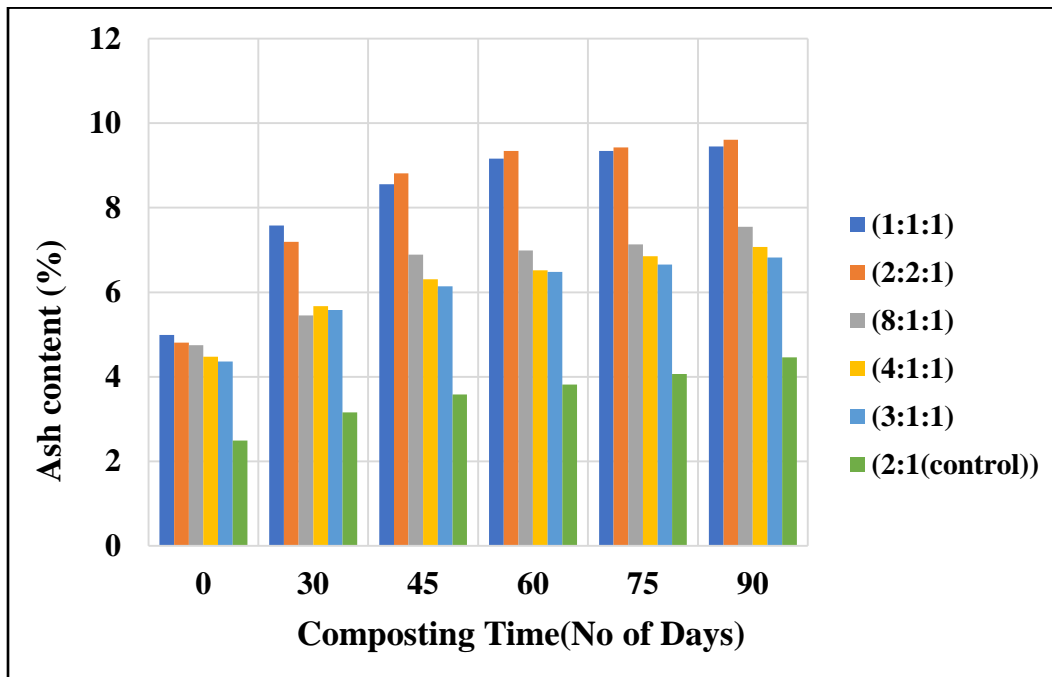


Figure 8: Mean Ash content of trials during composting

4.1.6 The Electrical Conductivity of the Composting Trials

Figure 10 shows the variation of the electrical conductivity of the six composting trials. In the composting materials, the electrical conductivity indicates the concentration of salts, reflecting the ionic concentration of both organic and inorganic salts. The salinity of the compost and its use as a soil supplement for crop cultivation are indicated by the concentrations of the ionic salts. Generally, in the current study, a small rise in EC was noted from the beginning to the end of the composting process. Mature compost's EC values might vary from 2 to 6 $\mu\text{S}/\text{cm}$, depending on the composting conditions and feedstock range by (Vasileiadou, 2024). After 90

days, the compost shows a consistent EC, signifying a reduction in microbial activity and the readiness for application. (Bazrafshan *et al.*, 2015). The breakdown of organic materials and water loss may liberate mineral salts such as phosphates and ammonium ions, raising the concentration of relative soluble salts and contributing to the rise in EC (Huang *et al.*, 2004). Most treatments show an initial increase in EC (peaking at 60-75 days) followed by a slight decrease. This pattern indicates initial salt release during decomposition. T2 showed the most stable salinity profile with a mean EC of 1.37-1.81 $\mu\text{S}/\text{cm}$. T1 and T5 reached EC levels that might be borderline for salt-sensitive plants. All values remain within acceptable limits for most crops ($<4 \mu\text{S}/\text{cm}$). T1 and T5 reached the highest EC values ($>2.0 \mu\text{S}/\text{cm}$). The control's lower EC (1.23) reflects less mineralization activity. 1:1:1 (T1) and 3:1:1 (T5) mean result (1.89 ± 0.00 and 1.84 ± 0.00) indicates high microbial activity and strong mineralization of nitrogenous and organic compounds. A rise in microbial activity that breaks down organic waste and lowers soluble salts causes the EC to decrease as composting proceeds (Yousefi *et al.*, 2012). The decline in EC of the composting trials after the 7th week may be due to the humification of organic materials that caused dissolved salt and macro-molecular organic acids to turn into macro-molecular humus (Chaher *et al.*, 2020). After the 9th week, the final EC in all trials was below $4.0 \mu\text{S}/\text{cm}$, which is good for plant production. According to studies by He *et al.* 2020, the moisture content gradually decreases, the EC peaks approximately 45 days later, and then stabilizes. The composting process results in the stabilization of organic matter, reducing the concentration of soluble ions. Final EC values ($\sim 3.0 \mu\text{S}/\text{cm}$) align with standards for mature, plant-safe compost (Horgan *et al.*, 2023).

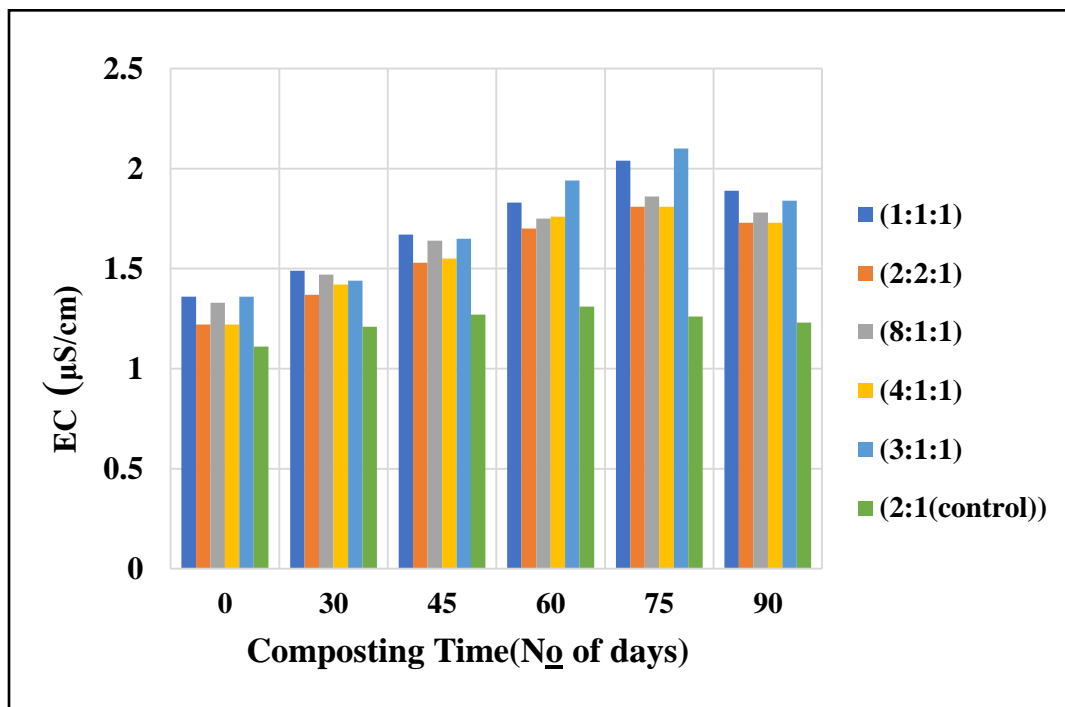


Figure 9: Electrical Conductivity (EC) Evolution of Compost Treatments over Composting Time

4.1.7 Carbon Content of the Compost

The early stage of the carbon content of the SD/SCGS/LFW (T1, T2, T3, T4, T5, and T6 or control; respectively) compost ranged between 20.56% and 36.15% (Figure 11). All treatments saw a small drop in carbon content between 30 and 75 days. But by day 60, the carbon content had somewhat increased, reaching 16.63, 27.22, 18.45, 17.57, 13.68, and 23.8% at SD/SCGS/LFW (T1, T2, T3, T4, T5, and T6 or control), respectively. At the maturation period of composting at 90 days, the Carbon content reached 13.76, 23.37, 16.41, 15.69, 10.54 & 20.5% at SD/SCGS/LFW (T1, T2, T3, T4, T5 & T6) respectively. The breakdown of organic materials required for microbes' metabolism, which results in their mineralization as carbon dioxide (CO₂), causes the TOC level to drop during composting (He *et al.* 2000). Total organic carbon generally decreases during the composting process because microorganisms use the organic carbon from the bulking agent as food for metabolic processes, which causes organic matter to be broken down by microbial activity in the presence of oxygen and CO₂ gas to be released, producing

organic matter. (Bello *et al.*, 2021). All treatments show decreasing values over time, indicating decomposition or loss of material during composting. T2 (2:2:1) starts with the highest value and maintains the highest value throughout composting time. T5 (3:1:1) shows the most rapid decrease. Control values are intermediate between T2 (2:2:1) and T3 (80%SD). The 1:1:1 (T1) and 3:1:1 (T5) mixtures likely have optimal C: N ratios (25-30:1) for microbial activity. The 2:2:1 (T2) mixture may have either too high carbon content (slowing degradation) or inhibitory compound accumulation. T3&T5 shows progressively faster degradation, suggesting better oxygen penetration in less dense mixtures. T2's resistance may indicate compaction or poor aeration. In the first fast phase (0–45 days), the degradation of Proteins, hemicellulose, and simple Sugars occurs. According to the data, the T5 (3:1:1) mixture indicated the most effective material breakdown throughout the course of the 90-day period, indicating that treatment composition has a major effect on decomposition kinetics during composting. The mature compost's overall organic carbon content varied between 13.68% and 23.37%. These findings are similar to those shown by Khater (2015), who discovered that the compost's total organic carbon ranged from 16.6 to 23.89%.

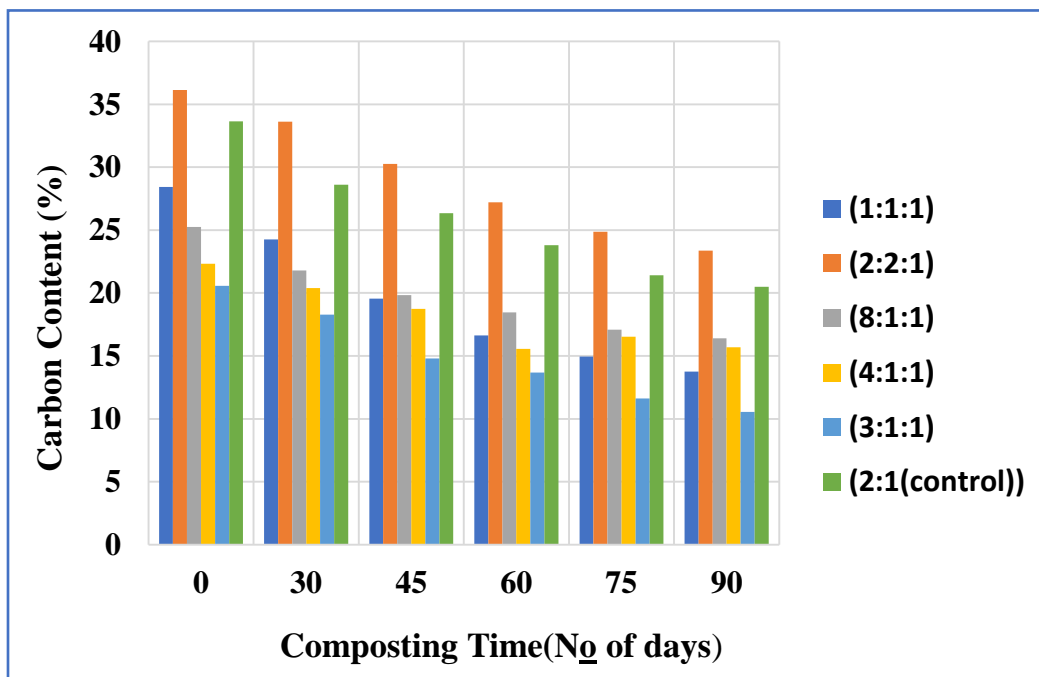


Figure 10: Variation of Carbon Content in Different Composting Treatments Over Time

4.1.8 Nitrogen Content of the Compost

The nitrogen content during the early and maturation stages of composting sawdust, coffee grounds, and limed fleshing waste varies significantly due to the composition and microbial activity involved. In the early stages, nitrogen levels can initially increase due to ammonification, where organic nitrogen is converted to ammonium. However, as composting progresses, particularly in the maturation stage, nitrogen loss occurs primarily through ammonia volatilization, especially at high temperatures (Gorliczay *et al.*, 2020).

The concentration effects brought on by the breakdown of organic compounds, which reduced the dry matter content because of the added bulking agents, are likely the reason why T1 and T5 had the highest nitrogen levels for this investigation. For treatments 1, 2, 3, 4, 5, and 6, the corresponding total nitrogen contents were 1.16%, 0.93%, 0.81%, 0.91%, 0.95%, and 0.7%. This result satisfies the quality compost criterion of > 0.7%, which is used by countries including the Netherlands, Belgium, and Italy (Hang *et al.*, 2021). Likewise, the outcome complies with minimum quality norms for finished compost in Nigeria, Thailand, and California (Hammed, 2015) for total N, which is 1-4 percent dry weight. Therefore, since the compost samples have a total N over 1%, they have fertilizing capability and can be used in agriculture. Figure 12 displays the average percentages of total nitrogen content in the mature compost. Higher pH levels (up to 6.5) can enhance microbial activity, but may also increase nitrification rates, potentially leading to nitrogen loss. (Braos *et al.* 2020). At the end of composting, the mineralization process becomes predominant, and an increase in the content of NO_3^- is frequently observed. (Sánchez-Monedero *et al.*, 2001).

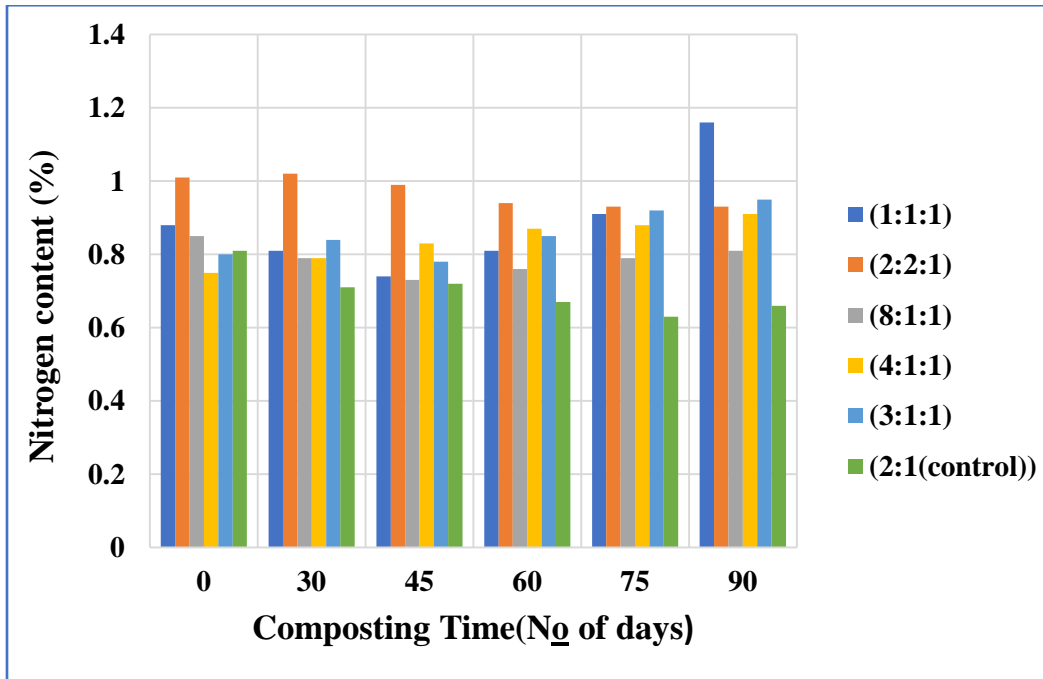


Figure 11: Changes in Total Nitrogen Content of Compost Mixtures over Composting Time

4.1.9 Carbon -to -Nitrogen (C: N) Ratio

Carbon and nitrogen are needed by microorganisms as a source of energy for metabolic activities. A balanced C: N ratio is beneficial for soil and plant growth as well as microbial development and production (Kebibeche *et al.*, 2018). As the composting progressed, the C/N ratio decreased throughout the period in all the treatments shown in Figure 13. A decrease in the C/N ratio was highest in T₃&T₅, moderate in T₂ and T₄, and lowest in T₁. The temperature was lowest in this Treatment and it recorded the lowest reduction in the C/N ratio value. In compost T₃, the changes in total nitrogen and organic carbon were great; therefore, the reduction of the C/N ratio was highest in this treatment. At the end of the process, the highest reduction in C/N ratio was in T₃, and the lowest reduction was observed in T₁. This result was in line with the result of Getahun *et al.* (2011) in the composting of municipal solid waste. The C/N ratio usually decreases during 90 days when organic waste mixtures, such as coffee husk, sawdust, and other materials, are composted. (Shemekite *et al.*, 2013), (Fialho *et al.*, 2009). The final value for C: N is 11.8, 25.1, 20.3, 17.2, 11.0, & 29.4 in treatment T₁, T₂, T₃, T₄, T₅, and T₆, respectively. Due to the similar amounts of organic additions and sawdust, T₁ and T₅ showed the most variation in

the C: N ratio, which may be explained by this. The C/N ratio of the compost samples under study, except T6, is less than 20, which is in line with the compost quality requirements employed by nations like Nigeria, California, and Thailand. As previously stated, the outcome falls within the boundaries of the Ethiopian Federal EPA recommendations, which suggested that high-quality compost has an ultimate C: N ratio of 29:1 or below (FEPA, 2004). Varying geographical locations might result in varying weather conditions, which can cause differences in the C: N ratio. Each country may establish its own standards, which can be demonstrated by measuring the essential macronutrients at different C: N ratio levels. Figure 13 shows the trend of the C: N ratio over the composting period.

All treatments show decreasing C: N ratios, indicating organic matter decomposition and nitrogen enrichment. The Initial ratios (~25–30) of T1 (1:1:1) & T5 (3:1:1) are ideal for microbial activity, promoting rapid carbon breakdown. Its exhibit the steepest declines, suggesting rapid carbon loss/nitrogen retention. T3 (8:1:1) & T4 (4:1:1) show intermediate trends, balancing C and N dynamics. The extreme initial C: N Ratios (35–40) of T2 (2:2:1) and control excess carbon slows microbial growth, requiring longer composting times. It maintains higher C: N ratios, reflecting slower decomposition. The high proportion of wood to limed fleshy waste in the compost combination may be the cause of the delayed pace of decomposition. According to Lennox et al. (2019), the presence of lignin, a very resistant component, made it extremely difficult for microorganisms to break down sawdust. The compost used in this study had a carbon to nitrogen ratio that varied from 11.01 to 29.43. The C: N ratio for compost quality and maturity has been found to vary widely between researches (14–40), according to Anwar *et al.* (2015). A C/N ratio below 20 is often viewed as an indicator of mature compost, suitable for application in soil without causing phytotoxic effects. (Azis *et al.*, 2023).

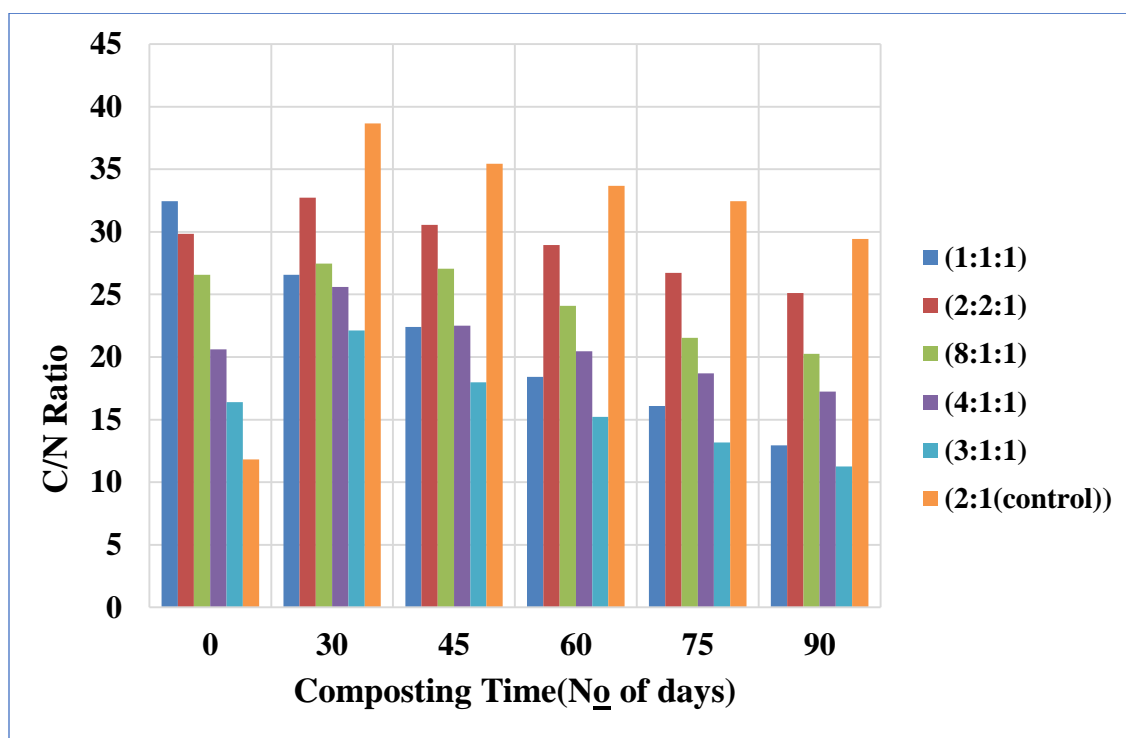


Figure 12: Change in carbon-to-nitrogen ratio of compost treatments during the composting period

4.1.10 Phytotoxicity Test/ Germination Index

The GI values of Wheat seeds in composting mixtures of initial mix ratios of 1:1:1(T1), 2:2:1(T2), 8:1:1 (T3), 4:1:1 (T4), 3:1:1 (T5), and Control (2:1) were 128.6, 50.1, 90.84, 102.4, 160.3 and 100, respectively. Wang et al. 2021 reported that a GI value of more than 80% is an indication of phytotoxic-free and mature compost. Similar suggestions were also reported by Tequila... On the seventh day, all of the wheat that had been planted had fully germinated. All test samples and the control had 100% germination. According to Table 6, the compost is mature; no more breakdown is occurring that could produce harmful compounds that could prevent intact root growth and seed germination. In comparison to other compost samples, T5, T1, and T4 had higher recorded germination index values. Because there are plant nutrients in the compost, the compost sample's root length is closer to the control's, as shown in Table 6, which shows that the germination index is higher than 80% for all treatments except T2. Composting will improve the soil's nutrient status (Gutser *et al.*, 2005).

Table 7: Verification of plant phytotoxicity and germination index for each treatment

After 7 days	Seeds	MRL	MSG	RE/RRL%	GI%
1:1:1 (T1)	Wheat	8.85	100	128.63	128.63
2:2:1 (T2)		3.45	100	50.14	50.14
8:1:1(T3)		6.25	100	90.84	90.84
4:1:1 (T4)		7.05	100	102.47	102.47
3:1:1 (T5)		11.03	100	160.32	160.32
2:1(Control)		6.88	100	100	100

An immature compost containing phytotoxic substances like ammonia or organic acids is represented by a low GI, whereas a high GI (usually >80%) denotes mature, non-toxic compost suitable for plant growth. As a maturity indication, GI changes are consistent with decreases in the C/N ratio, ammonium concentration, and pH stabilization. Limed fleshing waste at low proportions (10%) does not significantly reduce GI when balanced with high sawdust content (Zahra *et al.*, 2023).

4.2 Discussion

The physicochemical characteristics of Sawdust (SD), spent coffee Grounds (SCGS), and Limed fleshing waste (LFW) are shown in Table 8. The SD/SCGS/LFW composting process took 90 days, or twelve weeks, to complete, and the compost's characteristics were good. Getachew (2017) reported that the composting of coffee husk (CH), cow dung (CD), and poultry manure (PM) took a similar amount of time (90 days). Alves *et al.* (2019) reported the composting of sawdust (SD), Vegetable peels, and coffee grounds to maturity in 140 days. Composting of organic waste mixtures, including coffee husk, sawdust, and various other materials, typically results in a decrease of the C/N ratio over 90 days. They are free of non-biodegradable items (glasses, plastics, metals, and stones), have a good earthy scent, and range in color from dark brown to black, though they can vary (Appendices 9, 10, and 11). The tannery waste had an alkaline pH of 7.92. The alkaline character of the limed fleshing waste was most likely caused by the chemicals employed in the beam house process, including liming compounds, bicarbonates,

carbonates, and sulphides. These findings are consistent with those of Framis (2018) and Mahdi et al. (2007), who found that the waste from tanneries was very alkaline.

The sawdust had a highly acidic pH of 5.62. Omosebi (2018) reported a lower pH (4.36, acidic) for sawdust. The kind of tree species used may be the cause of the acidity. According to Ikenyiri et al. (2019), the sawdust's pH values varied depending on the type of wood, ranging from soft wood (5.29 to 5.48, severely acidic) to hard wood (5.75 to 6.18, moderately acidic). After 90 days of composting SD/SCGS/LFW, the pH profile was found to be mildly alkaline, ranging from 7.33 to 7.53. However, the types of raw materials employed and degraded determine the pH of the mature compost. When the pH measured in this study was compared to the minimal quality standards for finished compost in Nigeria, Thailand, and California (Hammed, 2015), it was found to be within the acceptable range. The organic carbon (32.76%), total nitrogen (6.77%), and C: N ratio (4.84) of limed fleshing waste used in this study (Table 2) were high in nitrogen content. These findings are closer to ABAJIHAD, 2012. The findings of these investigations' physicochemical characterization of the fleshing waste to be pH (11.4), organic carbon (53.86%), total nitrogen (13.1%), and C: N ratio (4.11:1). Tannery wastes are a good source of nitrogen for plants because of their high levels of organic carbon and nitrogen (Nabavinia et al., 2015).

Limed fleshing waste has a low C: N ratio (~3.2) and alkaline pH (~11.4), which can cause ammonia toxicity if not balanced (Shanmugam & Horan, 2009). It was discovered that the fleshing waste's C: N ratio was about one-sixth of the lowest acceptable value for composting. Before being treated, the solid wastes must be properly separated, processed, and combined with the right additives on the spot to make them more compatible with the particular treatment technique. It is necessary to evaluate and confirm this in advance. When composting, for instance, high carbon wastes (straw, paper, etc.) may be added if the C/N ratio is low; if it is high, high nitrogen wastes (sewage sludge, slaughterhouse waste, etc.) may be added to get the C/N ratio within the desired range. Compost can therefore be made from fleshy waste by combining it with other organic trash (ABAJIHAD, 2012)

The sawdust utilized in this investigation has the following physicochemical characteristics: total nitrogen (0.61%), organic carbon (55.4%), and C: N ratio (95.21). In addition to having a high

carbon to nitrogen ratio and electrical conductivity, the sawdust was high in organic carbon. Mahdi et al. (2007), who worked on the characterization and composting of tannery sludge, obtained similar findings. According to Nwankwo et al. (2014), another researcher found that sawdust had a 54% organic carbon content. The C:N ratio ranged from 23.41 to 95.21, with sawdust (SD) having the greatest C: N of 95.21 and SCGS having the lowest. Dan and associates (2018). Higher C: N ratios (499.64) and (114.84) for wood used in composting were reported by Alves et al. (2019). The C: N ratio of sawdust often varies greatly depending on the type of wood. During the composting process, the observed temperature did not rise above 40.5°C. Bacteria for rapid decomposition (40–60°C), fungi for stabilizing and humification (20–35°C).

Microbial activity is responsible for both the increased rate of temperature rise and the biological breakdown of organic materials; the temperature increase was noted within a few days of creating the compost. Mehta and Sirari (2018) reported that most pathogens die at 35°C and above. Microbial activity produces heat; during the composting process, the temperature rose initially, then decreased, and then stabilized when microbial activity decreased as a result of the organic waste being depleted. The temperature completely dropped to normal temperature after ninety days, or twelve weeks. The mature compost's total organic carbon content varied between 10.54% and 23.37%. These outcomes are similar to those of Khater (2015), who discovered that the compost's total organic carbon ranged from 16.6 to 23.89%. The compost used in this study had a C: N ratio between 11.01 and 25.12. According to Anwar et al. (2015), various investigations have shown that the C: N ratio for compost quality and maturity fluctuates widely from 14 to 40. Higher C: N ratios (>40) require more time for bacteria to break down waste because of a nitrogen shortage that reduces composting activity. Monitoring nitrogen levels at different intervals (e.g., 4, 8, 12, and 16 weeks) can provide insights into nitrogen transformations and losses (Fawole et al., 2019). At the end of composting, the mineralization process becomes predominant, and an increase in the content of NO_3^- is frequently observed (Sanchez-Monedero et al. 2001). Therefore, an increase in total nitrogen concentration is generally observed in the mature compost. In this study, in T1 and T5, the increment of nitrogen content. Proper aeration and moisture control can help reduce nitrogen losses.

An increase in EC would lead to phyto-inhibitory effects (Zhou et al., 2019). The electrical conductivity greater than 4 $\mu\text{S}/\text{cm}$ is considered injurious to plants (Manu et al., 2018) because

the soluble salts can negatively affect seed germination. In the initial stage of composting, the Value of EC in all treatments is low, but after a week, the EC value rises because as organic materials decompose, nutrients like ammonium (NH_4^+), nitrate (NO_3^-), potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}) are released into soluble forms. These ions increase the compost EC. All composting mixtures show a gradual EC increase until 75 days, with some stabilization after Day 90. T1 and T5 has highest mean EC (1.7-1.73 $\mu\text{s}/\text{cm}$, which indicates high microbial activity and strong mineralization of nitrogenous and organic compounds. These findings are similar to those of He et al. (2020). The final EC was below 4 $\mu\text{s}/\text{cm}$, which is good for plant production (He et al., 2020). The ash content represents the inorganic residue (minerals) left after combustion. All compost treatments show a progressive increase in ash content over 90 days, indicating continuous degradation of organic matter. T1 and T5 are effective mixtures with a higher stable ash profile. The sawdust proportion from T4 to T2% shows a gradual decline in ash content, due to its high lignocellulosic (organic) content, which decomposes more slowly and dilutes mineral buildup. Based on the results, it was determined that the samples had minimal phytotoxicity because their index values were above 80% except for T2, and their germination percentages (beyond 25% of the initial extract) were nearly negative. Additionally, the investigation showed that the materials did not significantly inhibit radicle elongation or seed germination (radicle emergence). Similarly, according to the test procedure listed in the equation. (3.5), the results of Qian *et al.* 2014) showed that the GI values varied from 68% (day 30) to 129% (day 90) in swine manure composting and from 88% (day 30) to 119% (day 90) in dairy manure composting. The SG values of all seeds were more than 100% except T2 (ten germinated seeds of ten seeds per Petri dish), which indicated that compost did not affect the germination of the seeds. Wheat seeds were treated with the resulting SD/SCGS/LFW compost. The wheat seeds' capacity to sprout in each treatment demonstrated that the compost SD/SCGS/LFW T1 (1:1:1), T3 (8:1:1), T4 (4:1:1), T5 (3:1:1), and Control (2:1) had no phytotoxic effects on the wheat seeds, which also retained moisture. According to Jeyapandiyar *et al.* (2017) and Tibu et al. (2019), compost that exhibits a germination rate of over 80% is free of phytotoxic chemicals and reaches an acceptable maturity. This result agrees with that obtained by (Us et al., 2022), who reported that moisture was the most important factor inhibiting seed germination and root elongation of all species examined.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

Tannery is considered an industry that generates a considerable amount of solid waste. As per the informal assessment made in Batu Tannery, all the solid wastes generated during leather processing are being collected and disposed of by open dumping together with municipal solid waste, which poses a serious environmental threat. Among the composting treatments assessed, the best overall performance was recorded for T5 (3:1:1), followed by T1 (1:1:1) on seed germination, indicating better maturity and quality of compost. Although liming fleshing waste has been identified as one of the environmentally problematic tannery by-products, it was shown in this study that its conversion into compost, when mixed with appropriate organic amendments, offers an effective and environmentally acceptable waste management option. Compost made from limed fleshing waste revealed favorable physico-chemical properties and nutrient content, confirming its suitability for use as bio-compost and natural fertilizer without causing disturbance to the environment. Treatment T5 showed better germination performance, but Treatment T1 showed better physico-chemical properties, further confirming the effectiveness of balanced organic mixtures. In general, Treatments 1 and 5, made of 33.3% Saw Dust + 33.3% Spent Coffee Grounds + 33.3% Limed Fleshing Waste and 60% Saw Dust + 20% Spent Coffee Grounds + 10% Limed Fleshing Waste, respectively, gave the most desirable nutritional values compared to the other treatments, mainly because of their lower proportion of saw dust. In addition, the physico-chemical properties of the matured composts were within the recommended standards of many countries. During composting, parameters such as pH and electrical conductivity showed an increase, while organic carbon, organic matter, and the C/N ratio were decreased, indicating effective stabilization and maturity of the compost.

5.2 Recommendations for Future Work

Recommendations for future work include the following:

- Long-term field experiments should be conducted to evaluate the agronomic performance of tannery waste compost under different soil types and cropping systems.
- The long-term effects of repeated compost application on soil physicochemical properties, microbial activity, and possible accumulation of salts or heavy metals need further investigation.
- Optimization of compost formulation by varying the proportions of organic amendments such as coffee grounds, sawdust, and other locally available agro-wastes should be explored to improve compost maturity, stability, and nutrient content.
- Large-scale and pilot-level composting studies at tannery sites are required to assess the technical feasibility, scalability, and operational challenges of the composting process.
- Economic feasibility and life cycle assessment (LCA) studies should be performed to compare tannery waste composting with conventional waste disposal methods.
- The environmental safety of tannery waste compost, including its impact on soil organisms and groundwater quality, should be evaluated through extended monitoring studies.
- Further research should investigate the performance of tannery waste compost on different crops to confirm its agricultural effectiveness and environmental safety.

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APPENDIX

Appendix 1: Determination of the Weight of a Single Piece of Wet Salted Hide

Sample no	1	2	3	4	5	6	7	8	9	10
The weight of a piece of wet salted hide	11.03	9.41	10.9	9.47	11.14	9.91	10.36	10.46	9.44	9.89
Average weight of a piece of salted hide	10.2±0.67									

Appendix 2: Waste generated from fleshing and trimming activity per kilogram of wet salted hide

S/N	Average weight of a single piece of WSH (Kg)	Weight of a single piece of WSH hide before fleshing and trimming (Kg)	Weight of a single piece of WSH after fleshing and Trimming (Kg)	Fleshing and trimming waste generated (Kg/Kg) of the raw hide
1	10.2	15.22	12.39	0.28
2		13.67	11.51	0.21
3		15.10	12.13	0.29
4		13.59	11.34	0.22
5		15.03	11.98	0.30
6		13.91	11.76	0.21
7		14.77	12.13	0.26
8		14.81	12.41	0.23
9		13.52	11.39	0.21
10		14.13	11.82	0.23
Ag		14.34	11.89	0.25

Appendix 3: Physicochemical properties of sawdust, spent coffee grounds, limed fleshing waste at start of composting process (day zero)

Mixtures	pH	Moisture (%)	Ash (%)	EC ($\mu\text{S}/\text{cm}$)	TOC (%)	N (%)	C/N ratio
1:1:1(T1)	6.75 \pm 0.02	41.45 \pm 0.01	4.99 \pm 0.04	1.36 \pm 0.00	28.42 \pm 0.06	0.88 \pm 0.02	32.44 \pm 0.56
2:2:1(T2)	6.35 \pm 0.01	44.29 \pm 0.01	4.81 \pm 0.05	1.22 \pm 0.00	36.14 \pm 0.04	1.01 \pm 0.01	35.49 \pm 0.37
8:1:1(T3)	6.46 \pm 0.02	43.77 \pm 0.01	4.75 \pm 0.01	1.33 \pm 0.00	25.24 \pm 0.04	0.85 \pm 0.01	29.69 \pm 0.33
4:1:1(T4)	6.52 \pm 0.03	43.33 \pm 0.00	4.48 \pm 0.03	1.22 \pm 0.00	22.32 \pm 0.03	0.75 \pm 0.01	29.63 \pm 0.26
3:1:1(T5)	6.55 \pm 0.03	39.66 \pm 0.00	4.36 \pm 0.04	1.36 \pm 0.00	20.56 \pm 0.02	0.80 \pm 0.01	25.6 \pm 0.19
Control (2:1)	6.13 \pm 0.02	40.54 \pm 0.01	2.49 \pm 0.01	1.11 \pm 0.00	33.65 \pm 0.02	0.81 \pm 0.02	39.74 \pm 0.23

Appendix 4: Physicochemical properties of sawdust, spent coffee grounds, Limed fleshing waste mix at day 30

Mixtures	pH	Moisture (%)	Ash (%)	EC($\mu\text{S}/\text{cm}$)	TOC (%)	N (%)	C/N ratio
1:1:1(T1)	7.43+0.02	40.47+0.03	7.58+0.02	1.49+0.00	24.25+0.11	0.81+0.02	29.83+0.41
2:2:1(T2)	7.51+0.01	43.24+0.03	7.19+0.02	1.37+0.00	33.61+0.36	1.02+0.01	32.73+0.19
8:1:1(T3)	7.35+0.03	41.49+0.02	5.45+0.01	1.47+0.00	21.78+0.13	0.79+0.02	27.46+0.40
4:1:1(T4)	7.22+0.01	40.59+0.03	5.67+0.05	1.42+0.00	20.39+0.38	0.79+0.01	25.59+0.39
3:1:1(T5)	7.50+0.02	38.60+0.02	5.58+0.03	1.44+0.00	18.29+0.22	0.84+0.02	22.13+0.17
Control (2:1)	6.45+0.02	39.79+0.04	3.16+0.04	1.21+0.00	28.60+0.33	0.74+0.01	38.65+0.12

$\mu\text{S}/\text{cm}$ = micro Siemens per centimeter

Triplicate measurement expressed on a dry basis

Mean \pm Uncertainty

Appendix 5: Physicochemical properties of sawdust, spent coffee grounds, Limed fleshing waste mix at day 45

Mixtures	pH	Moisture (%)	Ash (%)	EC ($\mu\text{S/cm}$)	TOC (%)	N (%)	C/N ratio
1:1:1(T1)	8.17 \pm 0.01	38.72 \pm 0.00	8.56 \pm 0.07	1.67 \pm 0.00	19.56 \pm 0.19	0.74 \pm 0.02	26.56 \pm 0.32
2:2:1(T2)	7.82 \pm 0.01	41.28 \pm 0.01	8.81 \pm 0.05	1.54 \pm 0.00	30.25 \pm 0.32	0.99 \pm 0.02	30.56 \pm 0.30
8:1:1(T3)	8.13 \pm 0.02	39.01 \pm 0.01	6.89 \pm 0.05	1.68 \pm 0.00	19.84 \pm 0.13	0.73 \pm 0.01	27.06 \pm 0.41
4:1:1(T4)	8.10 \pm 0.03	38.43 \pm 0.00	6.31 \pm 0.03	1.55 \pm 0.00	18.76 \pm 0.12	0.83 \pm 0.01	22.51 \pm 0.24
3:1:1(T5)	8.07 \pm 0.01	37.42 \pm 0.00	6.14 \pm 0.03	1.65 \pm 0.00	14.79 \pm 0.11	0.78 \pm 0.02	19.47 \pm 0.40
Control (2:1)	6.50 \pm 0.04	38.66 \pm 0.04	3.58 \pm 0.03	1.27 \pm 0.00	26.36 \pm 0.01	0.72 \pm 0.01	35.43 \pm 0.27

Appendix 6: Physicochemical properties of sawdust, spent coffee grounds, Limed fleshing waste mix at day 60

Mixtures	pH	Moisture %	Ash %	EC ($\mu\text{S/cm}$)	TOC (%)	N (%)	C/N ratio
1:1:1(T1)	7.66 \pm 0.02	36.81 \pm 0.01	9.16 \pm 0.04	1.83 \pm 0.00	16.63 \pm 0.16	0.81 \pm 0.01	20.6 \pm 0.36
2:2:1(T2)	7.73 \pm 0.01	40.37 \pm 0.00	9.34 \pm 0.04	1.70 \pm 0.00	27.22 \pm 0.28	0.94 \pm 0.01	28.96 \pm 0.30
8:1:1(T3)	7.72 \pm 0.03	38.06 \pm 0.00	6.99 \pm 0.08	1.74 \pm 0.00	18.45 \pm 0.11	0.77 \pm 0.01	24.06 \pm 0.33
4:1:1(T4)	7.70 \pm 0.01	37.35 \pm 0.00	6.52 \pm 0.07	1.76 \pm 0.00	17.57 \pm 0.17	0.88 \pm 0.01	20.45 \pm 0.49
3:1:1(T5)	7.59 \pm 0.02	36.43 \pm 0.01	6.48 \pm 0.01	1.94 \pm 0.00	13.69 \pm 0.13	0.92 \pm 0.02	16.24 \pm 0.12
Control (2:1)	6.21 \pm 0.01	36.56 \pm 0.00	3.82 \pm 0.04	1.31 \pm 0.00	23.80 \pm 0.15	0.71 \pm 0.01	33.68 \pm 0.21

$\mu\text{S/cm}$ = micro Siemens per centimeter

Triplicate measurement expressed on a dry basis

Mean \pm Uncertainty

Appendix 7: Physicochemical properties of sawdust, spent coffee grounds, Limed fleshing waste mix at day 75

Mixtures	pH	Moisture (%)	Ash (%)	EC ($\mu\text{S}/\text{cm}$)	TOC (%)	N (%)	C/N ratio
1:1:1(T1)	7.61 \pm 0.02	35.07 \pm 0.00	9.34 \pm 0.02	2.05 \pm 0.00	14.96 \pm 0.15	0.91 \pm 0.02	16.39 \pm 0.21
2:2:1(T2)	7.63 \pm 0.02	38.53 \pm 0.01	9.43 \pm 0.01	1.81 \pm 0.00	24.86 \pm 0.16	0.93 \pm 0.02	26.73 \pm 0.44
8:1:1(T3)	7.45 \pm 0.01	37.15 \pm 0.00	7.13 \pm 0.04	1.85 \pm 0.00	17.16 \pm 0.11	0.79 \pm 0.01	21.53 \pm 0.17
4:1:1(T4)	7.44 \pm 0.01	36.69 \pm 0.00	6.85 \pm 0.04	1.81 \pm 0.00	16.52 \pm 0.16	0.88 \pm 0.01	18.70 \pm 0.29
3:1:1(T5)	7.53 \pm 0.02	35.11 \pm 0.00	6.66 \pm 0.01	2.10 \pm 0.00	11.63 \pm 0.13	0.92 \pm 0.02	12.59 \pm 0.07
Control (2:1)	6.15 \pm 0.03	34.69 \pm 0.04	4.07 \pm 0.04	1.26 \pm 0.00	21.42 \pm 0.15	0.63 \pm 0.01	32.46 \pm 0.38

Appendix 8: Physicochemical properties of sawdust, spent coffee grounds, Limed fleshing waste mix at day 90

Mixtures	pH	Moisture (%)	Ash (%)	EC ($\mu\text{S}/\text{cm}$)	TOC (%)	N (%)	C/N ratio
1:1:1(T1)	7.54 \pm 0.04	34.66 \pm 0.01	9.45 \pm 0.03	1.89 \pm 0.00	13.76 \pm 0.13	1.16 \pm 0.02	11.83 \pm 0.16
2:2:1(T2)	7.33 \pm 0.01	35.51 \pm 0.02	9.61 \pm 0.06	1.73 \pm 0.00	23.37 \pm 0.13	0.93 \pm 0.02	25.12 \pm 0.17
8:1:1(T3)	7.38 \pm 0.02	35.54 \pm 0.00	7.55 \pm 0.03	1.78 \pm 0.00	16.41 \pm 0.19	0.81 \pm 0.01	20.26 \pm 0.24
4:1:1(T4)	7.33 \pm 0.02	34.83 \pm 0.01	7.07 \pm 0.01	1.73 \pm 0.00	15.69 \pm 0.18	0.91 \pm 0.01	17.24 \pm 0.18
3:1:1(T5)	7.49 \pm 0.02	34.17 \pm 0.01	6.82 \pm 0.01	1.84 \pm 0.00	10.54 \pm 0.17	0.9 \pm 0.01	11.01 \pm 0.12
Control (2:1)	6.09 \pm 0.02	32.73 \pm 0.06	4.46 \pm 0.05	1.23 \pm 0.00	20.50 \pm 0.21	0.66 \pm 0.01	29.43 \pm 0.18

$\mu\text{S}/\text{cm}$ = micro Siemens per centimeter

Triplicate measurement expressed on a dry basis

Mean \pm Uncertainty

Appendix 9: National Minimum Quality Standards for Compost (Nigerian)

Parameters	National Standard
odor	odorless
Color	variable
Texture	variable
Pathogens	None
Moisture content	15-25%
pH	6.5-7.5
Total organic carbon	At least 20%
C:N ratio	10-15
Nitrogen(N)	1.0-4.0%
Phosphorus(P)	1.5-3.0%
Potassium(K)	1.0-1.5%
Non-biodegradables materials (glass, stones, metals)	free

Source: Hammed (2015)

Appendix 10: Compost Quality Standard in Thailand

Parameters	National Standard
pH	5.5-8.5
Conductivity ($\mu\text{S}/\text{cm}$)	≤ 3.5
N (% , w/w)	≥ 1.0
P (% , w/w)	≥ 0.5
K (% , w/w)	≥ 0.5
C/N	≤ 20
Germination index (%)	≤ 80
Cd (mg/kg)	≤ 5.0
Cr (mg/kg)	≤ 300
Cu(mg/kg)	≤ 500
Pb (mg/kg)	≤ 500

Source: Hammed (2015)

Appendix 11: California Quality Standard for Finished Compost

Parameters	National Standard
Visual	All material is dark brown (black indicates possible burning). Parent material is no longer visible.
Physical	Structure is mixture of fine and medium size particle and humus crumbs. moisture: 30-40%, fine texture (all below 1/8" mesh)
odor	Smells like rich humus from the forest floor; no ammonia or anaerobic odor.
TOM%	20-35%
TN %	1.0-2.0%
C/N	<17:1
pH	6.5-8.5
Nitrate Nitrogen	250-350 mgkg ⁻¹
Nitrite Nitrogen	0 mgkg ⁻¹
Sulfide	0 mgkg ⁻¹
Cation exchange capacity (CEC)	>60 Cmolkg ⁻¹
Humic Acid Content	5-15%

Source: Hammed (2015)

Appendix 12: Quality standards taken from EU and composting council of Canada

Parameters	National Standard
pH	6.5-8.5
EC ($\mu\text{S}/\text{cm}$)	< 5.5
MC (%)	≥ 40
OM (%)	>20
OC (%)	NA
TKN (%)	≥ 0.7
TP (%)	≥ 0.5
K (%)	≥ 0.75
C/N%	< 25

Source: <http://www.compost.org/pdf/Certifica.PDF> and Composting Council of Canada, 2002)

Appendix 13: Pictures taken in Sample treatment preparation and characterization of raw materials, Chemical and physical test analysis of the final compost



(A) Raw Material



(B) Weighing of Material



(C) LFW in washing drum at De liming stage



(D) Adding the Material



(E) Mixing Material



(F) different ratio of mixtures



(G) Mixing materials with water



(H) Sample preparation for pH measurement



(I) Samples on orbital shaker



(J) Filtering the Samples



(K) pH Reading



(L) Weighing Empty Crucible



(M) Measuring sample temperature by thermometer



(N) Weighing of Sample



(O) Samples in the Oven



(P) Cooling the sample by desiccator



(Q) Samples in the muffle furnace



(R) Kjeldahl distillation unit



(S) Digestion flasks



(T) Determination of Total nitrogen Titration



(U) Determination of EC



(V) Matured Compost



(W) Wheat seeds (namely LEMU)



(X) Preparation of Germination Test



(Y) Germination test result 1



(Z) Germination test result 2



(Z1) Germination test