Comparative Study on Major Quality Parameters of Locally Produced Organic Fertilizers

Tilahun Zeleke Demissie

A Thesis Submitted to the Department of Applied Chemistry,

School of Applied Natural Science

Presented in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Applied Chemistry (Industrial Chemistry)

Office of Graduate Studies

Adama Science and Technology University

August, 2024 G.C.

Adama, Ethiopia

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DECLARATION

I, hereby declare that this Master Thesis entitle "**Comparative study on major quality parameters of locally produced organic fertilizers**" is my original work. That is, it has 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 acknowledged through citation.

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Name of student	Signature	Date

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the thesis entitled "**Comparative study on major quality parameters of locally produced organic fertilizers**" prepared under my guidance by **Tilahun Zeleke Demissie** submitted in partial fulfillment of the requirements for the degree of Master of Science in Applied Chemistry (Industrial Chemistry).

Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Eshetu Bekele (PhD)	________________________	________________
Major Advisor	Signature	Date

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I, the advisor of the thesis "**Comparative study on major quality parameters of locally produced organic fertilizers**" and developed by **Tilahun Zeleke Demissie**; here by certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Eshetu Bekele (PhD)	_________________	___________________
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We, the undersigned, members of the Board of Examiners of the thesis by **Tilahun Zeleke Demissie** have read and evaluated the thesis entitled "**Comparative study on major quality parameters of locally produced organic fertilizers**" and examined the candidate during the open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Applied Chemistry (Specialization in Industrial Chemistry).

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LIST OF ABBREVIATIONS

BD………………………..Bulk density

C: N……………………….Carbon to nitrogen ratio

$C_6 H_{12}O_6$ …………………..Glucose

CO_2 ……………………….Carbon dioxide

EC ………………………..Electrical conductivity

GHG………………………Green house gas

H_2O ………………………Water

H_2S……………………… Hydrogen sulphide

M………………………… Moisture

MSW…………………….. Municipal solid waste compost

BGI ……………………….Barley germination index

CGI……………………….Cabbage germination index

FKC………………………Sugar cane filtercake compost

lbs/cy……………………..Pounds /cubic yard

NH^{+}_4 ……………………..Ammonium

NO^{-}_3……………………..Nitrate

OM……………………….Organic matter

PWC……………………...Poultry waste compost

SME ……………………...Small and micro enterprises

SO^{2-}_4 ……………………..Sulphate

SWM……………………...Solid waste management

TC…………………………Total Carbon

TGI………………………...Tomato germination index

TN…………………………Total Nitrogen

TP ………………………....Total phosphorous

ABSTRACT

Population growth and changing lifestyles have led to a steady increase in the generation of municipal, industrial, and agricultural wastes, posing a significant environmental challenge. Composting offers a promising solution that is both economically and environmentally beneficial. To effectively implement this approach, it is crucial to focus on the quality of the feedstock and the production of high quality compost that meets established standards. This study examined the physicochemical characteristics of three different feedstock materials: municipal solid waste (MSW), sugar cane filtercake (FK), and poultry waste (PW), as well as their corresponding composts. The compost samples were also analyzed for their phytotoxicity. The aim was to compare the properties of these materials and evaluate their compliance with international standards for agricultural applications. In May 2023, composite samples were collected from three composting facilities: the Bishoftu municipal solid waste composting facility, the Metehara sugar factory compost yard, and the Bishoftu poultry waste composting. Representative samples were obtained by taking 10 sub-samples from various locations and depths of the compost/feedstock piles. These sub-samples were then thoroughly mixed to create 6 composite samples for each feedstock and its corresponding compost. The samples were dried, then crushed and sieved through 1.00 mm and 0.4 mm meshes. The physicochemical properties and phytotoxicity of the raw feedstocks and composts were evaluated using appropriate analytical methods. The ANOVA analysis revealed significant variations among the feedstocks. PW exhibited the highest electrical conductivity (7.48 dS/m ±1.18), organic carbon (36.12% ± 1.09), total nitrogen (3.37% ± 0.02), and total phosphorus (2.18% ± 0.27) content. MSW had the highest magnesium content (18.18 meq/100g). The physicochemical analysis and phytototcity test of the composts prepared from municipal solid waste (MSW), sugar cane filtercake (FK), and poultry waste (PW) also showed significant differences. PWC had the lowest pH (5.31 ± 0.15), the highest organic matter (64.43%±0.46) and the highest total nitrogen (3.54% ± 0.01). FKC exhibited the highest: pH (8.12±0.15), electrical conductivity (9.01ds/m ±0.15) and potassium (6.32% ± 0.11). MSWC had the lowest total Phosphorus (0.56 % ± 0.00634) and potassium content (0.62 % ± 0.04). The analysis of heavy metals in the compost showed that PWC had the highest concentrations of copper (103.74mg/kg±1.44) and zinc (783.11 mg/kg±7.92), while FKC showed the highest Mn content (935.47mg/kg± 4.82).MSWC had the highest Fe content (20,977.17mg/kg±143.55)and Ni content (38.10 mg/kg ±0.97). The highest germination index (GI) values of tomato were (85.51% ± 12.93) for PWC, and the highest germination index (GI) values of cabbage were (86.67%±5.20) for MSWC. Comparison with the international standards depicts that moderate to no phytotoxicity, which may support suitable seed germination and plant growth. In conclusion, the analysis of feedstock properties and compost quality provides valuable insights into the distinct compositions. Significant differences between compost samples highlight the need for careful selection of feedstock materials, optimizing feedstock blends to enhance compost quality, and application based on soil and plant requirements. Heavy metal concerns require developing robust quality assurance protocols and potential remediation to ensure compost safety and suitability.

Keywords: Feedstock, Compost, Physicochemical characteristics, Germination index, Municipal Solid Waste, Sugar Cane Filtercake, Poultry Waste.

1. INTRODUCTION

1.1. BACKGROUND OF THE STUDY

The increasing human population changes in lifestyles and economic trends has resulted in a progressive rise in waste generation from municipalities, industries and agricultural activities (Lopes et al.,2012). In 2016 the global average for waste generated per person per day was approximately 0.74 kilograms resulting in a total solid waste generation of around 2.01 billion tons. Looking ahead it is projected that by 2030 the annual waste generation worldwide will increase to 2.59 billion tons. Furthermore the estimates suggest that by 2050 waste generation across the globe will reach a staggering 3.40 billion tons (Kaza et al.,2018).

Ethiopia is Africa's second largest population with a population size of about 112 million and a growth rate of 2.6 % in 2019 and one of the fastest growing economies in the world. The rapid population and economic growth present a number of waste management challenges due to corresponding increases in waste generation as well as its accessibility. In the past years waste generation has increased from 9.7 tons/day in 2015 to 12.2 tons/day in 2020. It is estimated that the daily amount of waste will double from 2015 to 2030 (Sector brief Ethiopia.2023).The waste generation rate of big cities such as Addis Ababa are estimated to be 0.45 kg/capita/day and mainly generated from household (70%), street sweeping (10%), commercial (9%), industrial (5%) and others (5%). The average composition of Municipal solid waste generated are organic (65%) and recyclables including plastic and paper accounts (12%) (Sector brief Ethiopia.2023).Additionally Ethiopian sugar factories such as Wonji, Metehara and Finchaa produced approximately 107,587.7 tons of filter cake in the 2019/20 production year accounting for 4% of the total cane crushed (Annual plant and process conference, Ethiopian Sugar Corporation, July 2020).

Generally the management of biodegradable waste has been a major gap within the Ethiopian cities solid waste management (SWM) system causing serious issues to human health and the environment. The disposal of organic wastes in landfills or uncontrolled dump sites presents various challenges including leachate production, greenhouse gas emissions, offensive odors, and soil and water contamination (Mazhindu et al.,2012; Hettiarachchi et al.,2018).

Similarly excess filter cake (FK) in certain factories is disposed of in designated sites, while a portion is reintroduced to nearby fields as a soil conditioner or low-concentration fertilizer.
Most municipal systems collect solid wastes in a mixed form as source separated collection of waste is limited by infrastructure, personnel and public awareness. However, beneficial use of waste depends on efficient systems of waste segregation and collection, as well as marketing of the final product, which is identified as the major gaps/challenges in the value chain of SWM in most Ethiopian City. For instance, in order to effectively implement composting strong emphasis must be placed on segregation of wastes at source and creating market for the final product (compost). Hence research output which give more emphasis for waste sorting/segregation at source, compost quality and creating market for the final product is timely and paramount important to address the bottle neck of the sustainable SWM in the cities.

Composting is a natural process that involves the biological degradation of organic compounds under aerobic conditions. It is characterized by complex metabolic reactions performed by various microorganisms in the presence of nitrogen and carbon. Through composting a stable product known as compost is obtained. Microorganisms play a crucial role in converting complex organic compounds into simpler humic substances. The composting process consists of two phases in the first phase microorganisms break down the organic matter while in the second phase the organic matter transforms into a stable humic substance (Parveen et al.,2022). Studies have demonstrated the usefulness of stable humic substances derived from compost as organic fertilizers (Sisouvanh et al.,2021).

Creating nutrient-enriched organic fertilizers from organic waste materials not only reduces environmental pollution but also lowers the input cost of crop production (Shah et al.,2014).
However determining the physical and chemical properties of compost at the end of the processing period critically important to ensure high-quality compost (El-Sayed,2015).

Quality assessment of compost involves evaluating stability and maturity as well as considering the availability of nutrients for plant growth and the time required to produce mature and stable compost (Rashwan et al.,2021; Parveen et al.,2022).

Stability refers to the conversion of initially unstable complex organic matter into a simpler and stable composition. Maturity is associated with the absence of phytotoxicity as applying immature compost negatively impact soil and plant growth (Parveen et al.,2022).

The quality of compost produced by small and micro enterprises (SMEs) across various cities in Ethiopia is largely unassessed creating significant barriers to marketing their products and hindering the sustainability of these businesses. Despite the involvement of many SMEs in composting organic waste challenges such as a lack of knowledge and information about compost quality persist. Furthermore little is known about the effectiveness of utilizing compost derived from diverse local organic wastes as a fertilizer as well as the applicable production technologies for different feedstock types. To tackle these challenges it is crucial to conduct research on compost quality in Ethiopia that examines a range of feedstocks.

Therefore the aim of this research was to evaluate the quality of composts produced by different SMEs from three distinct sources MSW, FK and poultry waste (PW). By examining these diverse waste streams it provides insights into the feasibility and quality of composting each type enhancing understanding of local organic waste utilization. By comparing the physicochemical properties and maturity of composts derived from the different waste sources this research would offer valuable insights into the quality and suitability of the composts for agricultural use. The findings could contribute to effective waste management strategies, enhance the utilization of organic waste materials and promote sustainable practices and marketing of compost in the study region.

1.2. STATEMENT OF THE PROBLEM

The management of biodegradable waste, which constitutes 65% of the total municipal solid waste generated, has been a major gap within the Ethiopian cities SWM system causing serious issues to human health and the environment. On the other hand, sorting and selling the recyclables are the well-established business in the sector derived from the high demand of the recyclables by the recycling industry. In order to address the pressing issues of organic waste management which has a highly heterogeneous composition and high moisture content;

composting is found to be a preferred treatment method compared to landfills, incineration and recycling particularly in contexts like Ethiopia. While landfills have traditionally been used as a primary solution they involve significant financial burdens and environmental drawbacks such as greenhouse gas emissions and soil contamination. Recycling although beneficial faces challenges in Ethiopia due to inadequate infrastructure and limited financial incentives for private sector involvement. The existing recycling sector is underdeveloped focusing mainly on plastic and paper, which highlights the need for a more comprehensive approach. Moreover, large number of youth group and unions which contains mainly women is organized and certified in different cities of Ethiopia to be involved in composting organic waste provided that the limitations in the sector such as lack of knowledge, information on the quality of compost, and market for compost is addressed to sustain the initiatives. Besides little is known about the quality of compost derived from locally available diverse organic wastes in order to gain insights into the feasibility and efficacy of utilizing compost as an organic fertilizer and the compost production technologies applicable to the diverse range of feedstock types. Therefore it was crucial to conduct research on the composting practice in Ethiopia that utilize feedstocks from different sources and determine and compare the quality and nutrient status of organic fertilizers produced from commonly used sources including municipal solid waste, sugar cane filter cake and poultry waste.

1.3. OBJECTIVE OF THE STUDY

1.3.1. GENERAL OBJECTIVE

The general objective of this research is to investigate and compare the major quality parameters of locally produced compost/organic fertilizers derived from municipal solid waste, sugarcane filter cake and poultry farm waste.

1.3.2. SPECIFIC OBJECTIVES

- To examine the physicochemical properties of both the raw waste and composts.
- To determine potential contaminants, such as heavy metals present in the compost.
- To evaluate the phytotoxicity of the composts.

- To compare the compost quality derived from the three different organic waste sources and their compliance with international standards for agricultural applications.

1.4. SIGNIFICANCE OF THE STUDY

- The study provides valuable information about the quality of major nutrients and potential contaminants including heavy metals within three locally produced organic fertilizers derived from different sources: municipal solid waste, sugarcane filter cake and poultry waste. This information is crucial for SMEs, other compost producers and farmers in making informed decisions about the type of feedstock's used for improved composting practice, the quality of the compost/organic fertilizer produced, marketing of the compost and its usage.

- The findings of the study contribute to improving agricultural practices by identifying the nutrient content and potential contaminants in the organic fertilizers. This knowledge can help optimize fertilizer application, ensuring that crops receive adequate nutrition while minimizing potential risks associated with contaminants.

- The research addresses the need for sustainable waste management by utilizing organic waste materials such as municipal solid waste, sugarcane filter cake and poultry farm waste products. By converting these waste materials into organic fertilizers the study promotes the recycling and repurposing of organic waste, reducing environmental pollution and enhancing resource efficiency.

- The study supports the development of environmentally friendly agricultural practices by highlighting the potential of locally produced organic fertilizers.

- The information generated from the study can serve as a foundation for future research and innovation in the field of organic waste management and organic fertilizer production.

- Overall the study's findings have practical implications for agro industries, farmers and environmental policymakers offering valuable information on the nutrient content and potential contaminants in locally produced organic fertilizers derived from different waste sources.

2. LITERATURE REVIEW

2.1. SOLID WASTE MANAGEMENT

Solid waste management (SWM) has become a pressing issue in our contemporary world (Samal et al.,2019). It is crucial for the overall well-being and economic stability of society and it is often given high priority in city budgets. In fact in low-income countries an average of 19 percent of municipal budgets is allocated to solid waste management expenditures (Kaza et al.,2018).

To establish effective waste management practices, the construction and utilization of landfills are commonly employed as the initial step towards sustainability. Surprisingly only a mere 3 percent of waste is deposited in landfills in low-income countries. In contrast high-income countries demonstrate higher rates of recycling 29 percent and composting 6 percent (Kaza et al.,2018).

Additionally incineration is a more prevalent method of waste disposal. The management of waste using landfill however has significant financial implications. To cater to a population of 1 million people a municipality may have to invest approximately US$10 million for construction. On the other hand the cost of establishing a composting facility can vary ranging from a few million dollars for basic windrow composting facilities to about US$10 million for more advanced and mechanized setups. Finally for incinerators that incorporate heat and energy recovery incurred capital costs of around $600 per annual tone (Kaza et al.,2018). Table 1 summarizes the typical expenses related to waste management organized by major categories.

Table 1. Typical Waste Management Costs by Disposal Type (US $/ ton)

	Low income countries	**Lower middle income countries**	**Upper middle income countries**	**High income countries**
Collection and transfer	20 -50	30 -75	50 -100	90 -200
Controlled landfill to sanitary landfill	10 -20	15 -40	20 -65	40 -100
Open dumping	2 - 8	3 -10	_	_
Recycling	0 -25	5 -30	5 -50	30 -80
Composting	5 -30	10 -40	20 -75	35 - 90

Source: adopted from Kaza et al.,(2018)

In Ethiopia due to budgetary and infrastructure limitations local authorities face challenges in effectively handling the growing waste problem (Sector brief Ethiopia.2023).To address this issue in Addis Ababa the Reppie waste incineration plant was constructed in 2018 near the existing dump site. Its purpose is to minimize landfill waste by incinerating approximately 1.4 tons of municipal solid waste per day. The plant is designed to generate 20 MW of electrical power, meeting 30 percent of the city's electricity needs (Sector brief Ethiopia.2023).

Despite these efforts the recycling sector in Ethiopia remains largely under developed primarily due to inadequate domestic recycling infrastructure. Currently there are only a few formal recyclers specializing in plastic and paper recycling. However, there are numerous informal waste collectors who gather recyclable materials like plastic bottles, cardboard and metal scraps from the streets. Additionally there are local initiatives and social enterprises engaged in waste processing through recycling and two composting facilities are known to be operating in Addis Ababa. The country aspires to reduce, reuse and recycle waste but achieving this goal necessitates expertise and equipment throughout various stages of waste disposal including collection, sorting, treatment and disposal as well as reducing the reliance on landfills and establishing recycling infrastructure. To date private sector initiatives in

Ethiopia have been limited due to the lack of financial incentives. However there is potential for processed organic waste to be marketed as fertilizer and animal feed (Sector brief Ethiopia.2023).

The significance of economically viable biological techniques in solid waste management cannot be understated. It is important to highlight that implementing these approaches not only enables effective waste management but also plays a crucial role in maintaining ecological balance, which is of utmost importance in the present era (Mahapatra et al.,2022).

Composting is an essential solution to addressing waste management issues in a country by upholding the concepts of waste reduction, reuse and recycling. Consequently a thorough investigation of composting as a waste management approach is highly significant (Kaza et al., 2018).

Although small and micro-enterprises in Ethiopia are actively involved in composting they encounter a significant challenge concerning the quality of the compost they generate. The absence of awareness about the product's quality adversely affects composting businesses. Hence it is vital to emphasize assessment of compost quality as a priority, which will facilitate the production of consistent and marketable compost.

2.2. PRINCIPLES OF COMPOSTING

Composting is a critical component of an integrated solid waste management strategy, which includes approaches like waste reduction, reuse, recycling and proper waste management for environmental and human health safety. Composting involves the decomposition and partial transformation of organic matter into valuable assets by microorganisms in optimal conditions. Through this process these materials undergo a beneficial transformation producing a valuable resource for use as fertilizer in agriculture improving soil suitability. By facilitating the decomposition of organic matter composting not only reduces waste volume but also creates a sustainable and eco-friendly alternative to chemical fertilizers contributing to a circular economy. Overall composting is a practical and environmentally friendly waste management solution (Mandpe et al.,2020; Mehta et al., 2018; Misra et al.,2003).

Composting is now widely recognized as a recycling technique that can be applied to a wide range of organic materials including MSW, industrial waste and agricultural waste (Lopes et al.,2012).

The composting process relies heavily on various microorganisms including fungi, bacteria, actinomycetes and yeasts, which have a vital function. They break down the organic matter resulting in the production of carbon dioxide (CO_2), water (H_2O), heat and minerals that are beneficial for plants such as nitrogen, phosphorus and potassium (Das et al.,2011). The end product of composting is a stabilized substance that serves as a valuable amendment for agricultural soils or an organic fertilizer (Figure 1).

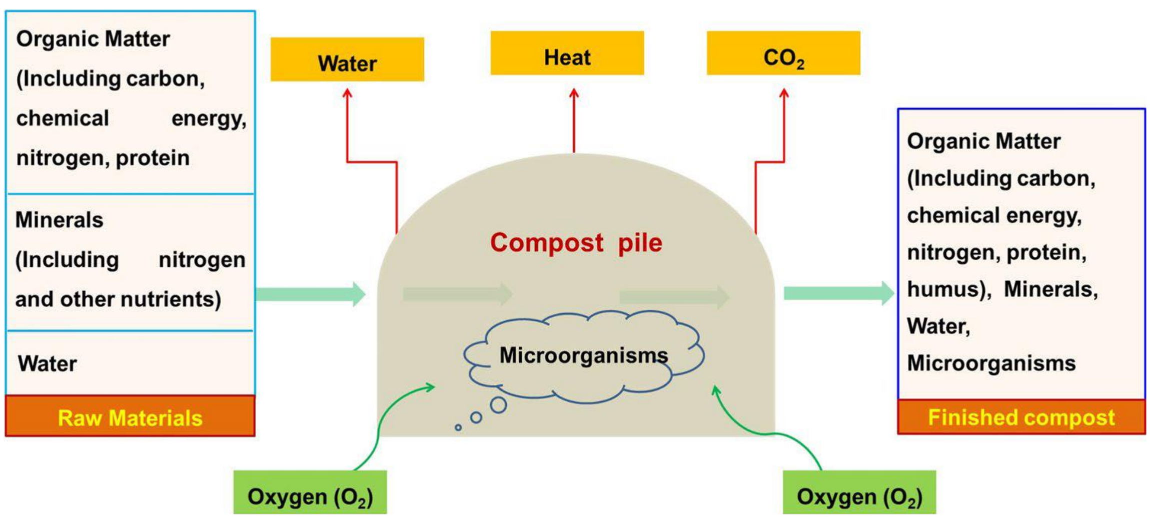

Figure 1. Composting process, indicating main input and output flows as presented by Mozhiarasi et al.,(2022)

Composting offers a valuable solution for enhancing the physical and chemical characteristics of soil. It is important to highlight that compost improves soil structure, leading to improved aeration, drainage and reduced erosion. Moreover it plays a crucial role in mitigating soil dehydration during droughts by increasing water retention capacity. Compost also acts as a binding agent for soil particles and enriches depleted soils with vital nutrients thereby contributing to the overall enhancement of soil physicochemical properties (Hernandez et al., 2014; Meena et al.,2021).

2.3. COMPOSTING PHASES

The process of composting can be divided into distinct phases. The first phase is characterized by the activity of microorganisms which aid in breaking down biodegradable materials and forming a stable organic residue. Following this is the maturation phase where the organic matter undergoes reorganization and transforms into stable molecules through a process known as humification (Lalremruati et al.,2023).

During the decomposition of carbon (C), nitrogen (N) and initial organic matter in composting, microorganisms produce heat, which can be monitored by observing temperature changes. These temperature patterns allow us to identify three distinct phases within the composting process along with a variable duration maturation phase (Roman et al.,2015).

2.3.1. HOT PHASE (MESOPHILIC PHASE)

The process of composting starts at ambient temperature but rapidly undergoes a temperature increase to approximately 45°C within a short period ranging from a few days to even just a few hours. This temperature rise occurs due to the metabolic activity of various microorganisms found in the organic material, which utilize N and C for their own growth. As soluble compounds like sugars break down organic acids are produced leading to a decrease in pH to around 4.0 or 4.5. This heightened temperature stage referred to as the hot phase usually persists for duration of two to eight days (Meena et al.,2021).

During the initial stage of composting known as the mesophilic phase or decomposition phase the bacterial population within the organic material combines carbon with oxygen to produce energy and carbon dioxide. Some of this energy is used by the microorganisms for their own growth and reproduction while the excess energy is released as heat. This phase involves the breakdown of readily biodegradable organic matter and the proliferation of mesophilic bacteria resulting in a rise in temperature within the composting material. Among these mesophilic bacteria certain strains like E. coli may be present although their growth is hindered as the process progresses into the thermophilic phase which is characterized by the dominance of thermophilic bacteria (Mandpe et al.,2020).

2.3.2. CURING PHASE (THERMOPHILIC AND HYGINIZATION PHASE)

The thermophilic phase, also known as the stabilization phase, is marked by the decomposition of slowly biodegradable substances and the intricate process of humification which involves the transformation of lignocellulosic compounds (Mandpe et al.,2020).

Once the temperature of the organic material surpasses 45°C the mesophilic microorganisms are replaced by thermophilic microorganisms primarily thermophilic bacteria. These thermophilic microorganisms are adapted to thrive in higher temperatures and play a vital role in breaking down complex organic substances like cellulose and lignin. Their metabolic activity also causes the pH to increase as nitrogen is converted into ammonia. As the compost pile's temperature exceeds 60°C bacteria capable of producing spores and action bacteria become prominent contributing to the degradation of compounds such as waxes and hemicelluloses.

The heightened temperature during this phase serves two important purposes. Firstly it aids in the elimination of contaminants and bacteria originating from fecal matter including Escherichia coli, Salmonella species, helminth cysts, phytopathogenic fungal spores and weed seeds. This phase is commonly known as the hygienization phase. Secondly the elevated temperature above 55°C effectively eliminates spores of phytopathogenic fungi, helminth cysts, weed seeds and other harmful bacteria present in the initial materials resulting in a sanitized end product (Roman et al.,2015; Meena et al.,2021).

2.3.3. COOLING OR MESOPHILIC PHASE II

The composting process progresses through various stages. Once the composting material exhausts its carbon and nitrogen sources the temperature gradually declines to approximately 40-45°C. Throughout this period the decomposition of polymers like cellulose persists and certain fungi become noticeable to the naked eye. When the temperature falls below 40°C the mesophilic organisms temporarily displaced during the thermophilic phase regain their activity. As a result the composting medium experiences a slight decrease in pH although it generally remains slightly alkaline. During this phase certain fungi flourish and generate visible structures. This cooling phase endures for several weeks and can sometimes be confused with the maturation phase (Roman et al.,2015). Observations have indicated that in the cooling phase the accessible manure seems to undergo digestion while the tougher materials remain relatively unaltered. This phase is distinguished by the resurgence of mesophilic microbes that were displaced during the preceding thermophilic phase. These mesophilic organisms assume control of the composting system and commence the breakdown of the more resistant organic constituents of the substrate (Mandpe et al.,2020).

2.3.4. MATURATION PHASE

In the maturation phase of composting the temperature of the compost pile gradually reduces to the ambient temperature range of 20-30ºC. This phase is marked by the condensation of carbonaceous compounds and polymerization which play a role in the creation of fulvic and humic acids (Roman et al.,2015; Meena et al.,2021). Figure 2 illustrates that temperature fluctuations during the composting process occur primarily in three phases mesophilic, thermophilic and cooling.

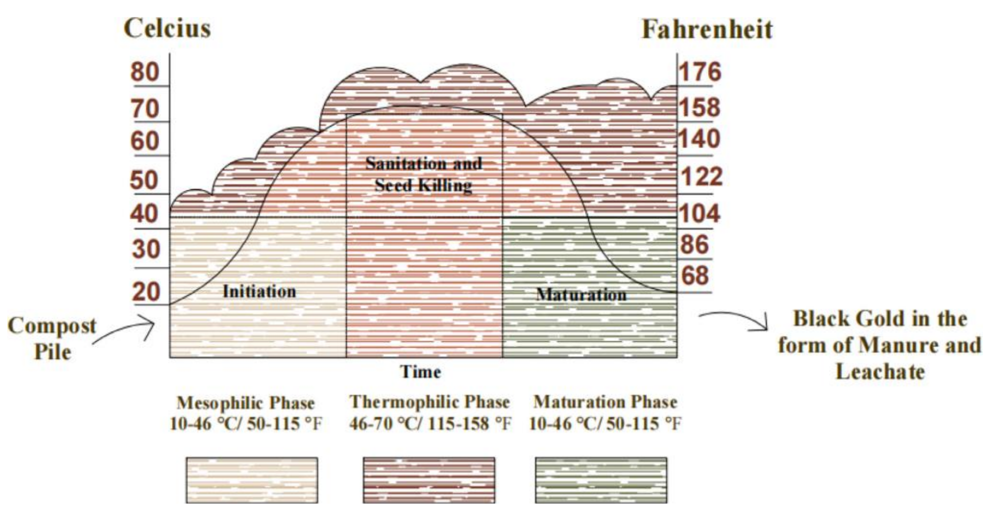

Figure 2. Temperature fluctuations during different phases of composting (Mahapatra et al .,2022)

2.4. TYPES OF COMPOSTING

Based on the microorganisms involved in breaking down organic waste, composting can be categorized into two primary types aerobic and anaerobic (Meena et al.,2021).

2.4.1. AEROBIC COMPOSTING

Aerobic composting is a process that occurs in the presence of abundant oxygen. During aerobic composting organic matter is broken down by aerobic microorganisms resulting in the production of carbon dioxide (CO_2), ammonia, water, heat, and humus. The resulting compost contains organic matter that is relatively stable and poses minimal risk of phytotoxicity. The heat generated in this process speeds up the breakdown of proteins, fats, cellulose and hemi-cellulose leading to a shorter processing time. Moreover the high temperatures achieved during aerobic composting can eliminate various microorganisms including those that are harmful to humans or plants as well as weed seeds. These favorable environmental conditions for aerobic composting also support the growth and proliferation of diverse bacterial species (Misra et al.,2003; Meena et al.,2021).

2.4.2. ANAEROBIC COMPOSTING

Anaerobic composting which occurs in the absence of oxygen is a naturally observed process. In anaerobic decomposition organic compounds are broken down by anaerobic microorganisms. Similar to aerobic microorganisms these anaerobic counterparts utilize nutrients like nitrogen and phosphorus for their growth. However, there are notable differences in how organic and inorganic compounds decompose within the compost pile. For instance organic nitrogen undergoes breakdown into organic acids and ammonia while a significant portion of carbon is released as methane gas (CH_4) with a smaller fraction being respired as CO_2 (Mehta et al.,2018).

2.5. METHODS OF COMPOSTING

Over time several composting methods have been developed. The choice of the most appropriate composting method depends on several factors including the production scale, quality of the input materials, geographical and climatic conditions and the preferences of the compost producer such as labor requirements (Van der Wurff et al.,2016)**.**

Various fundamental techniques are utilized in the composting process including passive stack composting, transitional stack composting, ventilated static stack composting and composting in closed reactors (Yusuf et al.,2017).

2.5.1. WINDROW COMPOSTING

Windrow composting is a method that involves arranging waste materials in elongated narrow piles known as windrows which undergo periodic turning for decomposition and aeration purposes. Turning these piles results in a decrease in their internal temperature while facilitating air circulation throughout the system. This controlled disturbance promotes efficient mixing of composting materials and boosts passive oxygenation ultimately contributing to faster degradation and the production of high quality finished compost (Mandpe et al.,2020; Misra et al.,2003).

Operators can control composting outcomes like pathogen removal, faster decay and fertile soil additives by adjusting the turning frequency and intensity of piles. Windrows for composting can be 0.9m-3.6m high and 3m-6m wide, built with equipment determining their size and shape. Aeration occurs through natural air movement, convection and diffusion. Porosity affects effective windrow size. Turning frequency depends on decomposition rate, moisture, porosity and desired composting time. Initial height decreases significantly within two weeks lasting three to nine weeks based on materials and turning frequency (Misra et al., 2003).

2.5.2. AERATED STATIC PILE COMPOSTING

Aerated Static Pile composting is a method that decomposes organic waste substrates without physical activity over a period of 30-35 days. This approach involves the use of perforated pipes for providing aeration to the waste piles which can be open, covered, semi-covered or in windrow form. The method takes the piped aeration system a step further by employing a blower to supply air directly to the composting materials enabling larger piles without the need for turning or agitation. Proper formation of the pile along with sufficient and uniform air supply results in the completion of the active composting phase within three to five weeks (Mandpe et al.,2020; Misra et al.,2003).

The aerated static pile composting method involves layering raw materials atop a bed of highly porous material like wood chips with an embedded perforated aeration pipe linked to a blower for air circulation. Pile height typically ranges from 150 to 245 cm influenced by material porosity, climate and construction equipment capabilities. Capping the pile with 15 cm of mature compost or bulking agent helps retain moisture, maintain temperature, deter insects and filter out ammonia and odors (Misra et al.,2003).

2.5.3. INVESSEL COMPOSTING

Invessel composting refers to a collection of methods that confine the composting materials within a building, container or vessel utilizing various forced aeration and mechanical turning techniques to expedite the composting process. This technology involves the decomposition of the organic fraction of waste in a closed container or vessel under controlled conditions. The composting process occurs inside a container which can be vertical tanks or horizontal drums and is typically fully enclosed with mechanical control of the required environmental factors. Common invessel systems such as horizontal drums prevalent in Europe rotate the drum to tumble and mix the organic matter during the compost process facilitating the addition of air and water. The invessel technology offers significant potential to reduce the duration needed to convert feedstock into a compost product. This methodology encompasses a variety of designs including those that combine elements of windrow and aerated pile methods to create different combinations of vessels, aeration devices and turning mechanisms (Misra et al., 2003; Manyapu et al.,2017).

2.5.4.VERMICOMPOSTING

Sericulture or the production of earthworms for organic material conversion into rich soil amendment involves the use of earthworms in a process called vermicomposting. In this process earthworms are introduced to organic waste which gradually transforms the waste into vermicompost black colored odorless substance resembling humus. Earthworms possess the ability to consume a wide range of organic matter devouring up to their own body weight in residues daily. Consequently their excretions known as castings are abundant in nitrate as well as essential nutrients like phosphorus, potassium, calcium and magnesium. Moreover the passage of soil through earthworms facilitates the growth of bacteria and actinomycetes with the latter being six times more prevalent in worm casts compared to the original soil (Misra et al.,2003; Ganti,2018; Samal et al.,2018).

2.6. FACTORS AFFECTING COMPOSTING

Since composting is a biological process it is crucial to understand and manage parameters that affect microbial activity. These parameters include oxygen levels or aeration, substrate moisture, temperature, pH and the carbon to nitrogen (C: N) ratio. It is worth noting that the composting process is influenced by external factors such as environmental conditions, composting method, raw materials and other variables which may introduce variations in these parameters. Nonetheless it is essential to continuously monitor and maintain these parameters within their optimal ranges (Roman et al.,2015).

OXYGEN

Composting is a process that relies on sufficient ventilation to support the respiration of microorganisms which release carbon dioxide (CO_2) into the atmosphere. When there is excessive aeration it leads to a drop in temperature and significant loss of moisture through evaporation. This can cause the decomposition process to halt due to water deficiency. The dehydration of microorganism cells occurs and some may produce spores while the activity of enzymes responsible for breaking down different compounds ceases. Maintaining appropriate aeration during composting is crucial allows for the respiration of microorganisms while avoiding both excessive moisture loss and excessive moisture accumulation ensuring the effectiveness of the composting process (Roman et al.,2015).

MOISTURE

The microbial activity and moisture level in composting material are closely related to each other as the water present in the raw material is used by the microorganisms for transportation of nutrient and energy through their cell membranes. The moisture level in the composting material varies based on the size of particles physical condition of the material and the composting system. The ideal level of moisture in the compost material should be around 55% (Meena et al.,2021).

TEMPERATURE

Composting begins at ambient temperature that can rise up to 65 °C with no need of human intervention (external heating). While during maturation phase the compost pile attains the ambient temperature. The high temperature and longer time period possess high rate of decomposition and hygeinization thus the temperature of the pile should not drop at faster rate (Meena et al.,2021).

pH

The composting pH depends on the source materials and varies in each phase of the process (from 4.5 to 8.5). During the early phases of composting the pH of compost pile acidified due to release of various organic acids by the microorganisms. In the thermophilic phase due to the conversion of ammonium into ammonia the pH raises the medium is become alkaline and finally stabilize at values close to neutral. The pH is a determinant factor for microorganisms' survival and the various groups of microorganisms have their optimal pH range for growth and multiplication. Most bacterial activity occurs at pH 6.0-7.5 while most fungal activity occurs at pH 5.5 to 8.0. The ideal range is from 5.8 to 7.2 (Meena et al.,2021).

CARBON: NITROGEN (C: N) RATIO

Microorganisms rely on specific macronutrients, such as C, N, P and K for their growth and metabolism. Among these carbon and nitrogen play a pivotal role in the composting process and serve as primary indicators of nutrient content. The relative proportions of carbon and nitrogen have a significant impact on composting as they influence microbial activity and decomposition rates. When the carbon to nitrogen ratio is appropriately balanced it generally indicates the presence of other essential nutrients in acceptable quantities. It is worth noting that the C: N ratio varies depending on the source material used for composting. Throughout the composting process this ratio undergoes a continuous reduction from an initial value of approximately 35:1 to around 15:1 (National Engineering Hand book,2010; Meena et al, 2021).

PARTICLE SIZE

Microbial activity is related to particle size that is easy access to the substrate. A very small size of composting particles increases the specific surface area which facilitates greater access the substrate. The ideal size of the parent materials for composting is 5 to 20 cm. the density of composting material is closely related to particle size and ultimately affects the aeration and moisture retention of the compost pile (Meena et al,2021). Table 2 presents the compost parameters that influence the composting process across its various phases.

Table 2 . Factors affecting Composting process with their respective optimum values

Parameter	**Ideal range at the beginning**	**Ideal range of thermophilic phase II**	**Ideal range of mature compost**
Oxygen	10%	10%	10%
Moisture	50% - 60%	45%-55%	30% - 40%
Temperature	45 – 60°C	45°CAmbient temp.	Ambient temperature
pH	6.5 – 8.0	6.0-8.5	6.5 – 8.5
C: N ratio	25:1 – 35:1	15/20	10:1 – 15:1
Particle Size	<25 cm	15 cm	<1.6 cm

Source: Roman et al., (2015)

COMPOSTING FEEDSTOCKS

Composting transforms various organic materials such as crop residues, animal wastes, food scraps, specific municipal wastes and appropriate industrial wastes in to humified materials. However it is important to note that different feedstock contribute varying amounts of carbon (energy) and nutrients to the compost (Van der Wurff et al.,2016).

Hence assessing compost quality requires analyzing various organic inputs and associated parameters throughout different composting techniques. Crucial factors for examination include nutrients, pH and moisture content. Comprehensive study into these variables and diverse composting recipes will enhance understanding of input materials' influence on output quality aid optimization, and guide best practices. Knowledge of this relationship contributes to effective waste management and enhanced soil productivity (National Engineering Hand book,2010).

MUNISIPAL SOLID WASTE (MSW)

MSW is among the most widely used feedstock materials for composting and collected from different sources such as homes, businesses, and institutions. The diverse materials in MSW have varying chemical properties that influence the appropriate treatment methods. Both the physical and chemical characteristics of MSW are important considerations in determining the optimal treatment approach (Millati et al.,2019).

The successful preparation of MSW composts relies on several factors including the characteristics of the organic materials the ratio of nitrogenous compounds to carbohydrates, the decomposition temperature and the microbial population engaged in the process. The quality of compost derived from various types of organic waste varies due to differences in their organic composition. To effectively manage waste and optimize the use of compost in agriculture it is crucial to identify the specific organic waste types that yield compost with higher nutrient contents for plants and superior overall quality (Seema.,2007; Parveen et al., 2022). The chemical composition of MSW varies depending on the type of waste generated. Table 3 presents the chemical compositions of MSW from different countries.

Table 3. Average chemical compositions of municipal solid waste in different countries

Country	PH	EC ds /m	C %	N %	P %	K %	C/N
Ethiopia	5.80-7.39	2.23-4.10	6.34-44.5	1.08 - 1.70	0.10-0.22	0.92	5 - 29
Pakistan	6.40	_	33.0	0.81	_	_	40
Brazil	_	_	42.0	1.10	_	_	38
China	_	_	29.4	1.60	_	_	18
India	7.12	_	29.2	0.85	0.35	0.53	35
Tanzania	9.3	15.7	23.1	1.39	0.26	3	17

Source: Mamo et al.,(2021); Tesfahun et al.,(2022) ; Seema.,(2007) ; Millati et al .,(2019); Vyas.(2011); Mengistu et al.,(2018); Vuai.(2010)

FILTER CAKE

Filter cake/press mud from sugar factory is another composting feedstock which is rich in organic matter and essential nutrients namely potassium and phosphorus. It offers great potential for utilization in crop production as it is not only supplies crucial nutrients but also improves the physical, chemical and biological characteristics of the soil. Similar to other organic waste press mud cake holds significant promise as a valuable asset for enhancing soil fertility and promoting higher agricultural yields (Kalaivanan et al.,2016).

Filter cake is a valuable by product of sugarcane processing that is used as a fertilizer in several countries including Brazil, India, Australia, Cuba, Pakistan, Taiwan, South Africa and Argentina. This residue is produced in large volumes around 30-40 kg per ton of crushed sugarcane. It contains a significant amount of organic matter and mineral elements essential for plant nutrition making it well suited for agricultural applications. Of the mineral constituents in filter cake phosphorus is particularly noteworthy as a fertilizer. As such the use of filter cake as a phosphorus source has been extensively studied (Renato et al.,2013).

The application of filter cake to soils has several beneficial effects on chemical properties. It increases the concentrations of nitrogen, phosphorus and calcium as well as the cation exchange capacity (CEC) of the soil. Additionally filter cake reduces the concentration of exchangeable aluminum (Al^{3+}) which can be toxic to plants. Overall, the abundant availability and nutrient rich composition of filter cake make it a valuable resource for improving soil fertility and supporting plant growth in agricultural systems (Renato et al.,2013).

An overview of the composition and chemical characteristics of sugar cane press mud is presented in Table 4.

Table 4.Chemical properties of press mud /filter cake as reported by different authors

Nutrients	**Amount %**	**Source**
PH	6.0 - 8.2	Suma et al.(2018)
EC (dS /m)	2.9 - 3.3	Sarangi et al. (2008) Gupta et al. (2011)
Organic Carbon	15.0 - 36.0	Renato et al. (2013)
Nitrogen	1.0 - 1.9	
Phosphorous	1.02 - 4.0	
Potassium	0.2 - 2.0	
Calcium	1.02 - 12.0	
Magnesium	0.32 - 2.0	
Sodium	0.03 - 0.1	
Sulfur	0.003 - 3.2	
Iron	0.008 - 0.3	
Manganese	0.01 - 0.3	
Zinc	0.12 - 0.4	
Copper	0.003 - 0.053	

POULTRY WASTE

Within the poultry industry poultry litter and manure waste refer to a combination of Poultry manure, spilled feed and bedding materials. This waste is the primary type of waste generated in poultry production. During the 47 day grow out period of poultry a substantial amount of manure is produced with an estimated average of 1 kg of manure per poultry bird. (Ma et al. 2019) The chicken population in Ethiopia has been estimated to reach 59.5 million (The Central Statistical Agency (CSA) reported in 2019).

Poultry manure contains a comprehensive array of 13 essential nutrients that are crucial for plant growth and development. These nutrients include N, P, K, Ca, Mg, S, Mn, Cu,Zn, Cl, B, Fe and Mo. By utilizing poultry manure as a fertilizer for crops or trees it becomes possible to meet a portion or even the entire nutrient requirements of the plants. The specific quantity of nutrients supplied depends on the nutrient composition of the manure as well as the amount of manure applied (Chastain et al.,2014).

Poultry litter is a valuable organic amendment due to its high content of organic matter originating from both the animal manure and the bedding materials used in poultry houses. In addition to organic matter poultry litter can also impact soil pH and the need for liming as the amount of calcium carbonate in the poultry feed can vary (Alabadan et al.,2009).

The primary nutrient components of poultry waste are N, P and K. However it also contains significant amounts of other essential plant nutrients such as Ca, Mg and S as well as various micronutrients. When managing poultry waste on site sampling testing and data collection are invaluable assets. This detailed information allows for more accurate planning and design of the waste management system leading to greater confidence in the system's performance and potential economic benefits for the owner. By conducting thorough on site assessments farmers and waste management professionals can better understand the specific nutrient composition and other characteristics of the poultry litter. This knowledge can then be used to optimize the application rates and timing, ensuring the most efficient and effective use of this nutrient-rich organic resource (Alabadan et al.,2009). Table 5 provides an overview of the chemical properties of chicken manure and litter, as documented by various authors.

Table 5 . Chemical properties of Chicken manure and litter as reported by different authors

Properties	Amount (%)		Source
PH	7.09 - 7.34	_	Hwang et al.(2020)
EC (dS /m)	3.76 - 5.78	_	Ravindran et al.
Organic carbon	30.61 - 41.8	_	(2017)
Nitrogen	2.3- 5.81	1.70 - 3.55	Chastain et al.(2014)
Phosphorous	16.89 - 21.2	1.22 - 1.57	
Potassium (mg/kg)	20.61	13750 - 19000	
Calcium(mg/kg)	41.55 - 1114.8	21000 - 44500	
Magnesium(mg/kg)	8.88 - 403.6	3750 - 4350	
Sodium(mg/kg)	3.73 - 131.4	4250 - 6500	
Sulfur	_	4100 - 7000	
Zinc (mg/kg)	383.8 - 330.1	285 - 340	
Copper (mg/kg)	39.3 - 41.6	110 - 250	

2.7. COMPOST QUALITY

Compost quality refers to the suitability of compost as a soil amendment based on its physical, chemical and biological properties (Roy et al.,2021; Kabasiita et al.,2022). The characteristics of the organic waste materials used as feedstock play a crucial role in the composting process and the ultimate quality of the compost. The most relevant factors that can influence the composting dynamics and end product quality include the chemical, physical and biological properties of the feedstock (Bernal et al.,2017).

From a chemical stand point the nutrient content, C: N ratio and pH of the feedstock materials are of paramount importance. These factors directly impact the microbial activity and the rate of organic matter decomposition during the composting process (Bernal et al.,2017).

The physical properties of the feedstock such as moisture content, porosity and particle size also significantly affect the aeration, moisture balance and overall efficiency of the composting system. Optimal physical conditions are necessary to create an environment that supports the thriving microbial communities responsible for the breakdown of organic matter. Biologically the feedstock should be free from pathogenic microorganisms, viruses, bacteria and fungi that could compromise the safety and quality of the final compost. Additionally the presence of non degradable materials such as glass, plastics, stones and metals should be minimized as their concentration will increase during the composting process ultimately resulting in a low quality compost product.

Overall to ensure high quality compost the characteristics of the feedstock materials should be carefully selected and managed to meet the specific nutritional, physical and biological requirements of the composting microorganisms. This will facilitate efficient organic matter decomposition and the production of stable, nutrient rich and safe compost for agricultural, horticultural and environmental applications (Bernal et al.,2017). Table 6 presents the quality standards for finished compost established by various national and international organizations.

Table 6. Quality Standards for Finished Compost

Indicator	CIWMB	Bord	WHO	Sri Lanka	Source
Moisture	30-40%				Prasad.
pH	6.5-8.5	6.9-8.3	6 - 8	6.5 – 8.5	(2003).Sadeghi, et
EC ds/m		2-6			al. (2015).
C: N	<17:1	≤25		10–25	Dandeniya et al.,
OM%	20-35		10 - 20		(2020).
T N%	1.0-2.0	0.8-1.9	0.4 - 3.5	>1.0	Life., (2008)
P %		0.4-1.1	0.13 – 1.53	>0.22	
K %		0.6-1.7	0.42 - 1.49	>0.83	
Ca %		1.57-5.07		>0.50	
Mg %		0.18-0.78		>0.30	

Where: CIWMB: California Integrated Waste Management Board, WHO: Wealth organization, Bord na Mona: a semi-state company based in Dublin, Ireland and founded in 1946.

Table 7 outlines the heavy metal limits for compost established by various national and international organizations.

Table 7. Heavy metals limits: EU states, U.S.A., Canada and Australia

Metal	EU-Range (mg/kg)	USA biosolids (mg/kg)	CCME (mg/kg)	Source
Arsenic (As)				Brinton. (2000)
Cadmium (Cd)	0.7-10	39	3–20	Canadian Council
Chromium (Cr)	70-200	1,200	210	of Ministers of the
Copper (Cu)	70-600	1,500	400	Environment
Mercury(Hg)	0.7-10	17	0.8–5	(2005)
Nickel (Ni)	20-200	420	62–180	Life. (2008).
Lead (Pb)	70-1,000	300	150–500	
Zinc (Zn)	210-4,000	2,800	700–1850	

Where: EU: European Union state, USA: United States of America

2.7.1.PHYSICAL PROPERTIES

Physical characteristics of compost include odor, color, moisture, particle size, density, water-holding capacity and inert materials. During composting organic compounds responsible for odors are degraded and the OM humification process gives a dark color to the mature compost then color and odor give a general idea of the decomposition stage of the material.

Particle size, density and water-holding capacity are related properties and have direct effects on subsequent water availability to plants while odor and inert contaminants are related to the environmental impact of the compost use (Bernal et al.,2017).

MOSTURE CONTENT (MC)

Moisture is very relevant with regard to maintaining the physical structure of compost. In composting, moisture is essential for the microorganism to transport the nutrients within cell walls (Parveen et al.,2022). Optimum MC of the compost is a vital factor for the microbial decomposition of organic waste and in an aerobic composting process it is around 50–60%, which is favored during the composting process (Elcik et al.,2016). However excessive MC leads to a lower rate of oxygen resulting in anaerobic conditions, which decrease OM degradation rate as well as promotes bad odor formation owing to the release of volatile compounds such as carbon and hydrogen sulfide (Manohara et al.,2014).

BULK DENSITY

Bulk density depends on both porosity and moisture content. Composts with a high or low bulk density might be more difficult to spread. They have lower porosity and or a higher percentage of water filled pore space. Composts with low bulk density can suffer from excessive pore space and low water retention important for compost use in growing media. The wet bulk density is highly dependent upon the moisture content, in contrast to the dry bulk density (Amery et al.,2020).

PARTICLE SIZE

Particle size can be judged visually but compost can also be sieved to determine different fractions (Amery et al.,2020).

COLOR

Compost color should vary between middle and dark brown. Darkness also depends on moisture content. Black compost often indicates too high temperatures during composting, leading to combustion. However, home-made compost involving worms and other bigger organisms can also be black (Amery et al.,2020).

ODOR

Mature compost should smells like a forest soil. Ammonia smell in an ongoing process indicates excessive N losses due to volatilization as a result of a feedstock mixture with a too low C: N ratio and or a too low moisture status. H_2S smell (rotten eggs) indicates anaerobic circumstances which are to be prevented for composting (Amery et al.,2020).

2.7.2. CHEMICAL PROPERTIES

Chemical criteria of compost quality include concentrations of macro and micronutrients and soluble salts, pH, the presence of degradable compounds, OM humification and the presence of organic and inorganic pollutants. The concentrations of macro and micronutrients and soluble salts affect the plant production and nutrition the pH influences the availability of nutrients to plants and the OM humification impacts plant growth and also soil fertility. The presence of nutrients in the compost is particularly relevant for compost intended to be used as an organic fertilizer (Bernal et al.,2017).

ORGANIC MATTER OR CARBON CONTENT

Low organic matter values in compost can result from mineral soil being mixed into the compost, either from feedstocks or by turning on bare ground. The use of purely organic waste streams results in a high level of organic matter in the stabilized compost product. On the other hand, a high level of organic matter can be an indicator of an unfinished composting process or unstable compost. This organic matter will be partly respired via microbial decomposition after application (Amery et al.,2020).

MAJOR AND SECONDARY NUTRIENTS

Major and secondary nutrient content of compost is important to estimate the fertilizer value and to know how much of the compost is preferably or can be applied (Amery et al.,2020).

Mineral nutrients such as K, Ca, and Mg are mainly present in plant available forms in compost. In biowaste compost P in soluble forms can account for 35% of total P equivalent to about 20% of organic P forms. Apparent P recovery in manure compost can be as high as 48% and P availability can be predicted adequately from water extractable and total P. With such information P and K from composts can be fully incorporated into the calculation of the fertilizer rate required for a given crop (Bernal et al.,2017).

NITROGEN

Nitrogen in compost is present in organic and inorganic forms (NH_4^+–N and NO_3^-–N) with the latter being readily available to plants. However the mineralizable organic N content of composts should be taken into account when calculating the compost application rate required to achieve the appropriate fertilization. However poorly transformed or immature compost can lead to N immobilization in the soil due to the existence of readily degradable organic C.

To optimize the fertilizer N replacement value of compost the material should have spent long enough in the maturation phase to achieve a good degree of maturation (Bernal et al.,2017). Mineral N (NO_3^--N and NH_4^+-N) is the N directly available for the plant (in contrast to the total N content). In well matured compost there is little or no NH_4^+-N (< 0.4 g/kg) a predominance of NO_3^--N and thus a NO_3^--N/NH_4^+-N ratio > 1) (Amery et al.,2020).

C: N RATIO

Enhancing the organic matter content of soil by adding compost will promote the root growth of plants make a clay soil lighter and easier to work make a sandy soil richer and make soil better able to hold water and nutrients. The C:N ratio of stable compost at the end of the process will be between 10:1 and 20:1 with the most stable composts falling in the lower end of this range. Compost with high C:N ratio will reduce N availability to plants due to nitrogen immobilization caused by available microflora. A final C:N above 20:1 may indicate a compost that will not readily release nitrogen while a final C:N ratio above 30:1 may indicate a compost that will inhibit nitrogen mineralization and tie up nitrogen from the soil. This affects compost use for farm land application and additional nitrogen supplementation is necessary for better plant growth (Shilev et al.,2006).

pH

The pH of compost is typically between 6.00 and 9.53, with the lower values for plant based composts and higher values for manure based compost. A too low pH can indicate immature compost (Amery et al.,2020).

ELECTRICAL CONDUCTIVITY (EC)

The electrical conductivity (EC) is used to evaluate the total salt content of the compost. A high salt content (> 1500 μS/cm) can induce salt stress, especially when compost is used in growing media (Amery et al.,2020).

2.8. COMPOST MATURITY

Maturity is the degree or level of the completeness of composting and implies improved qualities resulting from the aging or curing of a product. Compost characteristics such as color and odor give a general idea of the decomposition stage reached but they give little information with regard to the degree of maturation (Bernal et al.,2017).

Compost is considered to be young at the end of the thermophilic phase and mature at the end of the curing phase. It is important to note that compost maturity cannot be expressed in terms of weeks or months. The time needed to reach a specific maturity level will vary greatly depending on the input material and the process management. The effective maturity level can be determined by the NO_3^-N/Nmin ratio. Several parameters give information on the maturity level of the compost. Principally mature compost is stable and biologically less active compared to a young one. This means that the temperature of the compost does not rise anymore after compost turning and also that the respiratory activity is low. The C/N ratio of mature compost is about 15. Young compost contains mainly only NH_4 as mineralized N. Mature compost contains almost only NO_3 as mineralized (Van der Wurff et al.,2016).

2.9. COMPOST STABILITY

Compost stability typically refers to microbial activity and can be defined by the respiration or transformation of various chemical components in compost organic matter. Sometimes also the term compost maturity is used but this refers to the suitability of compost for plant production which is related to compost stability the potential symbiotic microbial activity and the absence due to degradation of phytotoxic substances. Compost stability is a criterion for compost maturity and is assessed as the potential organic matter decomposition (Bernal et al., 2017).

2.10. EVALUATING PHYSICOCHEMICAL CHARACTERISTICS OF VARIOUS COMPOSTS

Thorough examination of the composition and properties of compost considering factors like nutrient content, moisture levels, pH, organic matter percentage and the presence of contaminants offers valuable insights into the suitability and effectiveness of various feedstock composts for diverse agricultural and environmental purposes. This analysis encompasses compost derived from sources such as municipal solid waste, sugarcane press mud and poultry waste enabling a comprehensive understanding of their potential applications and environmental impacts. By delving into the physico-chemical makeup of compost from these sources we can enhance our knowledge of its potential benefits and drawbacks facilitating informed decision-making regarding its utilization and management practices. Table 8 illustrates the chemical composition of the three types of compost derived from various feedstocks as reported by different authors.

Table 8. The chemical makeup of three unique composts originating from various feedstocks

Properties	MSWC	FKC	PWC	Source
PH	9.2	7-8	6.9	Kabasiita et al. (2022)
EC (µS /cm)	4.70	1-1.4	8.33	Sarangi et al .(2008)
Organic carbon (%)	8.5	15.98	7.5	Suma .(2018)
Nitrogen (%)	0.5	1.27	1.04	Suhartini et al.(2020)
Phosphorous (%)	0.3	1.61	1.29	Li et al. (2021)
Potassium (%)	1.3	2.5-4.0	0.95	Delgado et al. (2010)
C:N, ratio	17	13	7	
Calcium (%)	2.0	4.3-5.0	5.10	
Magnesium (%)	0.6	0.32		
Iron (mg/kg)	17,148.5	1202		
Manganese (mg/kg)	0.1	253.2		
Zinc (mg/kg)	478.8	119.4	360.98	
Copper (mg/kg)	60.8	77.4	93.97	
Lead (mg/kg)	15.3		0	
Cadmium (mg/kg	0.13		3.09	
Chromium (mg/kg)	10.5		5.55	

Where: MSWC= Municipal Solid Waste Compost, FKC= Filter cake compost and PWC= Poultry waste compost

The reported values of various composts provide insights into their characteristics and implications for further investigation. Poultry compost exhibits an acidic nature with a pH value of 6.9, while municipal solid waste compost shows alkalinity with a pH of 9.2. In contrast sugar cane press mud compost demonstrates a neutral to slightly alkaline nature falling within a pH range of 7 to 8. When it comes to electrical conductivity (EC) which measures the salt content MSW compost has a high EC value of 4.7 dS/m indicating a higher salt content. On the other hand sugar cane pressmud compost demonstrates a lower salt content with an EC range of 1-1.4 dS/m.

The OC content reflects the organic matter load in composts. MSWC has an OC content of 8.5% indicating moderate organic matter content. In contrast sugar cane pressmud compost shows a higher organic matter content with 15.98% OC making it more abundant in organic material. Poultry compost lags slightly behind with an OC content of 7.5%. When comparing nutrient content MSWC has lower levels of N, P and K compared to FKC and PWC. FKC has relatively higher nutrient contents making it an ideal option for compost. PWC maintains moderate levels of N, P, and K.

In terms of the C:N ratio MSWC has a relatively higher carbon content compared to nitrogen with a C:N ratio of 17.2. In contrast FKC exhibits a balanced C:N ratio of 12.58 indicating a more optimal C:N ratio. PWC has a significantly lower C:N ratio of 7 indicating a reduced carbon content relative to nitrogen. In conclusion FKC stands out due to its superior nutrient content balanced C:N ratio and higher organic matter load compared to the other composts.

MSWC raises concerns with its high pH and EC values potentially related to alkalinity and salt content. However PWC shows promise with its reduced C:N ratio and moderate nutrient contents. Understanding the distinctions in compost production from different sources enables composters to effectively select suitable feedstocks for bioconversion processes. The heterogeneity of MSW presents both challenges and opportunities for resource recovery while sugar cane press mud's nutrient content makes it an ideal option for compost. PWC also offer attractive nutrient profiles. Further investigation into these composts can provide valuable insights for optimizing bioconversion applications. In Ethiopia there is a promising opportunity for researchers to explore compost quality specifically focusing on compost generated by innovative small and micro enterprises.

2.11. AGRICULTURAL BENEFITS OF COMPOST

The use of compost in agriculture is a promising practice with significant sustainability benefits (Tittarelli et al.,2007). Compost use can help conserve environmental equilibria and ensure the long term productivity of the land without depleting non renewable resources or energy. This contributes to the sustainability of resources. Compost application can provide full safety for farmers, operators and consumers meeting hygienic and sanitary standards. This supports the sustainability of human health. Compost can contribute to economically viable agricultural production generating profits for farmers. This enhances the overall economic sustainability of the farming system. The ability of a soil system to effectively utilize compost is not solely based on its capacity to decompose organic materials but also on the appropriate quantity that can be added without overburdening the system. Compost should be viewed as a valuable resource rather than a disposal problem as it can serve as a cost effective fertilizer and soil conditioner when properly understood and applied (Tittarelli et al.,2007).

Compost application is particularly beneficial in regions with intensive agriculture as it can maintain suitable soil structure and replenish organic matter content. Compost application has been shown to improve various soil properties including structure, cation exchange capacity, water holding capacity and permeability. Increased soil organic carbon from compost application is correlated with lower bulk density, higher aggregation and aggregate stability and improved water holding capacity. Evaluating the agronomic value of compost is more complex than that of mineral fertilizers due to the variable chemical composition of organic materials. The simplest method is to assess the supply of organic matter and plant nutrients particularly N and P. Crop yield response to compost follows the law of diminishing returns with higher agronomic value at lower application rates (Tittarelli et al.,2007).

By incorporating compost into soils the depleted nutrients are replenished ensuring their availability for future plant use. Moreover compost releases organic forms of vital nutrients like N, P, K and Ca which plants can readily absorb (Verma. et al.,2012).

Overall the use of compost in agriculture has the potential to address multiple aspects of sustainability including environmental, human health and economic considerations. By optimizing compost application and understanding its agronomic value farmers can leverage this resource to enhance soil health and productivity while contributing to the long term sustainability of their farming practices (Tittarelli et al.,2007).

3. MATERIALS AND METHODS

3.1. DESCRIPTION OF THE STUDY AREA

The experiment was conducted at the research center of the Ethiopian Sugar Industry Group situated within the Wonji/Shoa sugar estate in the East Shoa Zone of the Oromia National Regional State, Ethiopia. The estate is located at $8^{o}31'$ N latitude and $39^{o}12'$ E longitude, approximately 110 km east of Addis Ababa. It is positioned at an altitude ranging from 1223 to 1553 meters above sea level. The region experiences a semi-arid climate characterized by an average monthly rainfall of 70mm over a ten year period. The mean monthly maximum temperature is 27°C while the mean monthly minimum temperature is 12°C.

Composting Sites: The Metahara Sugar Estate located approximately 200 km southeast of Addis Ababa in the Oromia region of Ethiopia at coordinates 8° 53' N, 39° 52' E, sits at an altitude of 950 meters above sea level and experiences a semi arid climate. Additionally the Bishoftu Negegna municipal solid waste composting facility and poultry composting site situated in the East Shewa Zone of the Oromia Regional State Ethiopia, about 47 km southeast of Addis Ababa at coordinates 8° 45' - 8° 47' N, 38° 56' - 39° 00' E, ranges in altitude from 1748 to 1955 meters above sea level and is characterized by a temperate agro climatic zone.

3.2. MATERIALS

3.2.1. INSTRUMENTS AND EQUIPMENTS

This research utilized various instruments and equipments to analyze the physico-chemical properties raw waste and compost samples and phytotoxicty of the compost samples. The instruments employed included an analytical balance (Kern, Germany) , centrifuge (IKA,UK) , drying oven (Memmert 30-1060,Germany), electrical conductivity meter (CON 700,USA), flame photometer (PFP7,UK), inductively coupled plasma optical emission spectrometry (ICP-OES FSH-12-2010,Germany), Kjeldahl digestion block (Behr K20 ,Germany), Kjeldahl distillation unit (Behr S4 ,Germany), magnetic stirrer with hot plate (IKA RCT basic, UK), muffle furnace (Stuart Scientific 683, UK) , pH meter (Hanna 211, Romania), orbital shaker (GFL 3015 ,Germany) , sieves and spectrophotometer (Cecil CE2021, UK).

The glass wares employed includes automatic burettes, beakers, desiccators, core rings, Erlenmeyer flasks, filter funnels, funnel racks, glass Petri dishes, glass rods, Kjeldahl distillation tubes, magnetic stirring bars, measuring cylinders, moisture cans, mortar ,pestle, pipettes, plastic bottles, porcelain crucibles, test tubes, volumetric flasks, watch glass and wash bottles.

3.2.2. CHEMICALS AND REAGENTS

In this study a range of high quality analytical grade chemicals were employed to analyze the physico-chemical properties raw waste and compost samples and phytotoxicty of the compost samples. The chemicals utilized includes acetic acid (99%, CDH ,India), ammonium acetate (99%,Pspark,UK), ammonium chloride (99%,Fisher,UK), ammonium hydroxide (30% ,Pspark,UK), ammonium molybdate (99%, Fisher,UK), ascorbic acid (99%,Avonchem,UK), boric acid (99%, Pspark,UK), bromocresol green (Pspark,UK), buffer solutions (pH 4.0, 7.0, and 9.2, Fisher,UK), copper sulphatepentahydrate (99%,Fisher,UK), diphenylamine indicator (Pspark,UK), EDTA (99%,Avonchem,UK), ethanol (99%, CDH ,India), hydrochloric acid (37%,CDH,India), hydrogen peroxide (30%,CDH,India) , hydrofluoric acid (70%,Pspark,UK), nitric acid (70%,CDH ,India), orthophosphoric acid (85% , Pspark , UK) , oxalic acid (99%, Fisher,UK), phenolphthalein indicator (Fisher,UK), potassium antimony tartrate (99%, Fisher,UK), potassium chloride (99%, Pspark,UK), potassium dihydrogen orthophosphate (99%, Pspark,UK), potassium sulphate (99%, Pspark,UK), sodium acetate (99%, Pspark,UK), sodium bicarbonate (99%, Pspark,UK), sodium chloride (99%, Pspark,UK) , sodium hydroxide (99%, Fisher,UK), sodium sulphate (99%, Fisher,UK), sulfuric Acid (98%,CDH ,India), whatman no. 1, 41 and 42 filter paper (whatman ,England).

3.3. METHODS

3.3.1. COMPOSTING METHOD

The windrow composting method was utilized by the Bishoftu/Negegna municipal solid waste composters, Metehara sugar factory sugarcane press mud composters, and Bishoftu poultry waste composters association. The work procedures of windrow composting at these composting facilities as collected through site visits and interviews with composting experts and are outlined in the following description.

3.3.1.1. COMPOSTING MSW AT BISHOFTU COMPOSTING FACILITY

Waste Collection and preparation: The waste materials municipal solid waste were collected from residents of Bishoftu town and transferred to the composting site located near to solid waste landfill site of the town and at the composting site the solid waste was segregated as biodegradable and non-biodegradable fractions. The non-biodegradable is disposed to the landfill and the biodegradable Underwent shredding at the composting facility. This step increased the surface area of the waste promoting better microbial activity and decomposition. The shredded solid waste comprising 50% of the total waste was thoroughly mixed with 5% farm/crop residue, 20% cow dung, 25% green waste (such as grass clippings, leaves and other plant materials).The resulting mixture was then blended together (National Engineering Hand book,2010).

Formation of Windrows: The mixed waste was then shaped into windrows which were formed on grass basement and different crop shredded straws were used as a bulking agent. The windrows had dimensions approximately ranging from 1 to 1.5 meters in height, 3 to 3.5 meters in width and a length of 50 meters (Rynk et al.,1992; National Engineering Hand book,2010).

Monitoring: the moisture content was regularly monitored by adding water to ensure that the windrows maintain optimal moisture levels. The windrows were also regularly turned to ensure proper aeration and an even decomposition by using windrow compost turner machine. Furthermore, temperature monitoring was conducted regularly throughout the composting process to achieve and maintain temperatures between 55-70°C, was ideal for pathogen and weeds seed destruction and creates conducive temperature for the different beneficial microorganisms (Misra et al.,2003).

Composting Period: It took a period of 3 months for the composting process to be completed at the Bishoftu Negegna compost facility (Misra et al.,2003).

Screening: Once the curing period was complete, the compost underwent screening to remove any remaining contaminants or large particles.

Figure 3 illustrates the facility of the Bishoftu Negegna Composting Association along with the Aero-tiller machine.

Figure 3 Bishoftu Negegna Compost producers association composting facility

3.3.1.2. COMPOSTING FILTER CAKE AT METEHARA SUGAR FACTORY COMPOST YARD

Waste Collection and preparation: The main ingredient filter cake or sugarcane press mud was gathered from the Metehara sugar factory for the composting process and vinasse was also obtained from the ethanol distillery at the same factory then the waste materials underwent shredding to increase the surface area of the waste and promote better microbial activity and decomposition finally the sugarcane press mud was thoroughly mixed with 2 parts of vinasse (National Engineering Hand book,2010).

Formation of Windrows: The filter cake was spread in the composting yard in the form of windrows using a windrow maker machine. The pile had a height of 1.2 meters, a top width of 1.2 meters, a bottom width of 3 meters and a windrow length of 90 meters.Initially for the first two days the filter cake underwent atmospheric drying to reduce its moisture content from 70% to 50%. A cycle of spraying concentrated vinasse on the windrows was carried out in a cyclic manner. Before spraying a desired quantity of microbial culture with a specific count was sprayed (Rynk et al.,1992 ;National Engineering Hand book,2010).

Monitoring: The filter cake vinasse composite was properly mixed and aerated using an aero tiller machine with temperature and moisture levels measured before each aero tilling session and if the moisture fell below 50% it was increased to 70% by spraying water.

Composting Period: After approximately six weeks the temperature started to fall below 45°C, indicating that the composting process was nearing completion. The entire cycle took about 60 days to complete during which decomposition occurred resulting in the formation of humus rich compost (Misra et al.,2003).

Screening: Once the curing period was complete, the compost underwent screening to remove any remaining contaminants or large particles.

3.3.1.3. COMPOSTING POULTRY WASTE AT BISHOFTU COMPOSTING YARD

Waste Collection and preparation: Poultry waste including manure, bedding materials and feathers was collected from the poultry and the surrounding farms and the waste was segregated to remove any non compostable. The poultry waste was then shredded into smaller pieces to facilitate decomposition and it was subsequently mixed with other organic materials such as 1 part straw, 1 part vegetable waste and 1 part cow dung in a ratio of 7 parts poultry waste (National Engineering Hand book,2010).

Windrow Formation: The mixed poultry waste was then shaped into windrows which were formed on grass platforms. The windrows had dimensions 1.5 meters in height, 3 meters in width and a length of 10 meters (Rynk et al.,1992 ;National Engineering Hand book,2010).

Monitoring: The compost windrows needed to be periodically turned to ensure even decomposition and proper moisture distribution as this turning process helped incorporate oxygen which was essential for the decomposition process. Temperature monitoring was conducted regularly throughout the composting process with the aim of achieving and maintaining temperatures between 55-70°C as this range was ideal for pathogen and weed seed destruction (Misra et al.,2003).

Composting Period: After 3 months the composting process progressed to the maturation stage. During this phase the partially decomposed material was allowed to further stabilize and mature resulting in a more finished compost product (Misra et al.,2003).

Screening: Once the compost had sufficiently matured it could be screened to remove any remaining large particles or contaminants.

3.3.1.4. STORAGE AND UTILIZATION

Once the composting process was complete the final compost product was carefully stored in appropriate containers or neatly arranged into designated piles. This storage phase ensured the compost remained in a stable and ready to use condition until the time came for application.

The finished compost could then be applied to a variety of settings to provide significant benefits. It could be incorporated into agricultural fields to improve overall soil fertility helping to nourish crops and maximize yields. Similarly the compost could be used in gardens and landscaping areas where it would enhance the soil's ability to retain moisture and nutrients, ultimately promoting healthier plant growth and development.

3.3.2. SUMMARY OF THE DATA OBTAINED THROUGH ONSITE VISIT AND QUESTIONNAIRES

To ensure a complete and in depth comprehension of the composting process and variables a questionnaire was developed. The core objective of this comprehensive survey instrument was to gather detailed first hand information directly from the compost producers situated within the study sites.

The questionnaire sought to elicit comprehensive responses covering a wide range of composting related details. This included the specific types of organic feedstocks utilized the precise procedures and techniques employed during the critical mixing stage as well as the overall operational management strategies implemented throughout the entirety of the composting lifecycle. By directly engaging with the compost producers themselves it was able to obtain rich contextual insights. Table 9 presents the types of processes, feedstocks used and descriptions of those processes as reported by the composters.

Table 9. Process types, Feed stocks utilized and process description as reported by the composters

Composters	**Negegna (MSWC)**		**Metehara (FKC)**		**Bishoftu (PWC)**	
Process Types	Windrow		Windrow		Windrow	
Farm /crop residue	Leaves, stalks, cobs, pods and other crop		Sugar cane sheath ,leaves and other cane		Leaves, stalks, Straw other crop	
Farm /animal manure	Cow dung		_		Chicken manure and Cow dung	
Green	Leaves, grass, fruit and vegetable scraps		_		Leaves, grass, fruit and vegetable	
Industrial waste	_		Filter cake and Vinasse		_	
Municipal solid waste	MSW , from Bishoftu town landfill site		_		_	
Others	_		Soil		Bedding materials, feathers , waste	
Typical length of process (days)	85 -90		50 - 65		85 - 90	
Process description	Initial	Final	Initial	Final	Initial	Final
Average pile depth	1.5	1.0	1.5	0.9-1.0	1.5	1.0
Aeration mode	Positive	Positive	Positive	Positive	Positive	Positive
Av. pile temp ,^{o}c	45 to 65	30 to 40	65-75	30-45	45 to 75	30 to 40
Average pile pH	7.0	7.0	7.1	7.4	-	-
Average moisture %	-	-	34	30	-	-
Average C / N ratio	-	-	-	15.71	-	-

3.3.3. SAMPLING AND SAMPLE PREPARATION

The study utilized feedstock and compost samples obtained from the Bishoftu municipal solid waste composting site, the Metehara sugar factory composting yard for sugar cane filter cake and the composting yard for poultry waste at Bishoftu. Representative feedstock and compost samples from the aforementioned sites were taken by mixing nine subsamples from different levels of the section in the windrow along the whole profile. The sampling procedure is outlined below.

A spade of material was collected from near the surface of the windrow, another spade was taken from midway to the core and a third spade was obtained from near the core of the windrow. The samples were placed in a clean 5-liter plastic bucket. This process was repeated at each sampling location in the windrow.

Once sample collection was completed at all locations the material in the bucket was thoroughly mixed to create a composite sample for each type of compost/feedstock. About 1 kg of feedstock and compost sample from each site was placed in labeled plastic bags and transported to the laboratory (BSI PAS100:2018.,2020).

Upon arrival at the laboratory the samples were air dried and ground using a mortar and pestle to pass through 0.5 mm sieve (feedstock samples) and a 2.00 mm sieve (for compost samples) for further analysis (Methods Book for the Analysis of Compost, 2003).

Figure 4 .Compost /Feedstock sample preparation for physico-chemical analysis , Ethiopian sugar industry group research laboratory

3.3.4. PHYSICOCHEMICAL ANALYSIS

A comprehensive physicochemical analysis was conducted to explore the composition and quality of raw feedstock and composts using appropriate analytical method. The properties analyzed for feedstock samples includes pH, electrical conductivity, organic carbon content, total nitrogen, total phosphorus, total potassium, bulk density and moisture content. While for compost samples pH, electrical conductivity, organic carbon content, total nitrogen, total phosphorus, potassium, iron, manganese, copper, zinc, boron, arsenic, lead, cadmium, mercury, chromium, nickel, bulk density and moisture content were analyzed. By analyzing these properties valuable insights were gained into the nutrient composition potential contaminants and overall suitability of the feedstock for producing composts and composts for agricultural applications. The physicochemical analysis of both feedstock and compost samples was carried out in accordance with the methods outlined below.

3.3.4.1. MEASURMENT OF PH IN COMPOST /FEEDSTOCK WATER SUSPENSION

For a pH analysis standard buffer solutions with pH 4.0, pH 7.0, and pH 9.2 were prepared using distilled water and used to calibrate the pH meter. A 10 g compost sample was transferred to a 100 ml beaker, and then 50 ml of distilled water was added to the beaker to maintain 1:5 ratio of compost to water. The mixture was stirred and after 30 minutes, the pH of the compost sample was measured and recorded (Sahlemedhin et al.,2000).

Figure 5. Compost /Feedstock sample preparation for PH and EC analysis ,Ethiopian sugar industry group research laboratory

3.3.4.2. MEASURING THE EC OF COMPOST /FEEDSTOCK WATER SUSPENSION

For measuring EC, A 0.01 N solution of Potassium Chloride was prepared, and the electrical conductivity meter was calibrated using this solution, which exhibited a conductivity of 1.41 ds/m at 25ºC. In a 100 ml beaker 10 g of the compost sample was placed and then 50 ml of distilled water was added. The mixture was stirred for one hour and allowed to settle until the supernatant liquid became clearly visible at which point the electrical conductivity (EC) of the solution was measured (Sahlemedhin et al.,2000).

3.3.4.3. DETRMINATION OF % OM AND TOC

The crucibles at the Ethiopian sugar industry group research laboratory were heated in the muffle furnace at 550 ± 25 ◦C for 20 minutes then cooled in a desiccator and the tare mass (m_t) was determined with an accuracy of 0.1g next 5g of the air dried sample was weighed in crucibles with a precision of 0.01g and the samples with the crucibles were then dried in an oven at 105 ◦C for 4 hours, cooled and reweighed as mass (m_s) subsequently the crucibles were placed in a muffle furnace and heated gradually to 550 ± 25 ◦C for 2-4 hours until a constant mass was achieved the muffle furnace was cooled down to 100 ◦C and the crucibles were then placed in a desiccator and allowed to cool to room temperature after which the mass of the filled crucibles ($m_c + m_t$) was measured (Margesin et al.,2005).

The loss of mass (Δm: g) was calculated after ignition at 550 ˚C using the following equation.

$\Delta m = (m_s + m_t) - (m_c + m_t) = m_s - m_c$

Organic matter and total organic carbon were calculated using the following formula.

$$OM = \frac{(\Delta m)}{5} * 100 \ldots\ldots (3.1)$$

$$TOC = \frac{OM * 58}{100} \ldots\ldots (3.2)$$

Where:

OM: organic matter

TOC: total organic carbon

Δm: mass losse (g)

m_t: mass of empty crucible (g)

m_c:mass of burned sample plus mass of crucible (g)

m_s: mass of oven dried sample plus mass of crucible (g)

3.3.4.4. DETRMINATION OF % TOTAL NITROGE

A compost /feedstock sample weighing 0.5 g (<0.5 mm sieve) was precisely weighed and transferred into a digestion tube. A reference sample and two blanks were included. 2 g of catalyst mixture was added to the tube, mixed thoroughly and rinsed with a small amount of water to moisten the mixture. 7 ml of concentrated H_2SO_4 was added to the tube and mixed by swirling. The digestion tube stand with the samples was placed next to the preheated digestion block in the fume hood. The tubes and rack were placed on the digestion block preheated to 300°C. The samples were digested for 3 hours or until the digest turned white or pale yellow.

After cooling, 50 ml of distilled water was cautiously added, followed by another round of cooling. A boric acid solution (20 ml) was measured from a dispenser into a receiver Erlenmeyer flask corresponding to the number of samples. Two drops of indicator solution were added and the flask was placed under the condenser ensuring that the end of the condenser was immersed in the boric acid solution to prevent any loss of ammonia. Carefully 75 ml of 40 percent NaOH was poured down the neck of the distillation flask containing the digests and mixed gently. The prepared 250 ml Kjeldahl distillation flasks containing the digests were fitted to the corresponding holder closed promptly and the distillation was initiated by heating the flasks. Once about 80 ml of distillate was collected the receiver flask was removed and the process continued with the next sample. The receiver flask solution was titrated from green to a pink end point with 0.02 N H_2SO_4 using a stirrer bar. The burette reading was recorded. The magnet was transferred to the next flask to be titrated using a magnetic rod (Sahlemedhin et al.,2000).

Let V be the volume of 0.02 N H_2SO_4 used after correcting for the blank.

N x V = meq of N/g of soil

N x V x 14 = mg of N per g of soil

N x V x 0.014 = g of N per g of soil

$$\% N = \frac{(a - b)}{S} \times N \times 0.014 \times 100 \times mcf \quad (3.3)$$

Where:

a = ml of H_2SO_4 required for titration of sample

b = ml of H_2SO_4 required for titration of blank

s = air dry s ample weight in grams

N = Normality of H_2SO_4 (0.02 N)

0.014 = meq weight of nitrogen in g

mcf = moisture correction factor

Figure 6. Kjeldahl auto distillation unit on nitrogen analysis, Ethiopian sugar industry group research laboratory

3.3.4.5. DETERMINATION OF % TOTAL PHOSPHORUS

A finely ground and well-mixed compost /feedstock sample weighing 0.5 g was weighed into a 100 ml beaker. 5 ml of concentrated sulfuric acid was added to the beaker and it was gently swirled. 3 ml of 30% hydrogen peroxide was added to the beaker in 0.5 ml portions. The mixture was vigorously swirled taking caution as foaming may cause overflow in samples high in organic matter. After the reaction with hydrogen peroxide subsided 1 ml of concentrated hydrofluoric acid was added to the beaker in 0.5 ml portions and it was gently swirled. The beaker was placed on a hot plate at 150 °C for 10-20 minutes to eliminate excess hydrogen peroxide. Once slightly cooled approximately 15 ml of distilled water was used to wash down the sides of the beaker. The contents of the beaker were mixed and cooled to room temperature. The content of the beaker was quantitatively transferred through a filter paper to a 50 ml volumetric flask. Two additional washings of the beaker were performed using 10 ml of distilled water and the washings were filtered and made up to volume in the volumetric flask.

The phosphate stock solution (50 mg P/l) was prepared by dissolving 0.2197 g of oven-dried (40 °C) KH_2PO_4 in deionized water. Then 25 ml of H_2SO_4 (2.5 mol/l) was added and the mixture was diluted to 1 L with deionized water. To obtain the working phosphate standard solution (5 mg P/l) 10 ml of the stock solution was diluted to 100 ml with deionized water.

The following transfers were made into 50 ml volumetric flasks. Next working solutions for the standard series with concentrations ranging from 0 to 0.2-0.4-0.6-0.8-1 mg/1 P were prepared. For each concentration the corresponding volume of the diluted 5 mg/l standard solution was pipetted into 50 ml volumetric flasks. Specifically 0-2-4-6-8-10 ml of the diluted standard solution was pipetted into separate flasks. Finally each flask was diluted to the mark with distilled water. An aliquot of 10 ml of the compost /feedstock extract containing total phosphorus was transferred if the expected concentration of P in the compost /feedstock was less than 400 mg/kg otherwise 5 ml or less was used. An aliquot of 25 ml of the compost /feedstock extract containing labile phosphorus was transferred. The aliquots were diluted with distilled water to approximately 25 ml if necessary and 8 ml of the mixed reagent was added. The solutions were diluted to volume and mixed well. After 10 minutes the absorbance was measured at 880 nm using a spectrophotometer. A blank was prepared, which included all reagents except the P solution (Margesin et al.,2005).

A graph was established with the absorbance on the Y-axis and the mg/l P on the x-axis. The sample concentrations were read off from the standard curve.

The total content of P (P_t; mg/kg oven-dried compost /feedstock sample) is calculated using the following equation:

$$P_t = \frac{P * 50}{m} \qquad (3.4)$$

P: concentration of P (mg/l) measured

m :mass of air-dried compost /feedstock

Figure 7. Spectrophotometer and prepared samples for phosphorus analysis, Ethiopian sugar industry group research laboratory

3.3.4.6. DETERMINATION OF % POTASSIUM

10 grams of compost /feedstock that passed through a 0.5mm sieve were weighed and placed into a 100 ml shaking bottle. Then 50 ml of extracting solution was added and the mixture was shaken for 30 minutes at a minimum rate of 180 oscillations per minute. The filtrate was filtered and collected in a 100 ml Erlenmeyer flask. The extracts were diluted 10 times using the extracting solution.

The dilution series for the potassium standard, with a concentration of 100 mg/l, was prepared. Firstly, 100 ml of the 1000 ppm K potassium stock solution was pipetted into a 1-liter volumetric flask and it was then diluted to the mark with distilled water. Next working solutions for the standard series with concentrations ranging from 0 to 2-4-6-8-10 mg/1 K were prepared. For each concentration the corresponding volume of the diluted 100 mg/l standard solution was pipetted into 50 ml volumetric flasks. Specifically 0-1-2-3-4-5 ml of the diluted standard solution was pipetted into separate flasks. Finally each flask was diluted to the mark with Morgan's extracting solution. The transmittance curve was established by aspirating the standard series working solutions into the flame. Similarly the samples were aspirated and the transmittance was recorded (Sahlemedhin et al.,2000).

A graph was established with the % transmittance on the Y-axis and the mg/l K on the x-axis. The sample concentrations were read off from the standard curve.

$$K\ (\text{mg/kg Compost}) = (a-b) * \frac{50}{1000} * \frac{1000}{S}\, df * mcf = 50 * df * \frac{a-b}{S} \times mcf \quad \ldots\ldots\ldots\ldots\ldots\ldots (3.5)$$

Where:

a = concentration of K, measured in the sample (mg/l)

b = concentration of K, measured in the blank (mg/l)

s = air –dry soil sample weight in g (10 g)

df = dilution factor

50 = ml of extractant used/sample

Mcf = moisture correction factor

Figure 8. Flame photometer and prepared samples for Potassium analysis, Ethiopian sugar industry group research laboratory

3.3.4.7. DETRMINATION OF % CALCIUM + % MAGNESIUM

At the Ethiopian sugar industry group research center laboratory a 5.0 g compost/feedstock sample was weighed and added to a 100 ml beaker. Then 40 ml of a 1 M pH 7.0 ammonium acetate solution was added to the beaker. Instant stirring was performed using a stirring rod and the beakers were covered with watch glasses. The samples were left to stand overnight. The following day the soaked samples were transferred to filter funnels placed on 100 ml volumetric flasks. The remaining sample was washed with approximately 10 ml of a 1 M pH 7.0 ammonium acetate solution ensuring that each filtration was completed before the next addition. The washing process was repeated twice, with an additional 25 ml aliquot of a 1 M pH 7.0 ammonium acetate solution. Subsequently the volumetric flasks were removed and the volume was adjusted to the desired level using distilled water.

A 100 ml Erlenmeyer flask was used to pipette 10 ml of the ammonium acetate compost/feedstock extract. To bring the volume up to 50 ml, 40 ml of distilled water was added. Methyl orange was added to the flask followed by 2 to 3 drops of 0.1 N HCl until the color turned orange. Then, an excess of 0.1 N HCl (0.2 ml) was added. The content was boiled for 3 minutes and allowed to cool to 60°C. To achieve a pH of approximately 10, 2 ml of KCN solution (from a burette) and the buffer (ammonium hydroxide/ammonium chloride) solution were added. A mixture of Eriochrome Black T and NaCl was added in a small amount. The solution was titrated with 0.02 N EDTA-disodium salt until a pure turquoise blue color was obtained without any trace of red (Sahlemedhin et al.,2000).

$$Ca + Mg\ (meq/100g) = \frac{N * T * V * 100 * mcf}{A * S} \quad \text{(eqn. 3.6)}$$

Where

N = Normality of EDTA (0.02 N)

T = Volume of 0.02 N EDTA-disodium salt used

V= Total volume of extract (100 ml)

A = Aliquot of sample taken for titration (10 ml)

S = Air-dry weight of sample (g)

mcf = Moisture correction factor

100 = to convert to l00g soil bases

3.3.4.8. DETRMINATION OF % CALCIUM

The ammonium acetate compost/feedstock extract was transferred to a 100 ml Erlenmeyer flask and the volume was brought to 50 ml by adding 40 ml of distilled water. Methyl orange was added to the flask along with 2 to 3 drops of 0.1 N HCl until the color turned orange. Then an excess of 0.2 ml of HCl was added. The contents were boiled for 2 to 3 minutes and then cooled to approximately 60°C. Next 10 ml of freshly prepared 1 N NaOH, 2 ml of KCN solution, and a pinch of HHSNN were added to the flask. The solution was titrated with 0.02N EDTA-Na solution until a pure turquoise blue color was achieved with no trace of red (Sahlemedhin et al.,2000).

$$\text{Ca (meq/100g)} = \frac{N * T * V * 100 * mcf}{A*S} \ldots\ldots\ldots\ldots\ldots\ldots \text{(eqn. 3.7)}$$

Where

N = Normality of EDTA (0.02 N)

T = Volume of 0.02 N EDTA-disodium salt used

V= Total volume of extract (100 ml)

A = Aliquot of sample taken for titration (10 ml)

S = Air-dry weight of sample (g)

mcf = Moisture correction factor

100 = to convert to l00g soil bases

Mg (meq/100 g) = Ca + Mg (meq/100 g) – Ca (meq/100 g)……………………… (3.8)

3.3.4.9. DETRMINATION OF HEAVY METALS

At Horticoop Ethiopia laboratory a 500 mg dry compost sample was weighed and quantitatively transferred into the digestion tube then 5 ml of a 1:1 (v/v) mixture of distilled, deionized water and concentrated HNO_3 were added to the tube the slurry was thoroughly mixed and covered with a watch glass the resulting mixture was heated to 95°C ± 5°C for 15 minutes without boiling after cooling 5 ml of concentrated HNO_3 was added the cooled mixture was then refluxed for 30 minutes with the cover replaced this step was repeated several times to ensure the complete disappearance of the brown fume indicating the oxidation of the sample by HNO_3 once the oxidation process was complete the solution mixture was heated again to 95°C ± 5°C without boiling for 1 hour with a cover always maintained over the vessel after this step the sample solution was cooled and 1 ml of distilled deionized water and 1.5 ml of 30% H_2O_2 were added the vessels were covered with a watch glass and heated to initiate the peroxide reaction careful warming was applied to prevent losses caused by vigorous effervescence heating continued until the effervescence subsided and the solution was then cooled subsequently 30% H_2O_2 was added incrementally in 0.5 ml aliquots with warming until the effervescence was minimal or there was no noticeable change in the sample appearance the total volume of 30% H_2O_2 added was recorded to be less than 5 ml at this stage the sample was covered with a ribbed watch glass and heated at 95°C ± 5°C without boiling for 1 hour and 30 minutes finally the digested solution was cooled to room temperature and reconstituted to a volume of 50 ml with distilled, deionized water, reagent blanks, spike samples and certified reference materials were also prepared using a similar procedure and the resulting mixture was analyzed by ICPOES to determine the total potentially heavy metal element contents with the digests stored in a refrigerator at 4°C until analysis (Method 3050B .,1996).

$$\text{Concentration of micronutrient (mg/kg)} = \frac{(C * V * 1000)}{W} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (3.9)$$

Where:

C is the concentration of the element in micrograms per liter (µg/l).

V is the volume of the solution used for the analysis in liters.

W is the weight of the sample used for the analysis in kilograms.

3.3.4.10. DETRMINATION OF % MOISTURE CONTENT

At the Ethiopian sugar industry group research center laboratory a clean dry pre weighed and moisture free moisture can was used to weigh out 10 g of air dry compost /feedstock with a precision of 0.001 g (weight A = air-dry sample + moisture can weight) the moisture can with the sample was placed in an oven and kept at 105°C for 24 hours / till constant weight without the lid on the moisture can after 24 hours the moisture can was taken out of the oven covered with the lid and placed in a desiccator to cool for 30 minutes subsequently the moisture can was removed from the desiccator and weighed (Margesin et al.,2005).

$$\text{Percent moisture (wt \%)} = \frac{(A - B) * 100}{B - \text{Weight of moisture can}} \quad (3.10)$$

Where:

A = weight of air-dry compost /feedstock (10g) + tin weight

B = weight of oven dry compost /feedstock in grams + Weight of moisture can

3.3.4. 11. DETRMINATION OF BULK DENSITY

At the Ethiopian sugar industry group research center laboratory the core ring was filled with the compost sample compost protruding beyond the ends of the core ring was trimmed using a straight edged knife or a sharp spatula the volume of the sample established in this manner was equivalent to the volume of the sample core ring, the sample core ring containing the samples were placed in an oven set to 105°C and kept there until a constant mass was achieved with a minimum duration of 48 hours subsequently the samples were removed from the oven and allowed to cool within a desiccator the samples were immediately weighed after being taken out of the desiccator (m_t) and the attainment of a constant mass was confirmed (Margesin et al.,2005).

$$(\rho b) = \frac{md}{V} \quad (3.11)$$

md= mt – ms

ρb :bulk density (g/cm^3)

md :mass of the compost sample dried at 105°C (g)

mt : mass of the compost samplewithin the sample core ring dried at 105°C (g)

m_s : mass of empty sample core ring (g)

3.3.5. PHYTOTOXICITY TEST OF COMPOSTS

In addition to the physicochemical analysis the maturity of the composts was determined through a phytotoxicity test. Barley (Hordeum vulgare), Cabbage (Brassica oleracea), and Tomato (Solanum lycopersicum) seeds were selected as the indicator plants to represent a range of sensitivity to potential phytotoxic compounds in the compost samples. The germination percentages of these three species were measured to determine the extent to which the composts may have inhibited or promoted seed germination and root growth.

This test played a crucial role in establishing whether the composts had reached a mature state where they could be safely used without causing harm to plants or the environment.
The phytotoxicity tests were performed on the samples of compost products adhering to the methods outlined below.

Procedure

At the research center laboratory of the Ethiopian Sugar Industry Group, a germination test was conducted using seeds of barley (Hordeum vulgare), cabbage (Brassica oleracea), and tomato (Solanum lycopersicum), following the methodology suggested by Zucconi et al. (1985).

The extract was prepared by adding 10g of compost sample to a 100ml flask, which was then filled with distilled water up to the 100ml mark. The flask was subsequently shaken at a speed of 125rpm for 16 hours at room temperature using an orbital shaker. Finally, the resulting compost–water extract was filtered. A 150 mm / 30 mm glass Petri dish was prepared by placing Whatman filter papers inside. The filter paper was moistened with 5 ml of the filtered compost-water extract. Subsequently, 50 seeds each of Barley, Cabbage, and Tomato were placed on the moistened paper. As a control, distilled water was used. The Petri dish was covered and placed in an oven set at 25 °C. On days 3 and 6, the number of germinated seeds and the length of roots were measured for Barley, Cabbage and Tomato seeds respectively (Zucconi et al.,1985).

$$\text{Germination percentages (G \%)} = \frac{\text{No of seed germinated in each extract}}{\text{No of seed germinated in control}} * 100 \ldots\ldots\ldots\ldots (3.12)$$

$$\text{Root growth percentage (RG \%)} = \frac{\text{Mean root length in each extract}}{\text{Mean root length in control}} * 100 \ldots\ldots\ldots\ldots (3.13)$$

$$\text{The germination index (GI \%)} = \frac{\text{G \% * RG \%}}{100} \ldots\ldots\ldots\ldots (3.14)$$

3.3.6. DATA ANALYSIS

The physicochemical quality analytical data was processed using SPSS software. A one-way ANOVA (analysis of variance) was conducted on the experimental analytical data. Mean separations were then performed using the least significant difference (LSD) method.

4. RESULTS AND DISCUSSIONS

In this section the suitability of feedstocks for composting and quality of the compost produced mainly from these feedstocks municipal solid waste compost, sugar cane filtercake compost and poultry waste compost for agricultural applications has been assessed and their compliance with international standards is evaluated. The results were presented and discussed with a focus on highlighting any significant findings and implications.

4.1 PHYSICO-CHEMICAL CHARACTERSTICS OF RAW FEEDSTOCKS

The ANOVA analysis summary presented in Table 10 provides an evaluation of the physico-chemical analytical results obtained from feedstock samples. The results revealed significant variations among those parameters offering valuable insights into the composting materials derived from different sources. The highest pH values of the feedstocks were observed in MSW (8.2 ± 0.54), followed by FK (7.92 ± 0.23) and PW (6.88 ± 0.04). The differences in pH between all three feedstocks were found to be statistically significant.

The pH of the feedstock can significantly impact microbial activity, nutrient availability and the overall stability of the system (Meena et al.,2021).

The pH of compost fluctuates throughout the composting process, depending on the source materials used. Typically the pH range falls between 4.5 and 8.5 over the course of the process. pH is a critical factor for the survival and growth of the microbial communities driving the composting process. Most bacteria thrive best in a pH range of 6.0-7.5 while fungi prefer a slightly wider range of 5.5 to 8.0. The ideal overall pH range for optimal microbial activity and efficient composting is between 5.8 and 7.2 (Meena et al.,2021).

The results suggest that the MSW, FK and PW feedstocks are in good condition in terms of pH. The differences observed in pH among the three feedstocks highlight the importance of thoroughly characterizing the feedstock properties before initiating the composting process. By understanding the initial pH of the feedstocks composting operators can make informed decisions to maintain the ideal pH range throughout the process ensuring efficient microbial activity and nutrient availability for the successful production of high quality compost. The previous study by Said (2010) reported a pH of 9.3 for MSW which is higher than the 8.20 ±

0.54 found in the present study. The previous study by Hwang et al. (2020) found a pH of 7.09 for poultry waste which is slightly higher than the 6.88 ± 0.04 reported in the present study. The previous study by Meunchang et al. (2005) reported a pH of 7.7 for filter cake which is lower than the 7.92 ± 0.23 found in the present study.

EC of the feedstocks exhibited the highest (7.48 ± 1.18 dS/m) in PW while FK displayed the lowest (1.04 ± 0.43 dS/m). Statistically significant differences in EC were observed between PW and FK as well as between PW and MSW (4.94 ± 0.14 dS/m). Soluble salt content as measured by EC can greatly affect germination and plant growth (Epstein,2011).

High EC values such as the one observed for PW can indicate the presence of high amounts of soluble salts which can have a negative impact on the composting process and the quality of the final compost (Epstein,2011).Typically an EC value below 4 dS/m is considered suitable for effective composting as higher values can inhibit the activity of microorganisms and plant growth in the final compost product (Epstein,2011). If the feedstock has a high initial electrical conductivity it is best to incorporate a low salt bulking agent or another feedstock having a low salt content. If however after composting it has been determined that the product's intended use is for low salt tolerant crops the salt content of the compost must be reduced. This can be done by leaching the salts out of the compost or diluting the compost with a low-salt compost product (Epstein,2011).

The statistically significant differences in EC between PW and FK, as well as between PW and MSW suggest that these feedstocks have different salinity levels and may require different management strategies during the composting Process. For the PW feedstock with the highest EC, special attention should be paid to managing the salinity levels, such as through the addition of bulking agents or amendments to dilute the soluble salts. The lower EC value of FK suggests that it may be more suitable as a standalone feedstock or as a component in a feedstock mixture to balance the salinity levels. The MSW feedstock with an intermediate EC value may require a tailored composting approach to optimize the process and the quality of the final compost. The previous study by Said (2010) reported a much higher EC of 15.7 dS/m for MSW this suggests that the MSW used in the previous study had a higher concentration of soluble salts or ions. The previous study by Hwang et al. (2020) found an EC of 3.76 dS/m for poultry waste which is lower than the 7.48 dS/m ± 1.18 reported in the present study had a lower salinity. The previous study by Meunchang et al. (2005) reported a much lower EC of 0.8 dS/m for filter cake compared to the 1.04 ± 0.43 dS/m found in the present study had a lower concentration of soluble salts or ions.

Furthermore the OC content of the feedstocks was the highest in PW (36.12% ± 1.09) while FK (23.22% ± 0.66) and MSW (14.81 ± 0.65%) displayed lower levels of OC. These differences were statistically significant. The previous study by Hwang et al. (2020) reported a lower OC content of 30.61% for poultry waste compared to the 36.12 %± 1.09 found in the present study. The previous study by Meunchang et al. (2005) found an OC content of 27.84% for filter cake which is higher than the 23.22% ± 0.66 reported in the present study. The previous study by Said (2010) found an OC content of 23.12 % for MSW which is higher than 14.81% ± 0.65 reported in the present study.

Additionally the investigation related to TN content in the feedstocks showed the highest TN content (3.37 ± 0.02%) in PW followed by MSW (1.10 ± 0.02%) and FK (0.57 ± 0.01%). Statistically significant differences in TN were observed among all the three feedstocks. The previous study by Hwang et al. (2020) reported a much higher TN content of 5.81% for poultry waste compared to the 3.37 % ± 0.02 found in the present study. The previous study by Meunchang et al. (2005) found a TN content of 1.8% for filter cake which is higher than the 0.57 ± 0.01% reported in the present study. The previous study by Said (2010) reported a TN content of 1.39% for MSW which is higher than the 1.10% ± 0.02 found in the present study.

Similarly PW demonstrated the highest TP content (2.18 ± 0.27%) while FK (0.39 ± 0.07%) and MSW (0.54 ± 0.02%) had lower TP levels. This difference was also statistically significant between PW and FK as well as between PW and MSW. The previous study by Hwang et al. (2020) reported a much higher TP content of 16.89% for poultry waste compared to the 2.18 % ± 0.27 found in the present study. The previous study by Meunchang et al. (2005) found a TP content of 0.96% for filter cake, which is higher than the 0.39 % ± 0.07

reported in the present study. The previous study by Said (2010) reported a TP content of 0.26% for MSW, which is lower than the 0.53% ± 0.02 found in the present study.

The highest Ca content of the feedstocks was displayed by PW (51.31 ± 1.83 meq/100g), followed by FK (40.40 ± 1.44 meq/100g) and MSW (29.90 ± 1.07 meq/100g). Whereas MSW exhibited the highest Mg content (18.18 ± 0.65 meq/100g) followed by FK (12.12 ± 0.43 meq/100g) and PW (7.27 ± 0.26 meq/100g). These differences were in Ca and Mg content were statistically significant among all three feedstocks.

PW displayed the highest K content (1.97 ± 0.07%) while FK (0.58 ± 0.03%) and MSW (0.52 ± 0.01%) exhibited lower levels of K. Statistically significant differences in K were observed between PW and the other two feedstocks but not between FK and MSW. The previous study by Meunchang et al. (2005) found a K content of 0.39 % for filter cake which is lower than the 0.58 % ± 0.03 reported in the present study. The previous study by Said (2010) reported a K content of 3.0 % for MSW which is much higher than the 0.52 % ± 0.01 found in the present study. Hwang et al. (2020) observed a K content of 2.06 % for PW which is higher than the 1.97 % ± 0.07 found in the present study.

Regarding to the moisture content of the feedstocks FK showcased the highest moisture content (69.5 ± 0.56%) followed by PW (41.6 ± 0.20%) and MSW (35.5 ± 0.50%). Statistically significant differences in moisture content were observed among all three feedstocks.

Table 10. The physico-chemical properties of the feedstock samples

Properties	PW	FK	MSW
pH	6.88 ± 0.04 a	7.92 ± 0.23 b	8.20 ± 0.54 b
EC (ds/m)	7.48 ± 1.18d	1.04 ± 0.43e	4.94 ± 0.14f
OC (%)	36.12 ± 1.09a	23.22 ± 0.66b	14.81 ± 0.65c
TN (%)	3.37 ± 0.02d	0.57 ± 0.01e	1.10 ± 0.02f
TP (%)	2.18 ± 0.27a	0.39 ± 0.07b	0.53 ± 0.02b
Ca (me/100g)	51.31 ± 1.83d	40.40 ± 1.44e	29.90 ± 1.07f
Mg (me/100g)	7.27 ±0.26a	12.12 ±0.43b	18.18 ± 0.65c
K (%)	1.97 ± 0.07d	0.58 ± 0.03e	0.52 ± 0.01e
Moisture (%)	41.6 ± 0.20a	69.5 ± 0.56b	35.5 ± 0.50c

Where: LSD refers to least significant difference. Different letters (a, b, c, etc.) within each row indicate that the samples are significantly different at the 0.05 significance level ($\alpha = 0.05$) according to the LSD test. Values within the same row that are followed by the same letters are not significantly different from each other.

The physicochemical properties of the three feedstocks PW, FK and MSW were comprehensively analyzed as presented in Figure 9. The analysis revealed substantial differences among the three feedstock samples. The MSW feedstock had a significantly high pH of 8.20 ± 0.54 which falls within the acceptable range for mature compost as per the Bord na Mona standards (6.9-8.3) (Prasad,2003). In comparison Singh et al. (2023) reported a lower pH of 6.97 for MSW used in composting while Mengistu et al. (2017) observed a pH of 7.39 for MSW in their study.

The PW feedstock contained significantly higher levels of electrical conductivity (EC, 7.48 dS/m ± 1.18), organic carbon (36.12% ± 1.09), (TN, 3.37% ± 0.02), (TP, 2.18% ± 0.27), (Ca, 51.31 meq/100g ± 1.83) and (K, 1.97% ± 0.07). In contrast, the FK feedstock had a significantly higher moisture content (41.6 ± 0.20) and the MSW feedstock contained a high level of (Mg, 18.18 meq/100g ± 0.65).

The high EC of 7.48 dS/m in the PW feedstock exceeds the recommended range for composts as per the Bord na Mona standards (2-6 dS/m) (Prasad, 2003). This high EC can be attributed to the presence of elevated levels of salts such as sodium, chloride, potassium, nitrate, sulfate and ammonia. While low salinity may indicate a lack of available minerals high salt levels can result from appreciable amounts of soluble minerals which can potentially inhibit biological activity or cause issues with land application (Woods End Laboratories, Inc.,2013).

The OC content of the PW feedstock (36.12%) was higher than the values reported by Hwang et al. (2020) for chicken manure (30.61%) and the average reported by Ravindran et al. (2017) (35.25%). The high OC content in the PW feedstock suggests a favorable C/N ratio which is crucial for proper composting and ensuring a balanced nutrient profile for plant growth (Ravindran et al.,2017).

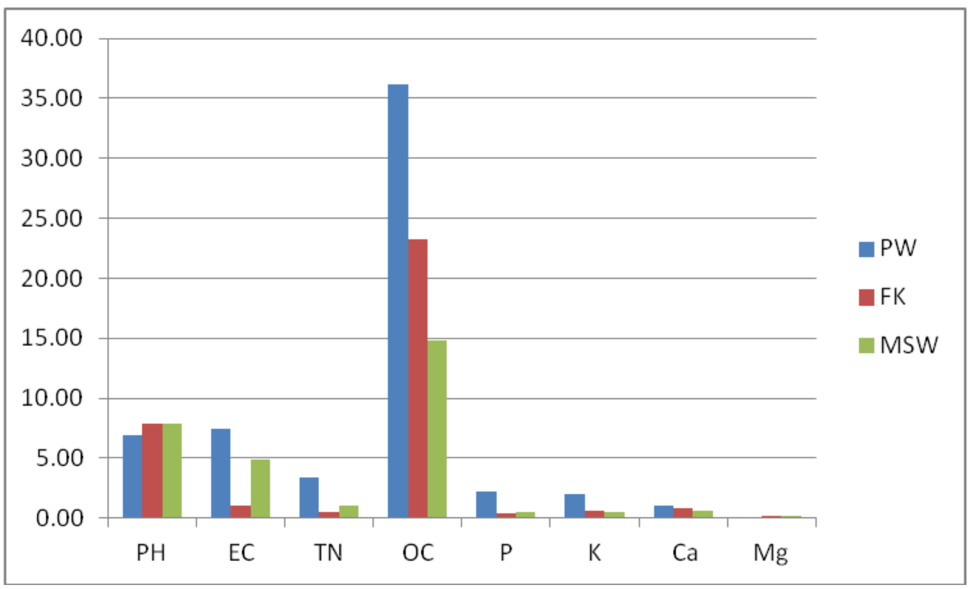

Figure 9. Mean values of physico-chemical analytical results of feedstock samples

PW contains significantly higher levels of TN at 3.37% which exceeds the range for mature compost (0.8-1.9%) as per the Bord na Mona standards (Prasad, 2003). The high TN content in PW coupled with its high OC suggests a well balanced nutrient profile making it a potentially valuable soil amendment (Ravindran et al.,2017). Furthermore the TP content in PW is 2.18% which is higher than the typical range for mature compost (0.4-1.1%) as per the

Bord na Mona standards (Prasad, 2003). The K content in PW at 1.97% is also slightly higher than the mature compost range (0.6-1.7%) as per the same standards (Prasad,2003).

Naylor et al. (1999) have reported a wider range of plant nutrients in poultry waste feedstock including TN (1.3-14.5%), TP (0.15-4.00%), and Ca (0.71-14.90%) which are much higher than the Bord na Mona standards (Prasad, 2003). The elevated levels of these three major chemical components (TN, TP and K) in PW can potentially improve soil nutrient availability and enhance the suitability of PW as a soil amendment (Epstein,2011).

The preparation of compost plays a vital role in the composting process as it directly impacts the quality and suitability of the final product for different applications. Feedstocks which serve as the raw materials for composting exhibit unique characteristics that influence the composting conditions and the resulting compost quality. These variations in feedstocks necessitate the careful selection of appropriate materials based on specific objectives such as soil amendment or waste management. For instance feedstocks with high carbon and nutrient content may be well suited for soil amendment (Epstein,2011).

Choosing the right feedstocks is critical as it determines the composting conditions including moisture, carbon and nitrogen content and physical properties. Feedstocks with differing levels of organic matter, plant nutrients, particle size and contaminants can significantly impact the composting process and the quality of the final product. Therefore understanding the characteristics of different feedstocks is essential for selecting the most suitable materials for a particular application (Rynk,1992).

Furthermore the selection of feedstocks can also influence the composting process and the quality of the final product. Feedstocks with low nutrient levels may require the addition of nutrient rich materials to enhance the fertility of the resulting compost. In conclusion the selection of feedstocks is a crucial step in the composting process as it directly affects the quality and suitability of the final product for various applications. Understanding the characteristics of different feedstocks and selecting the most appropriate ones for specific purposes can optimize the composting process and ensure the production of high-quality compost. The information provided can be valuable in choosing suitable feedstocks for soil amendment waste management, or meeting specific nutrient requirements (Rynk,1992).

Further research is necessary to explore the practical implications of these findings and optimize the utilization of these feedstocks in real world composting scenarios.

4.2 PHYSICO-CHEMICAL CHARACTERSTICS OF THE COMPOSTS

The physicochemical properties of compost samples are crucial in understanding their potential as soil amendments and their ability to support plant growth. The physico-chemical analysis results of the three compost samples PWC, FKC and MSWC were presented in Table 11. The analysis provides valuable insights into the distinct properties and differences between the three compost samples with respect to pH, EC, OC, OM, C: N ratio, TN, TP, K, Ca, Mg, moisture content, and bulk density.

Table 11. Mean values of the physico-chemical properties for the three compost samples.

Properties	PWC	FKC	MSWC
Moist%	53.60 ±0 .40a	40.13 ± 0.23b	29.07 ± 0.60c
Bulk density (g/cm^3)	0.58 ± 0.01d	0.64 ± 0.01e	0.68± 0.01f
pH	5.31 ±0.15a	8.12 ±0.15b	7.42 ±0.18c
EC(ds/m)	5.48 ±0.24d	9.01 ±0.15e	4.65 ± 0.21f
OC (%)	37.37 ±0.26a	21.90 ±1.81b	12.96 ±0.29c
OM (%)	64.43 ±0.46d	37.76 ±3.12e	22.34 ±0.50f
C:N	10.56 ±0.92a	14.93 ±1.20b	11.09 ±0.39a
TN (%)	3.54 ±0.01d	1.47 ±0.01e	1.17 SD ± 0.02f
TP **(%)**	3.29 ±0 .09157a	0.96 ±0.03b	0.56 ± 0.00634c
K (%)	2.74 ± 0.03d	6.32 ±0.11e	0.62 ± 0.04f
Ca(me/ 100g)	67.47 ± 2.41a	44.99 ± 26.23b	24.32 ± 14.18c
Mg (me/100g)	5.25 ± 0.19d	10.91 ± 0.39e	17.78 ± 0.63f

Where: Different letters within each row indicate that the samples are significantly different at a significance level of $\alpha = 0.05$, according to the LSD test. Values followed by the same letters within a row were not significantly different.

PWC had the highest moisture content (53.60 ± 0.40%) and the lowest bulk density (0.58 ± 0.01 g/cm^3) while MSWC had the lowest moisture content (29.07 ± 0.60%) and the highest bulk density (0.68 ± 0.01 g/cm^3). The LSD values indicate that the moisture content and bulk density of the three samples are significantly different from each other.

According to the California Integrated Waste Management Board Compost Quality Standards (2008) the recommended moisture content for finished compost should be in the range of 30-

40% (Life, 2008). Additionally the Government of India's Ministry of Agriculture and Rural Development specifies that the bulk density of finished compost should be less than 1 g/cm^3 (The Fertilizer Control Order, 1985).The data presented suggests that the three composts met the recommended standards. The bulk density of all three composts was within the standard range of less than 1 g/cm^3. Similarly the moisture content of the composts was more or less within the recommended range of 30-40% (Life, 2008).This is an important parameter as the moisture content affects the physical and microbial properties of the compost which in turn can influence its effectiveness as a soil amendment. Composts with appropriate moisture content and low bulk density are generally easier to handle, incorporate into the soil, and provide benefits such as improved soil fertility, water holding capacity and plant growth (Tittarelli et al.,2007).

The pH values of the three compost samples varied significantly and PWC had the lowest pH (5.31 ± 0.15), which was significantly lower than both MSWC (7.42 ± 0.18) and FKC (8.12 ± 0.15). The difference in pH between MSWC and FKC was also statistically significant. The EC values showed a similar pattern, with FKC having the highest EC at 9.01 ± 0.15 ds/m, followed by PWC (5.48 ± 0.24 ds/m) and MSWC (4.65 ± 0.21 ds/m). The differences in EC between all three compost samples were statistically significant.

The pH values of the compost samples showed mixed results when compared to the Bord na Mona standard (2003) which specifies a pH range of 6.9 - 8.3 (Prasad, 2003). The MSWC and FKC fell within the acceptable pH range specified by the Bord na Mona standard. In contrast, the PWC had a significantly lower pH of 5.31. However it is noted that the PWC pH of 5.31 was still within the compost specification range of 5.0 - 8.5 for general landscape applications as per the U.S. EPA archive document (Ackerman,2004). The pH of compost is crucial as it can impact the availability and uptake of nutrients by plants as well as influence the soil's ability to support beneficial microorganisms (Hargreaves et al.,2008). Overall the three composts fall within acceptable pH ranges for general landscape and plant applications but the variations in pH levels should be taken into account when selecting the most appropriate compost for a given soil and plant system. The lower pH of the PWC compost led to higher water-extractable concentrations of some metals. Under acidic conditions micronutrients tend to be more soluble and available for plant uptake.Therefore managing the compost pH may be a potential approach to mitigate the heavy metal availability (Hargreaves et al.,2008).

The EC values also showed variable adherence to the Bord na Mona standard (2003) range of 2 - 6 dS/m (Prasad,2003). The PWC and MSWC had EC values fell within the recommended range. The FKC had the highest EC at 9.01 dS/m. However this EC value for the FKC was still within the compost specification maximum limit 10 dS/m for general landscape applications as per the U.S. EPA archive document (Ackerman,2004).

Hwang et al. (2020) reported a pH of 7.3 and an EC of 3.2 dS/m for poultry waste compost. Sarangi et al. (2008) observed a pH range of 7 - 8 and an EC between 1 and 1.4 dS/m for filter cake compost. The FKC had a relatively higher EC compared to the previous studies it was still within the acceptable limit specified for general landscape use. This suggests that the FKC may be suitable for soil amendment and plant applications but its potential impact on soil and plant health should be carefully evaluated. Excess salts in soils including sodium (Na) can be detrimental to plant growth and soil structure. Electrical conductivity is a measure of the dissolved solute content of the soil and is commonly used as an indicator of soil salinity (Hargreaves et al.,2008).Composts with EC values within the recommended range are generally considered suitable for application without posing a risk of excessive salinity (Epstein,2011).

PWC had the highest OC and OM content of (37.37% ± 0.26 and 64.43% ± 0.46) respectively. These values were significantly higher than those of FKC (21.90 % ± 1.81 OC and 37.76 % ± 3.12 OM) and MSWC (12.96 %± 0.29 OC and 22.34 % ± 0.50 OM).

Comparing the OM results of the present study with similar materials Shyamala and Belagali (2015) reported an OM content of 17.4% in MSWC, Teshome et al. (2014) found an OM content of 29.31% in FKC and Suhartini et al. (2020) reported an OM content of 59.75% in PWC. These findings are more or less equivalent to the OM contents observed in the current study. The OM content of the three compost samples PWC, FKC and MSWC was found to be greater than 25%. This OM content level is considered the recommended range for good quality compost suitable for agricultural use in the UK as per the guidelines provided by Life (2008).The high OM content of these three compost samples indicates that they possess desirable characteristics for use as compost in agricultural settings. By meeting the quality standards established in the UK these compost materials could be effectively utilized to improve soil fertility and promote plant growth when applied to agricultural land.

The organic matter content of compost is an important indicator of its potential to improve soil fertility. Compost with higher OM content can enhance soil structure water holding capacity and nutrient availability when applied to the soil (Diacono and Montemurro.,2010).

This is because organic matter acts as a store house for essential plant nutrients such as nitrogen, phosphorus and sulfur which are gradually released through the process of mineralization (Larney and Angers.,2012). Additionally, the humic substances in compost can chelate and solubilize micronutrients making them more accessible to plants (Canellas et al., 2015).

The C: N ratio was highest in FKC (14.93 ± 1.20), followed by MSWC (11.09 ± 0.39) and PWC (10.56 ± 0.92). The difference in C:N ratio between PWC and FKC was statistically significant but the difference between PWC and MSWC was not. The C:N ratios observed in the current study are lower compared to the average C:N ratios reported in the previous studies.

Vyas (2011) found an average C:N ratio of 18.83 in MSWC. Teshome et al. (2014) observed an average C:N ratio of 15.48 in FKC. Hwang et al. (2020) reported an average C:N ratio of 20.5 in PWC. The C:N ratio of the raw feedstock materials used to produce each compost type can vary significantly. Feedstocks with a higher carbon content relative to nitrogen will result in composts with a higher C:N ratio (Epstein,2011).

The composting method, duration, aeration and other parameters can influence the final C:N ratio of the compost. Differences in the composting process between the studies could lead to variations in the C:N ratios even for similar feedstocks (National Engineering Hand booK

,2010). The degree of decomposition and stabilization of the organic matter in the compost can affect the C:N ratio. More mature and stabilized composts tend to have lower C:N ratios as the carbon is mineralized and released as CO_2 during the composting process (Bernal et al.,1998).

Differences in sampling techniques and analytical methods used to determine the C:N ratio in the different studies could also contribute to the observed variations. The C:N ratio is an important indicator of compost maturity as it reflects the balance between the carbon and nitrogen content in the compost (Bernal et al.,1998).

The California Integrated Waste Management Board Compost Quality Standards for finished compost (2008) recommend that the carbon to nitrogen ratio of the material should be less than 17:1 (Life.,2008). The C: N ratios observed in the study for all three compost types FKC, MSWC and PWC fell within this recommended range indicating that the compost materials were well balanced in terms of their carbon and nitrogen content and met the standard requirements for finished compost. The C/N ratio of the three composts lower than 17 may indicate their suitability for addition to soil (Bernal et al.,1998).

PWC had the highest TN (3.54% ± 0.01) and TP (3.29% ± 0.09157) content which were significantly higher than the corresponding values in FKC and MSWC. FKC had also the highest K (6.32 % ±0.11) which was significantly higher than the corresponding values in PWC and MSWC. LSD values indicate that the nutrient contents of the three samples are significantly different from each other. Suhartini et al. (2020) found that PWC had a TN content of 1.04%, TP content of 1.29% and K content of 0.95%. Sarangi et al. (2008) reported that FKC had a TN content of 1.27%, TP content of 1.61 % and K content of 2.5-4%. Shyamala and Belagali (2015) found that MSWC had a TN content of 0.80%, TP content of 0.97% and K content of 0.18%.

The nutrient contents of organic composts can vary depending on the feedstock used for composting. Differences in the types and proportions of organic materials can lead to variations in the final nutrient profile of the compost (Epstein.,2011). The composting methods, duration and conditions e.g., temperature, moisture and aeration can influence the nutrient transformation and retention during the process leading to differences in the final nutrient composition (National Engineering Hand booK, 2010).

During the composting process the transformation and potential losses of different nutrients N, P, K can vary depending on the feedstock and process parameters. For example nitrogen can be lost through ammonia volatilization while phosphorus and potassium may be more conserved in the final compost (Epstein,2011). Differences in the analytical techniques and methods used to determine the nutrient contents in the various studies could also contribute to the observed variations.

According to the standards for compost established by the Sri Lanka Standards Institution the desirable threshold values for mature composts are TN > 1.0% ,TP > 0.22% and K > 0.83% (Dandeniya et al.,2020).The analysis of the three compost samples PWC, FKC and MSWC revealed that all three samples met these desirable threshold values for TN, TP and K content.

This suggests that the PWC, FKC and MSWC compost samples are likely balanced and mature compost types based on the nutrient content standards set by the Sri Lanka Standards Institution. The information implies that these composts could be well suited for agricultural applications as they align with the standards established for mature nutrient-rich compost.

PWC had the highest Ca content (67.47 ± 2.41 me/100g) and the lowest Mg content (5.25 ± 0.19 me/100g). FKC had the highest Mg content (17.78 ± 0.63 me/100g). The LSD values show that the Ca and Mg contents of the three samples are significantly different from each other.

Shyamala and Belagali (2015) found a Ca and Mg content of 14.5 and 3.2 me/100g respectively in MSWC. Suma and Sathish (2018) reported a Ca and Mg content of 40.5 and 17.5 me/100g respectively in FKC. Hwang et al. (2020) found a Ca and Mg content of 0.4 and 0.1 me/100g respectively in PWC. The Ca and Mg contents observed in the current study are more or less equivalent to the values reported in these previous studies.

The results indicate that the three compost samples PWC, FKC and MSWC have significantly different in physico-chemical properties. PWC had the highest organic matter, nutrient (N, P, K) and calcium content but it has the lowest pH and EC. FKC had the highest pH, EC and Mg content while MSWC had the lowest organic matter, nutrient and moisture content but the highest bulk density. These differences in compost properties can be attributed to the different raw materials and composting processes used to produce each type of compost.

To further investigate the differences between the compost samples the study employs the LSD statistical analysis. The LSD values confirm that the variations in the physicochemical properties among the three compost samples are statistically significant. This suggests that the samples have distinct nutrient profiles and consequently may exhibit different effects on soil properties and plant growth when used as soil amendments.

4.3 MICRONUTRIENTS AND HEAVY METALS LEVELS OF THE COMPOSTS

The analysis of heavy metal concentrations in compost samples is crucial for evaluating the suitability and safety of the compost for agricultural applications. The analysis of micronutrients and heavy metals in the three compost samples PWC, FKC and MSWC is presented in Table 12. This analysis offers valuable insights into the unique properties and variations in micronutrient and heavy metal content among the samples.

Table 12. Mean values of micronutrients and heavy metals of the compost samples

Properties (mg/kg)	PWC	FKC	MSWC
Mn	871.41 ±9.19a	935.47 ± 4.82b	708.03 ± 2.40c
Fe	5463.75±34.80d	19711.3±160.33e	20977.17±143.55f
Cu	103.74 ±1.44a	62.83 ± 0.62b	44.40 ±0.60c
Zn	783.11±7.92d	265.44± 2.59e	182.00 ±2.35f
B	34.14±0.57 a	18.19 ± 0.29b	13.25 ±0.65c
Cr	29.2423±0.52d	43.90 ±0 .51e	35.80 ±0.82f
Ni	22.15±0.61a	19.82 ±0 .41b	38.10 ±0.97c
Pb	75.16±2.12a	72.76 ± 1.65a	62.61 ±2.87c
As	0.5657±0.02d	0.5680 ± 0.01d	0.6357 ±0.02f
Cd	2.60±0.07d	6.32 ±0 .16e	6.04 ±0.12f
Hg	3.70±0.22a	3.86 ± 0.23a	2.08 ±0.13c

Where: Different letters indicate that samples are significantly different at ($\alpha = 0.05$) according to LSD test with in a row and values followed by the same letters with in a row were not significantly different.

Table 13. Heavy metals limit: EU states, U.S.A., Canada and Australia

Metal	EU-Range (mg/kg)	USA biosolids (mg/kg)	CCME (mg/kg)	Australian biosolids (mg/kg)	Source
As				60	Brinton. (2000)
Cd	0.7-10	39	3–20	20	Canadian Council of Ministers of the Environment (2005)
Cr	70-200	1,200	210	500-3000	
Cu	70-600	1,500	400	2500	
Hg	0.7-10	17	0.8–5	16	Life. (2008).
Ni	20-200	420	62–180	270	
Pb	70-1,000	300	150–500	420	
Zn	210-4,000	2,800	700–1850	2500	

The mean value of Mn in PWC is 871.41 mg/kg ±9.19. The mean value of Mn in FKC is 935.47 mg/kg ±4.82.The mean value of Mn in MSWC is 708.03 mg/kg with a standard deviation of ±2.40.The LSD analysis shows that the mean value of Mn in FKC is significantly higher than PWC and MSWC while the mean value of Mn in PWC is significantly higher than MSWC. The higher Mn content in FKC and PWC compared to MSWC may be attributed to the differences in the source materials and composting processes. The significantly higher Mn content in FKC compared to PWC and MSWC suggests that application of FKC as a soil amendment may provide a more abundant source of this essential nutrient for plant growth.

Vyas (2011) reported that the average manganese (Mn) content in MSWC was 369.68 mg/kg. Subsequently Suma and Sathish (2018) found a higher Mn content of 566.40 mg/kg in FKC. The current study has observed Mn content values that are higher than the concentrations reported in these previous studies. This suggests that the Mn content in the compost samples analyzed in the current work is elevated compared to the MSWC and FKC samples investigated earlier. Some possible reasons for the higher Mn content in the current study could be differences in the source and composition of the organic waste materials used to produce the compost. The type and origin of the feedstock can significantly influence the mineral content including Mn, in the final compost (Hossain et al.,2017).Variations in the composting process such as duration, temperature and aeration which can affect the availability and retention of Mn during decomposition. Potential contamination or the addition of Mn rich amendments during the composting or post-processing stages (Hossain et al., 2017).

Manganese is an essential micronutrient for plants playing a vital role in various physiological processes such as photosynthesis, respiration and enzyme activation (Millaleo et al., 2010). The availability of Mn in the soil can be influenced by factors like pH, organic matter content and microbial activity (Hossain et al.,2017). It is important to note that the availability and uptake of Mn by plants can be influenced by various soil and environmental factors such as pH, organic matter content and the presence of other nutrients (Hossain et al.,2017).

The mean value of Fe in PWC is 5463.75 mg/kg with a standard deviation of ±34.80.The mean value of Fe in FKC is 19711.3 mg/kg with a standard deviation of ±160.33. The mean value of Fe in MSWC is 20977.17 mg/kg with a standard deviation of ±143.55. The LSD analysis shows that the mean value of Fe in FKC and MSWC is significantly higher than PWC while the mean value of Fe in MSWC is significantly higher than FKC.

Although the LSD analysis shows that the overall higher Fe content in all the three composts suggests that they may be well suited as soil amendments to address Fe deficiencies in plants. The higher Fe content in PWC (5463.75 mg/kg ± 34.80), FKC (19711.3 mg/kg ± 160.33) and MSWC (20977.17 mg/kg ± 143.55) can be attributed to the source materials and the composting process used for each type of compost.

Vyas (2011) reported an average iron (Fe) content of 20,160.33 mg/kg in MSWC. The Fe content observed in the current study appears to be equivalent to the values reported by Vyas (2011). In contrast Suma and Sathish (2018) found a lower Fe content of 1,242 mg/kg in FKC which is lower than the 19,711.3 mg/kg Fe content reported in the current study. The discrepancy between the Fe content in the current study and the previous report by Suma and

Sathish (2018) for FKC samples could be attributed to several factors. The higher Fe content observed in the current study's FKC samples compared to the previous report by Suma and Sathish (2018) suggests that the compost analyzed in the current work may have a different feedstock composition or processing history. Potential contamination or the addition of Fe rich amendments during the composting or post processing stages.

The mean value of Cu in PWC is 103.74 mg/kg with a standard deviation of ±1.44.The mean value of Cu in FKC is 62.83 mg/kg with a standard deviation of ±0.62. The mean value of Cu in MSWC is 44.40 mg/kg with a standard deviation of ±0.60. The LSD analysis shows that the mean value of Cu in PWC is significantly higher than FKC and MSWC while the mean value of Cu in FKC is significantly higher than MSWC.

The mean value of Zn in PWC is 783.11 mg/kg with a standard deviation of ±7.92.The mean value of Zn in FKC is 265.44 mg/kg with a standard deviation of ±2.59. The mean value of Zn in MSWC is 182.00 mg/kg with a standard deviation of ±2.35. The LSD analysis shows that the mean value of Zn in PWC is significantly higher than FKC and MSWC while the mean value of Zn in FKC is significantly higher than MSWC.

Vyas (2011) reported that the average copper (Cu) and zinc (Zn) contents in municipal solid waste compost (MSWC) were 512.4 mg/kg and 767.33 mg/kg, respectively. These values represent relatively high concentrations of these micro nutrients in the MSWC samples analyzed in that study. In contrast Suma and Sathish (2018) found much lower Cu and Zn contents in FKC with values of 71.60 mg/kg and 157.20 mg/kg, respectively. This suggests that the FKC samples had significantly lower concentrations of these heavy metals compared to the MSWC reported by Vyas (2011). Further Li et al. (2021) investigated the Cu and Zn contents in PWC and reported values of 61.66 mg/kg and 424.11 mg/kg respectively. The Cu content in PWC was even lower than that observed in the FKC samples by Suma and Sathish (2018) while the Zn content was higher than in the FKC but still lower than the MSWC reported by Vyas (2011).

The differences in the Cu and Zn contents among these various compost types MSWC, FKC and PWC can be attributed to several factors such as source and composition of the organic waste materials used as feedstock for composting the processing methods and conditions employed during the composting duration, temperature and aeration which can affect the availability and retention of Cu and Zn in the compost. Potential contamination or addition of Cu and Zn rich amendments during the composting or post processing stages (Dıaz-Barrientos et al.,2003; National Engineering Hand book.,2010).

According to the standard limits for heavy metals in compost the allowable ranges and values for Cu are EU: 70-600 mg/kg, US biosolids: 500 mg/kg,CCME: 400 mg/kg and Australian bioslids: 2500 mg/kg (Brinton, 2000; Canadian Council of Ministers of the Environment, 2005;life .,2008) . For Zn the allowable ranges and values are EU: 210-4,000 mg/kg, US biosolids: 2,800 mg/kg, CCME: 700-1,850 mg/kg and Australian bioslids 2500 mg/kg (Brinton, 2000; Canadian Council of Ministers of the Environment, 2005;life ,2008). The findings of the current study's PWC, FKC, and MSWC analyses all fell within the four standard limit ranges suggesting that the feedstock materials utilized for the composts were appropriate in terms of their Cu and Zn content.

Cu deficiency in plants can lead to stunted growth chlorosis (yellowing of leaves) and reduced crop yield. Excessive Cu on the other hand can be toxic to plants and cause oxidative stress (Alloway, 2008). Zn is another essential micronutrient that is critical for various plant metabolic processes including protein synthesis, auxin production and the activity of several enzymes. Zn deficiency in plants can lead to stunted growth, chlorosis and reduced root development while excessive Zn can be toxic and cause oxidative stress (Alloway,2008).

Compost containing appropriate levels of Cu and Zn within the standard limits such as the present study samples can help improve the availability and uptake of Cu and Zn by plants thereby enhancing their growth and productivity. The Cu and Zn content in compost can also help counteract Cu and Zn deficiency in soils which is a common issue in some regions due to factors such as soil type, pH and organic matter content (Rengel,2015; Alloway,2008).

The mean value of B in PWC is 34.14 mg/kg with a standard deviation of ±0.57. The mean value of B in FKC is 18.19 mg/kg with a standard deviation of ±0.29. The mean value of B in MSWC is 13.25 mg/kg with a standard deviation of ±0.65. The LSD analysis shows that the mean value of B in PWC is significantly higher than FKC and MSWC while the mean value of B in FKC is significantly higher than MSWC. The variations in B content among the different composts PWC, FKC and MSWC can be attributed to the inherent B levels in the respective feedstocks the presence of B-containing supplements or additives used in the source materials and the dilution or concentration effects during the composting process. The relatively higher B content in PWC can be attributed to the inherent B levels in poultry manure which is the primary feedstock for this compost. Poultry feed often contains B containing supplements such as boric acid or borax to meet the nutritional requirements of the birds (Gunes et al.,2003). The B from these supplements can accumulate in the poultry manure and subsequently be present in the PWC. Additionally the bedding materials used in poultry farms such as wood shavings or straw may also contribute to the B content in the final PWC (Bolan et al., 2003).

Boron is an important micronutrient. At elevated concentrations it can be phytotoxic particularly when pH values and nitrogen concentrations are low conditions that are most common in immature composts (Ryan and Chaney 1993). According to the standard limit for B in compost in Austria which is 100 mg/kg (Brinton, 2000), the values of B in the samples of PWC, FKC and MSWC were within the safe range for plant application. This suggests that the composts in the study were low in boron and would not pose a risk to plants if applied. Boron is an essential micronutrient for plants but can be toxic in high concentrations so it is important to ensure the levels in compost and other soil amendments are within the recommended limits.

The mean value of Cr is highest in FKC 43.90 mg/kg, followed by MSWC 35.80 mg/kg and PWC 29.24 mg/kg. Compared to the standards, EU Range: 70-200 mg/kg, USA biosolids: 1,200 mg/kg, CCME: 210 mg/kg and Australian biosolids: 500-3,000 mg/kg the Cr concentrations in all three compost types PWC, FKC and MSWC are well below the maximum limits set by the standards.

The mean value of nickel (Ni) is highest in MSWC (38.10 mg/kg) followed by PWC (22.15 mg/kg) and FKC (19.82 mg/kg). Compared to the standards EU-Range: 20-200 mg/kg, USA biosolids: 420 mg/kg, CCME: 62-180 mg/kg and Australian biosolids: 270 mg/kg the Ni concentrations in all three compost types PWC, FKC and MSWC are well below the maximum limits set by the standards.

The mean value of arsenic (As) is highest in MSWC (0.6357 mg/kg) followed by FKC (0.5680 mg/kg) and PWC (0.5657 mg/kg). The As concentrations in all three compost types PWC, FKC and MSWC are well below the maximum limit set by the standard Australian biosolids: 60mg/kg.

The mean value of lead (Pb) is highest in PWC (75.16 mg/kg) followed by FKC (72.76 mg/kg) and MSWC (62.61 mg/kg). Compared to the standards: EU-Range: 70-1,000 mg/kg, USA biosolids: 300 mg/kg, CCME: 150-500 mg/kg and Australian biosolids: 420 mg/kg the Pb concentrations in all three compost types (PWC, FKC and MSWC) are well below the maximum limits set by the standards.

The mean value of cadmium (Cd) is highest in FKC (6.32 mg/kg) followed by MSWC (6.04 mg/kg) and PWC (2.60 mg/kg). Compared to the standards: EU-Range: 0.7-10 mg/kg, USA biosolids: 39 mg/kg, CCME: 3-20 mg/kg and Australian biosolids: 20 mg/kg the Cd concentrations in all three compost types (PWC, FKC and MSWC) are well below the maximum limits set by the standards.

The mean value of mercury (Hg) is highest in FKC (3.86 mg/kg) followed by PWC (3.70 mg/kg) and MSWC (2.08 mg/kg). Compared to the standards: EU-Range: 0.7-10 mg/kg, USA biosolids: 17 mg/kg, CCME: 0.8-5 mg/kg and Australian biosolids: 16 mg/kg. the Hg concentrations in all three compost types (PWC, FKC, and MSWC) are well below the maximum limits set by the standards.

The study reported mean values of Cr, Ni, Pb, Cd, and Hg in MSWC as 35.80, 38.10, 62.61, 6.04, and 2.08 mg/kg, respectively. In contrast Vyas (2011) found higher average values of Cr

(113.18 mg/kg), Ni (48.85 mg/kg), Pb (182.62 mg/kg), Cd (8.58 mg/kg) and lower Hg (0.08 mg/kg) in MSWC.The current study reported mean values of Cr, Ni, As, and Cd in PWC as 29.24, 22.15, 0.57, and 2.60 mg/kg, respectively. In comparison, Li et al. (2021) found higher values of Cr (76.17 mg/kg), Ni (28.22 mg/kg), As (27.22 mg/kg), and Cd (3.09 mg/kg) in PWC.

The source and composition of the municipal solid waste and poultry waste may vary depending on the geographical location, waste management practices and environmental conditions (Hargreaves et al., 2008). The degree of compost maturity and the specific composting methods employed can influence the heavy metal levels in the final product (Luo et al., 2017). Factors such as aeration, temperature and the use of bulking agents during the composting process can affect the availability and transformation of heavy metals (Luo et al., 2018).

4.4. PHYTOTOXICITY TEST

The phytotoxicity test using barley, cabbage, and tomato seeds as indicator plants was a crucial step in evaluating the maturity and safety of the different compost types. This test aimed to assess the potential adverse effects of the composts on seed germination and root growth, which is an important indicator of the compost's readiness for safe agricultural or horticultural applications. The results presented in table 14 provide valuable insights into the phytotoxicity levels of the PWC, FKC and MSWC.

Table 14. Barley, cabbage and tomato seeds mean germination (%) in compost water extract

Compost type	% Germinated		
	Barley	**Cabbage**	**Tomato**
PWC	95.33 ±3.06a	84.33 ±4.04b	87.33 ±10.97c
FKC	96.67 ±3.05a	81.00 ±1.73b	82.00 ±1.73c
MSWC	96.00 ±0.00a	87.00 ±5.29b	87.67 ±9.61c

Where: Different letters indicate that samples are significantly different at ($\alpha = 0.05$) according to LSD test with in a column and values followed by the same letters with in a column were not significantly different.

The barley seed germination percentages are high across all the compost types ranging from 95.33% to 96.67%, with the highest percentage (96.67%) observed in FKC followed by MSWC (96.00%) and PWC (95.33%). The cabbage seed germination percentages are lower compared to barley ranging from 81.00% to 87.33% with the highest percentage (87.00%) observed in MSWC followed by PWC (84.33%) and FKC (81.00%). The tomato seed germination percentages range from 82.00% to 87.67% with the highest percentage (87.67%) observed in MSWC followed by PWC (87.33%) and FKC (82.00%). The LSD values indicate that the differences in germination percentages among the three compost types are not statistically significant at the 0.05 level for all three crops.

Barley seeds showed high germination percentages (over 95%) across all the compost types with no statistically significant differences among them. Cabbage and tomato seeds had relatively lower germination percentages compared to barley but the differences were not always statistically significant.

The MSWC appeared to have the least phytotoxic effect as it resulted in the highest germination percentages for cabbage and tomato seeds compared to the other compost types.
Paradelo et al. (2008) found that using MSWC extract resulted in high germination percentages of 106%, 96% and 100% for barley, ryegrass and cress, respectively. Warman

(1999) reported 100% germination rates for cress, radish and cabbage seeds when using MSWC in a direct seed test. These additional studies further demonstrate that MSWC tends to have a low phytotoxic effect and can support high seed germination rates. The consistent findings across multiple studies suggest that MSWC is a compost type that is relatively safe and beneficial for plant growth at least in terms of its impact on seed germination.

While the MSWC showed the highest performance on barley, cabbage, and tomato seeds, the PWC and FKC also displayed high germination percentages for these seeds. The high germination percentages (mostly above 80%) reported for the compost samples suggest that these composts have undergone proper composting and stabilization processes (Zucconi et al., 1985). This indicates that the compost products are mature and non phytotoxic, meaning they do not contain any phytotoxic (plant toxic) substances that could inhibit seed germination and plant growth (Zucconi et al., 1985).

Table 15 presents the germinated barley, cabbage and tomato seeds mean root length, standard deviation (SD), LSD and statistical significance in compost water extract treatments. The data provides insight into the effects of different compost types on the root growth of these three plant Species.

Table 15 . Barley, cabbage and tomato germinated seeds mean root growth % in compost water extract

Compost type	**% Root growth**		
	Barley	**Cabbage**	**Tomato**
PWC	73.33 ±15.07a	69.83 ±23.46b	97.43 ±4.45d
FKC	60.83 ±1.44a	98.96 ±1.78c	84.60 ±15.40d
MSWC	72.50 ±12.99a	100 ±0.00c	66.63 ±8.89e

Where: Different letters indicate that samples are significantly different (at α = 0.05) according to LSD test with in a column and values followed by the same letters with in a column were not significantly different.

The highest barley root growth percentage was observed in the PWC at 73.33% with standard deviation of 15.07.The FKC had the lowest barley root growth at 60.83%, the MSWC had a barley root growth of 72.50% all were not significantly different from each other. The MSWC had the highest cabbage root growth at 100% with no standard deviation. The PWC and FKC had significantly lower cabbage root growth compared to the MSWC, with the PWC at 69.83% and the FKC at 98.96%.The PWC had the highest tomato root growth at 97.43%.The FKC had the second highest tomato root growth at 84.60% which was not significantly higher than the MSWC at 66.63%.

The different compost types had varying effects on the root growth of barley, cabbage and tomato germinated seeds. The MSWC showed the highest cabbage root growth while the PWC had the highest barley and tomato root growth. These results suggest that the choice of compost type can significantly influence the root development of different plant species.

Table 16 presents the germination index (GI) of barley, cabbage and tomato seeds in compost water extracts derived from different compost types.

Table 16. Barley, cabbage and tomato germination index % in compost water extract

Compost type	**% GI**		
	Barley	**Cabbage**	**Tomato**
PWC	69.73 ±13.06a	58.33 ±17.65b	85.51 ±12.93d
FKC	58.78 ±1.20a	79.97 ±0.05c	69.65 ±13.70d
MSWC	69.60 ±12.47a	86.67 ±5.20c	57.96 ±4.35e

Where: Different letters indicate that samples are significantly different (at $\alpha = 0.05$) according to LSD test with in a column and values followed by the same letters with in a column were not significantly different.

The germination index (GI) results from the experiment with barley showed a range of 69.73 to 58.78 % (Table 16). When tested with tomato seeds the GI values ranged from 85.51 to 57.96 %. Similarly for cabbage seeds the GI varied between 86.67 and 58.33 %.

The consistent finding of GI values exceeding 50% across the different seed types suggests the composts have undergone appropriate stabilization and maturation processes (Zucconi et al., 1985). A GI < 50% means high phytotoxicity, values between 50% and 80% indicate moderate phytotoxicity, and values > 80% indicate no phytotoxicity (Zucconi et al., 1985). Since all the compost samples had a GI > 50% and some of them GI > 80%, this suggests that the composting process appears to have eliminated the phytotoxic (toxic to plants) properties of the raw material. Low GI values typically less than 50% are often associated with the presence of phytotoxic compounds or conditions that inhibit seed germination and plant growth.

For example a study by Gao et al. (2010) found that heavy metal contamination in soil led to a significant reduction in the GI of various crop seeds indicating the phytotoxic effects of the metals. Low GI values typically less than 50% are often associated with the presence of phytotoxic compounds or conditions that inhibit seed germination and plant growth (Zucconi et al., 1985).

High GI values, generally above 80%, suggest that the tested substance or condition has no phytotoxic effect on seed germination (Zucconi et al., 1985).

A study by Bakonyi et al.,(2013) found that the application of biofertilizers with high GI values had minimal phytotoxic effects on maize. Furthermore factors such as pH, salinity and organic matter content can also affect the GI and the overall phytotoxicity of a substance (Zucconi et al.,1981).The study samples PWC, FKC and MSWC composts exhibit moderate to no phytotoxicity.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSIONS

The study found significant variations across multiple parameters. The feedstocks exhibited differing levels of pH, EC, OC, OM and plant nutrients such as TN, TP, K, Ca and Mg. These differences can significantly influence the composting process and the quality of the final compost product.

The significant differences between the compost samples, as confirmed by the LSD analysis suggest that they may have varying effects on soil properties and plant growth when used as soil amendments.

The heavy metal analysis of the compost samples in the present study indicated that they are suitable and safe for agricultural applications. This is because the concentrations of all heavy metals were within the standard regulatory limits ensuring their suitability for use in agriculture. The GI test revealed that the PWC, FKC and MSWC composts exhibited moderate to no phytotoxicity.

Overall the comprehensive analysis provides valuable information for selecting the most appropriate compost for specific agricultural applications based on the desired soil and plant requirements.

5.2 RECOMMENDATIONS

Based on the findings of this study the following recommendations are provided:

- The study found that the composts exhibited moderate phytotoxicity potentially due to insufficient maturity. Composters should develop a culture of closely monitoring the quality of their feedstock, in process compost material and the final compost product to ensure proper maturity and stability is achieved.

- The study provided insights into the physico-chemical characteristics of the poultry, filter cake and municipal solid waste feedstocks. Composters should use this information to optimize the selection and blending of these materials to improve the quality and stability of the resulting composts.

- To address the issues of phytotoxicity and potential pathogenic concerns composters should implement robust process control measures throughout the composting operation. This may include monitoring key parameters such as temperature, moisture and oxygen levels to ensure optimal conditions for decomposition and pathogen reduction.

- The findings of this study underscore the importance of developing and implementing comprehensive quality assurance protocols for composting operations. This should include regular testing and evaluation of the feedstock, in process material and final compost product to ensure compliance with relevant standards and guidelines.

- To further investigate the effects of the compost samples field level studies on the impact on plant growth and yield are necessary.

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7. APPENDICES

APPENDIX 1. One way ANOVA for selected parameters

a. Anova for pH

Compost	N	Mean	Std. D	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
PWC	3	5.3133	.15275	.08819	4.9339	5.6928	5.18	5.48
FKC	3	8.1200	.15395	.08888	7.7376	8.5024	7.99	8.29
MSWC	3	7.4200	.18083	.10440	6.9708	7.8692	7.23	7.59
Total	9	6.9511	1.27303	.42434	5.9726	7.9297	5.18	8.29

Note: Std.D = standard deviation.

b. Multiple comparisons using LSD for Ph

Compost		Mean Difference	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
PWC	FKC	-2.80667*	.13311	.000	-3.1324	-2.4810
	MSWC	-2.10667*	.13311	.000	-2.4324	-1.7810
FKC	PWC	2.80667*	.13311	.000	2.4810	3.1324
	MSWC	.70000*	.13311	.002	.3743	1.0257
MSWC	PWC	2.10667*	.13311	.000	1.7810	2.4324
	FKC	-.70000*	.13311	.002	-1.0257	-.3743

*. The mean difference is significant at the 0.05 level

c. Anova for EC

Compost	N	Mean	Std.D	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
PWC	3	5.4767	.23861	.13776	4.8839	6.0694	5.31	5.75
FKC	3	9.0067	.14978	.08647	8.6346	9.3787	8.84	9.13
MSWC	3	4.6533	.21733	.12548	4.1134	5.1932	4.49	4.90
Total	9	6.3789	2.01071	.67024	4.8333	7.9245	4.49	9.13

Note: Std.D = standard deviation.

d. Multiple comparisons using LSD for EC

Compost		Mean Difference	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
PWC	FKC	-3.53000*	.16773	.000	-3.9404	-3.1196
	MSWC	.82333*	.16773	.003	.4129	1.2338
FKC	PWC	3.53000*	.16773	.000	3.1196	3.9404
	MSWC	4.35333*	.16773	.000	3.9429	4.7638
MSWC	PWC	-.82333*	.16773	.003	-1.2338	-.4129
	FKC	-4.35333*	.16773	.000	-4.7638	-3.9429

* The mean difference is significant at the 0.05 level.

e. Anova for OM

Compost	N	Mean	Std. D	Std. Error	95% Confidence Interval for Mean Lower Bound	Upper Bound	Minimum	Maximum
PWC	3	64.4273	.46133	.26635	63.2813	65.5733	63.90	64.73
FKC	3	37.7640	3.12051	1.80163	30.0122	45.5158	35.46	41.32
MSWC	3	22.3400	.50406	.29102	21.0878	23.5922	21.80	22.79
Total	9	41.5104	18.50873	6.16958	27.2834	55.7375	21.80	64.73

Note: Std.D = standard deviation.

f. Multiple comparison using LSD for OM

Compost		Mean Difference	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
PWC	FKC	26.66333*	1.50588	.000	22.9786	30.3481
	MSWC	42.08733*	1.50588	.000	38.4026	45.7721
FKC	PWC	-26.66333*	1.50588	.000	-30.3481	-22.9786
	MSWC	15.42400*	1.50588	.000	11.7393	19.1087
MSWC	PWC	-42.08733*	1.50588	.000	-45.7721	-38.4026
	FKC	-15.42400*	1.50588	.000	-19.1087	-11.7393

* The mean difference is significant at the 0.05 level.

g. Anova for TN

Compost	N	Mean	Std. D	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
PWC	3	3.5392	.00970	.00560	3.5151	3.5633	3.53	3.54
FKC	3	1.4672	.00970	.00560	1.4431	1.4913	1.46	1.47
MSWC	3	1.1685	.01800	.01039	1.1238	1.2133	1.15	1.18
Total	9	2.0583	1.11823	.37274	1.1988	2.9179	1.15	3.54

Note: Std.D = standard deviation.

h. Multiple comparisons using LSD for TN

Compost		Mean Difference	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
PWC	FKC	2.07200*	.01067	.000	2.0459	2.0981
	MSWC	2.37067*	.01067	.000	2.3446	2.3968
FKC	PWC	-2.07200*	.01067	.000	-2.0981	-2.0459
	MSWC	.29867*	.01067	.000	.2726	.3248
MSWC	PWC	-2.37067*	.01067	.000	-2.3968	-2.3446
	FKC	-.29867*	.01067	.000	-.3248	-.2726

*. The mean difference is significant at the 0.05 level.

i. Anova for TP

Compost	N	Mean	Std. D	Std. Error	95% Confidence Interval for Mean Lower Bound	Upper Bound	Minimum	Maximum
PWC	3	3.2890	.09157	.05287	3.0615	3.5165	3.19	3.36
FKC	3	.9590	.02735	.01579	.8910	1.0269	.93	.98
MSWC	3	.5594	.00634	.00366	.5436	.5751	.55	.57
Total	9	1.6024	1.27758	.42586	.6204	2.5845	.55	3.36

Note: Std.D = standard deviation.

j. Multiple comparisons using LSD for TP

Compost		Mean Difference	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
PWC	FKC	2.33001*	.04515	.000	2.2195	2.4405
	MSWC	2.72960*	.04515	.000	2.6191	2.8401
FKC	PWC	-2.33001*	.04515	.000	-2.4405	-2.2195
	MSWC	.39959*	.04515	.000	.2891	.5101
MSWC	PWC	-2.72960*	.04515	.000	-2.8401	-2.6191
	FKC	-.39959*	.04515	.000	-.5101	-.2891

k. Anova for K

Compost	N	Mean	Std. D	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
PWC	3	2.7443	.03362	.01941	2.6608	2.8278	2.72	2.78
FKC	3	6.3166	.10919	.06304	6.0453	6.5878	6.20	6.41
MSWC	3	.6188	.04096	.02365	.5170	.7205	.57	.65
Total	9	3.2265	2.49434	.83145	1.3092	5.1439	.57	6.41

Note: Std.D = standard deviation.

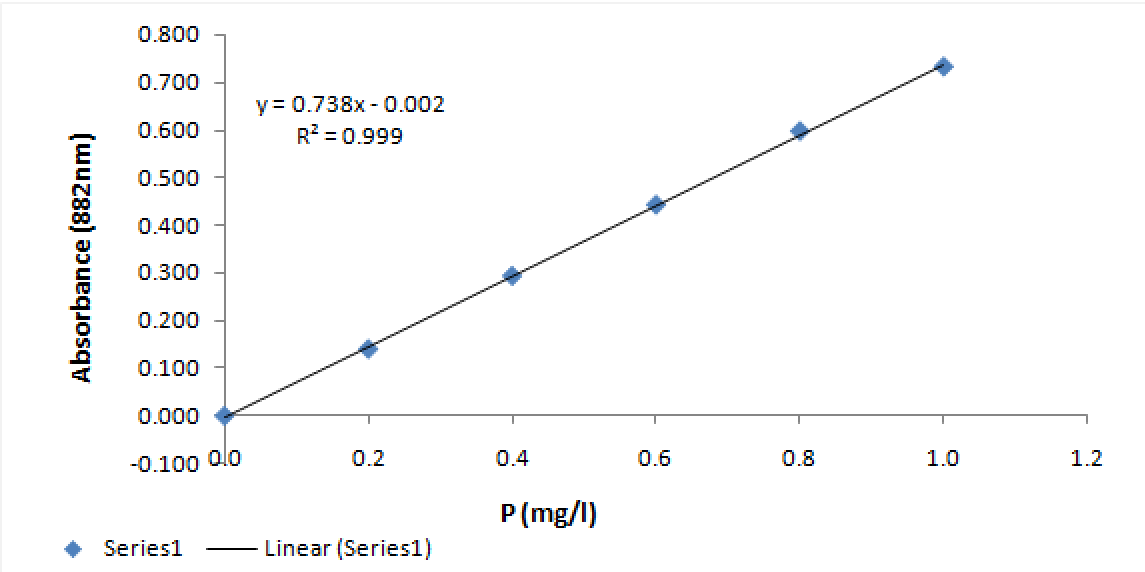
l. Multiple comparisons using LSD for K

Compost		Mean Difference	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
PWC	FKC	-3.57232*	.05721	.000	-3.7123	-3.4323
	MSWC	2.12550*	.05721	.000	1.9855	2.2655
FKC	PWC	3.57232*	.05721	.000	3.4323	3.7123
	MSWC	5.69782*	.05721	.000	5.5578	5.8378
MSWC	PWC	-2.12550*	.05721	.000	-2.2655	-1.9855
	FKC	-5.69782*	.05721	.000	-5.8378	-5.5578

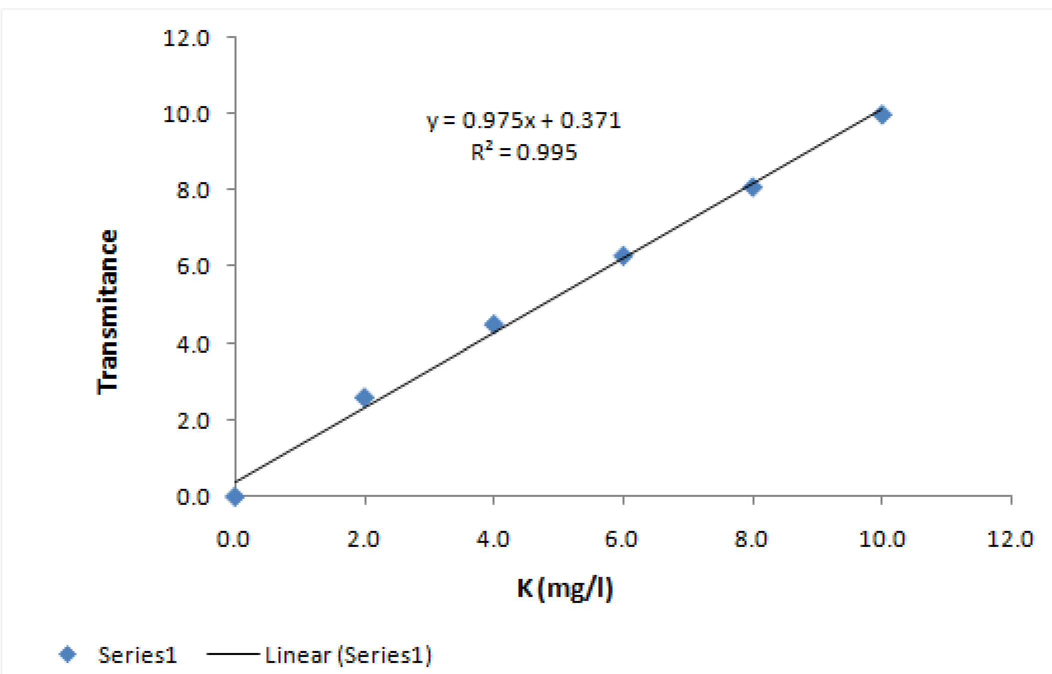
* The mean difference is significant at the 0.05 level.

APPENDIX **2.** Figures of Regression graphs

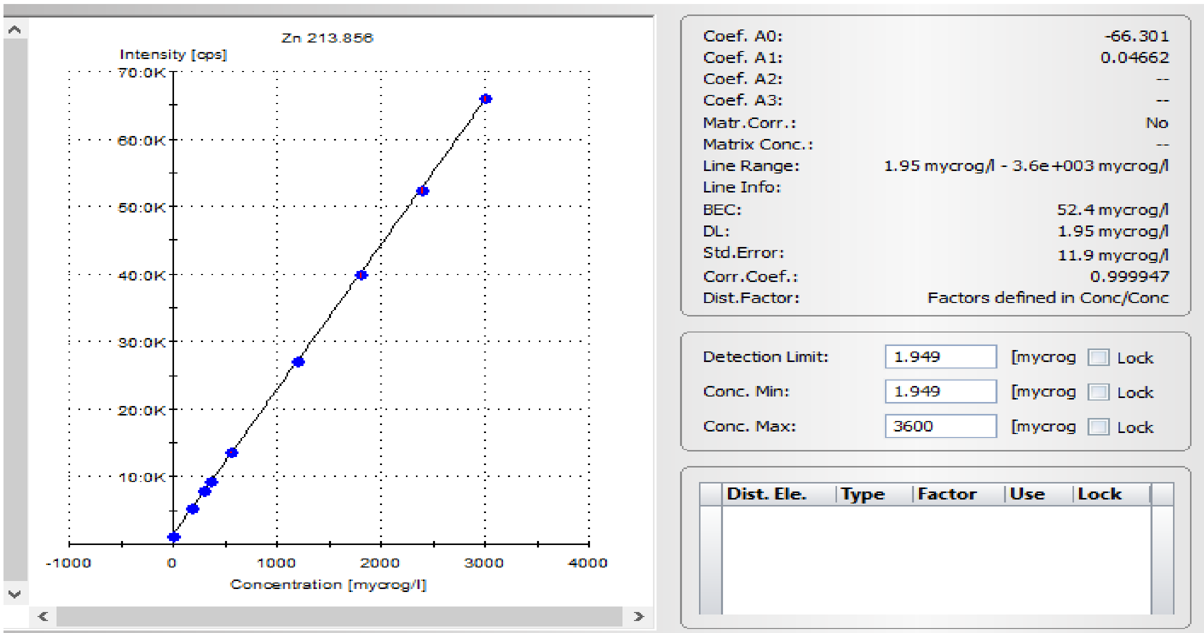
- **Absorbance versus to concentration graph, for total P analysis**



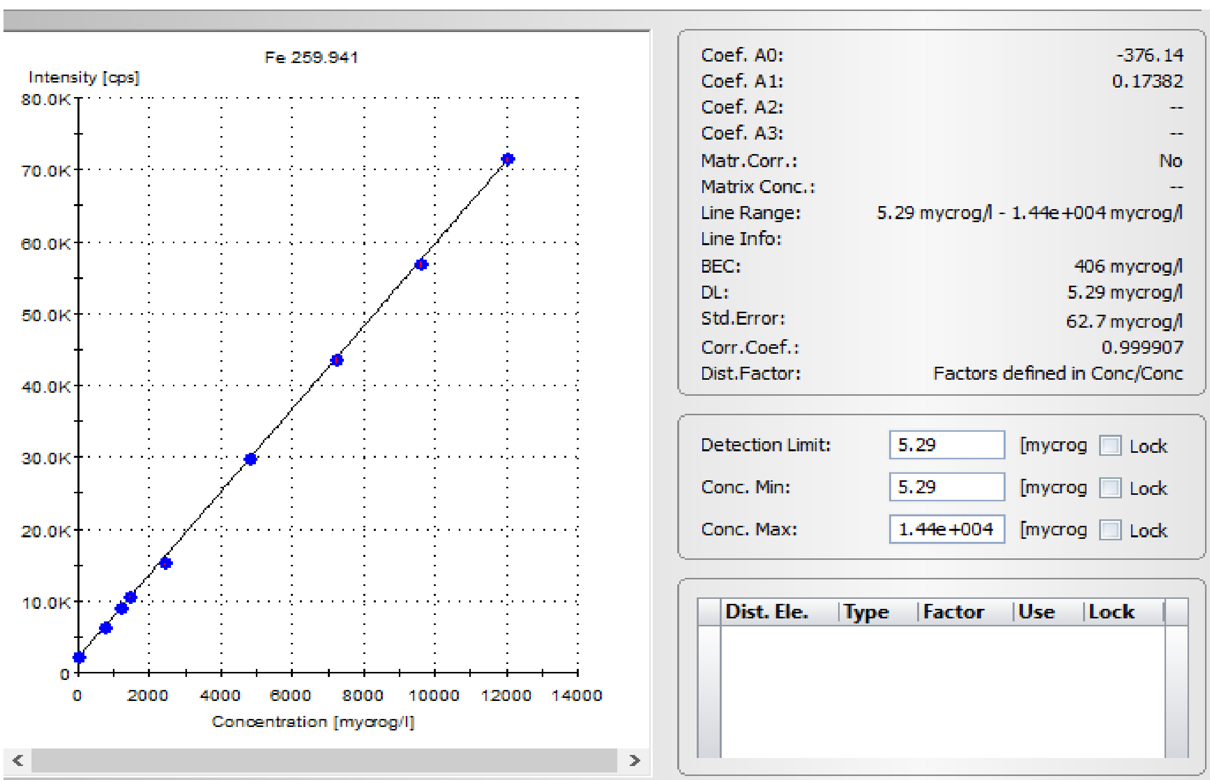
- **Transmitance versus to concentration graph, for K analysis**



3.Intensity versus to concentration graph , for Zn analysis



4.Intensity versus to concentration graph, for Fe analysis



Appendix 2. Pictures

Final Product Compost

Sampling

Sample preparation

PH and EC analysis

ICPOES, at Horticoop Ethiopia Lab

On total P analysisAppendix