ASSESSMENT OF VERMI-TECHNOLOGY IN SOLID WASTE MANAGEMENT

THESIS

Submitted in fulfillment of the requirement of Degree of

DOCTOR OF PHILOSOPHY

to

The Faculty of Sciences

by

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July, 2023

Dedicated

with

love

to

a pure soul

My adorable sister

Kanika

(in her loving memory)

DECLARATION

I hereby declare that this thesis entitled, **"Assessment of Vermi-Technology in Solid Waste Management"** by **Monika Mago**, being submitted in fulfillment of the requirements for degree of Doctor of Philosophy in Environmental Sciences under the Faculty of Sciences at J.C. Bose University of Science & Technology, YMCA Faridabad, during the academic year 2022-23, is a bonafide record of my original work carried out under guidance and supervision of **Dr. Renuka Gupta, Associate Professor, Department of Environmental Sciences**, J.C. Bose University of Science & Technology, YMCA, Faridabad and **Dr. V.K. Garg, Professor, Department of Environmental Science & Technology**, Central University of Punjab, Bathinda and has not been presented elsewhere.

I further declare that to the best of my knowledge, the thesis does not contain part of any work which has been submitted for the award of any degree either in this university or in any other university.

Dated:	**Monika Mago**
Place: Faridabad	**YMCAUST/PH06/2014**

CERTIFICATE

This is to certify that the thesis entitled, **“Assessment of Vermi-Technology in Solid Waste Management”** by **Monika Mago**, being submitted in fulfillment of the requirement for degree of Doctor of Philosophy in **Environmental Sciences** under the Faculty of Sciences, J.C. Bose University of Science & Technology, YMCA, Faridabad, during the academic year 2022-23, is a bonafide record of work carried out under our guidance and supervision.

We further declare that to the best of our knowledge, the thesis does not contain any part of any work which has been submitted for the award of any degree, either in this university or in any other university.

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Dated:
Place: Faridabad **Monika Mago**

ABSTRACT

The paradigm shifts towards technological reverberation and industrial advancement in developing nations like India, along with the increasing rates of population growth and urbanization has consequently accelerated the solid waste generation. The urban cities are facing a mammoth of challenges in handling plenteous mass of waste generated and potential threat to environment and peoples' health. Waste heap itself is breeding ground for diseases, risk for sanitary workers / rag pickers coming in direct contact with solid waste, source of air, soil and water contamination and locally small yet a significant contributor of greenhouse gas emissions. It is the melancholy that despite all the efforts by municipal authorities / agencies in collecting waste from almost all the areas of city somehow connection between waste collected and managed is not retained. A cocktail of biodegradable and non-biodegradable waste is found lying everywhere aggravating the problem that should be addressed on a serious note. This urged us to draw the attention of community, researchers and civic authorities towards the quantum of waste generation that have been unintentionally neglected. Waste generated is neither put / gathered / disposed or managed in an appropriate manner. As major fraction of solid waste stream has a load of organic materials from residential, market, agricultural and industrial sources, focus is kept on conversion of this wet organic waste into vermimanure after source-segregation of waste generated. In the remaining fractions of waste, the dry fraction can be given for recycling / recovery of useful materials, finally left with only non-recyclable portion to be landfilled.

"Assessment of Vermi-technology in Solid waste management" aims to find a sustainable solution and contribute in city's waste management by harnessing the potential of vermicomposting technology in managing the organic waste burden. It is important to know the local conditions, quantity and types of waste produced at city level, socio - economic factors and disposal pattern as an input for effective solid waste management. Magnitude of problem sounds big, still perception of efficient waste management relies on change in attitude "not my waste" and "not my problem" along with an individual's / community's participation and support of municipal authority. Complete study has been sectioned into 12 chapters encompassing the problem of solid waste disposal / management, household waste composition and quantity (through a sample area study), proposing a four bin vermicomposter for managing household solid waste, understand source and nature of waste generated, select a variety of biodegradable wastes for vermicomposting, assessing their physical, chemical and biological characteristics along with nutrient dynamics and maturity indices and pot culture experiments to evaluate suitability as manure. A few recommendations and future scope have been given

inclusive of conclusions of study. Chapter 1 introduces by addressing the solid waste management issue troubling the nation and narrows down to a city's problem of piled wastes that are socially, aesthetically, economically and environmentally straining the civil authority. It describes the sources of solid waste, disposal, management / treatment methods, impacts of improper solid waste disposal and Integrated Solid Waste Management hierarchy that keeps landfilling as the last option. Current status of waste generation, manner of disposal (ultimately at landfill) and waste management in Faridabad city (India) has been outlined and relevance of study along with the study objectives in this context have been made. Chapter 2 opens up with the description of vermicomposting system, earthworms involved, classification, changes in different parameters and factors affecting the process. The chapter reviews and summarizes the existing literature for various vermicomposting studies carried out previously for different kind of wastes. Chapter 3 discusses in detail the methodology and materials used in the study. The general methodology for all the studies and experimental design have been presented in the chapter before moving to the experimental work. Chapter 4 focusses on the management of household solid waste (through decentralization) and is sectioned into four parts starting with the waste characterization and composition analysis in Faridabad city (India), vermicomposting of household solid waste, effect of earthworm stocking & seasonal temperature variations on household waste vermicomposting and designing a prototype of four bin vermicomposter for organic waste management at household level.

Chapter 5 investigates the vermicomposting potential of food processing industry waste for recovery of nutrients. Residual biomass of two cruciferous vegetable wastes (cabbage leaf waste and cauliflower waste) were vermicomposted separately and their nutrient levels and maturity were assessed via different methods including FT-IR analysis and germination index. Chapter 6 reports the vermicomposting of Bakery sludge using fruit and vegetable waste as co - amendment (reducing the amount of cow dung) and enhancement in performance of bakery sludge in vermicomposting due to presence of this co-amendment was investigated. Chapter 7 purposes the management of banana leaf waste biomass by vermi-technology. Chapter 8 demonstrates the utilization of market fruit and vegetable waste which is rich in organic matter, macro and micro nutrients can be sustainably transformed into valuable product bio manure. Chapter is divided into two sections; first section is based on vermicomposting of mixed fruit and vegetable wastes from domestic and commercial areas and second section assesses the potential of vermicomposting in gaining nutrients from carrot leaf waste.

Chapter 9 forms the basis for managing rice residue (agricultural waste) which has very slow degradation rate and often burnt openly in fields leading to severe air pollution in pre-winter season. Rice residue was co-blended with leaf litter in suitable proportions to make proper feed environment for earthworms along with cow dung to obtain vermicompost having improved nutrient levels. Chapter 10 considers sustainable management of rice weed *Echinochloa crus-galli* by employing vermicomposting technology. Mixing with cow dung in apt amounts make it a favorable feed substrate for earthworms and vermi-technology provides solution to the weed problem by converting it into valuable fertilizer and facilitating on site management of *E.crusgalli*. Chapter 11 exhibits the influence of vermicomposts as potting media on growth of ornamental / medicinal plants. Chapter has two sections, former assesses the effect of cabbage and cauliflower vermicomposts on growth parameters of ornamental plant Marigold, *Tagetes erecta* and latter examines the influence of household solid waste vermicompost on growth and productivity of Sadabahaar, *Catharanthus roseus* (an ornamental as well as a medicinal plant). Chapter 12 concludes the study with the outcomes of all the experiments in nut shell. A few suggestions and recommendations have been provided followed by the scope of future study.

“Finally, thesis is winded up with a hope and belief of unwinding the mindsets of people towards waste which is an ultimate resource if used mindfully.”

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List of Abbreviations

Symbols	**Meaning**
ANOVA	Analysis of Variance
BR	Benefit Ratio
BS	Bakery Sludge
C:N	Carbon to Nitrogen
C:P	Carbon to Phosphorus
CAB	Cabbage Leaf Waste
CAU	Cauliflower waste
CD	Cow Dung
CE	Cow excrement
CRLW	Carrot Leaf Waste
FT-IR	Fourier Transform - Infrared Spectroscopy
FVW	Fruit and Vegetable Waste
GI	Germination Index
HSD	Honestly Significant Difference
HSW	Household Solid Waste
MCF	Municipal Corporation Faridabad
NPK	Nitrogen, Phosphorus, Potassium
RR	Rice Residue
RRG	Relative Root Germination
RSG	Relative Seed Germination
SPSS	Statistical Package for Social Sciences
TAP	Total Available Phosphorus
TK	Total Potassium
TKN	Total Kjeldahl Nitrogen

Chapter 1

INTRODUCTION

Solid waste management has emerged as a significant developmental challenge worldwide due to rapid urbanization, industrial advancement and population growth. According to estimates, waste generation increases proportionately with rate of urbanization and population, resulting in a consistent decrease in per capita land area. Due to poor collection and disposal practices, this waste ends up as roadside garbage or poorly-managed landfills at most of the places which produce harmful gases and leachates, contaminate water bodies, transmits vector-borne diseases, increases respiratory problems due to air-borne particles, harms animals that eat waste unknowingly and many more. Municipalities, government & non-government organizations, and the scientific community are under continuous stress to manage the copious amount of waste generated.

As per World Bank's report (2018), approximately 2.0 billion Metric Tons (MT) of municipal solid waste is produced on yearly basis worldwide and about 33% is not disposed off in environment friendly manner. The report projects that global waste generation will increase by 70% in next 30 years with 3.4 billion tons of waste generation annually. The developed countries generate higher quantities of waste as a result of advanced lifestyle standards; the fractions of waste produced are treated due to financial and technological advancements. As a result, their overall waste generation and disposal is reduced. But the developing nations don't have strong technological framework for eco-friendly waste disposal due to their weaker economies. The condition is critical for developing nation like India, comprising 1.38 billion population which makes 17.86% of global population. Of this, 32.8% population is urban which is increasing at 3 - 3.5% per annum, as a result, the rate of waste generation/capita/year is also increasing by 1.3%. With this rate of percent increase in per capita waste generation, total waste production is estimated to escalate from 62.0 million MT to 165.0 million MT per annum in 2030. According to Central Pollution Control Board (CPCB), New Delhi report (2013), out of total waste collected, only 12.45% waste is scientifically processed, and rest is disposed off in open dumps.

Indian city municipalities are facing difficulty to handle such vast quantity of municipal solid waste generated on daily basis and ultimately huge fraction of solid waste is left untreated due to inefficient facilities, finance and infrastructure [1]. According to estimates, if current approach of dumping unmanaged municipal solid waste keep on going, by 2050, the country will need an area almost of size of New Delhi ($\approx$88 square kilometers), the country's capital city to dump its waste (ASSOCHAM and PwC, 2017). Poorly managed waste resulted from many years of development necessitates urgent action at all levels of society. Solid wastes are the residual materials generated by natural and anthropogenic activities which are neither of use at the point of generation nor escape into air and water. These are generated from various sources and can be categorized differently (Table 1.1). In addition, the construction and demolition waste including scrap building materials and debris is also rising at a very fast rate.

Municipal Solid Waste (MSW) management is gaining momentum in urban areas of India, but the majority of cities exhibit inefficiencies in environmentally sound and sustainable waste management. With the burgeoning population and indifferent civic services coupled with wasteful consumerism, the symptoms of strain on the environment and living conditions are conspicuously evident in urban areas. Heaps of garbage and waste of every type strewn here and there have become very common in these areas. Per capita waste generation has also accelerated at a rate of 0.26 kg/day to 0.85 kg/day (CPCB India, 2018). Figure 1.1 represents waste generation/capita/day in Indian cities [2]. It is obvious from the figure that waste generation in some cities has been high owing to city's expansion & economic growth, urbanization, expanding population and living standards. Income level affects consumerism and use & throw attitude of people, thereby affecting waste generation. A callous attitude of people towards waste aggravates the situation [3] The huge solid waste generated surpasses the

Table 1.1: Solid Wastes – Categories, Sources and Types

Classification	**Sources**	**Types**
Municipal Solid Waste	• Residential - Households, buildings/ apartments, etc. • Commercial - Market places, hotels, restaurants, shopping malls, institutions • Open areas - Streets, parks, playgrounds, etc. • Treatment plants- Water and waste - water treatment processes.	Food waste, garden waste, residual sludge, paper waste, etc.
Industrial Waste	• Wastes produced during the industrial activity e.g. Food processing, textiles, paper & allied products, chemicals, rubber, food products, petroleum & refineries, etc.	Chemicals, metals, scrap products, glue, gypsum, asbestos resins, glass, organic dyes, etc.
Hazardous Waste	• Residential, commercial or industrial activities and that produce waste of hazardous nature due to characteristics - ignitability, corrosivity, reactivity, toxicity.	Volatile organic chemicals, toxic gases & liquids, inflammable substances, etc.
Bio-medical Wastes	• Waste produced during the diagnosing and treating humans and animals as well as scientific research.	Chemical, pathological wastes, infectious wastes, sharp objects, laboratory wastes, pharmaceutical wastes, etc.
Plastic Wastes	• Waste generated from indiscriminate use and disposal of plastic into the physical environment.	Food wraps, plastic containers and stoppers, carry bags, straws as well as stirrers, etc.
E-Waste	• Electrical and electronic equipments discarded by consumers, discards from manufacturing and repair processes.	LCD monitors, smart displays, and tablets, Laptops, computers, mobile, etc.

Source: Assocham and PwC (2017)

assimilation capacity of ecosystems and the insufficient installed capacity for its handing, promotes the proliferation of open dumps in most of the regions. As per available research studies, the following two major issues are related to improper solid waste disposal:

a) Loss/ under-utilization of energy/resource contained in waste

b) Social cost related to resulting health problems in the community living in the vicinity of dumpsites and public misery/suffering due to poor waste collection services. Increasing incomes, unplanned enhanced urban growth, and luxurious living standards have generated higher quantities and variable composition (enhanced utilization of paper, plastic and inorganic contents) of MSW in the country. Physical composition of MSW relies on consumption pattern, food habits, life style, seasonal variation, per capita income etc. Studies reveal that the percentage of the organic matter forms the highest proportion (Table 1.2) in Indian cities whereas in developed countries, paper, plastics and glass / metals has maximum share than organic waste due to use of packaged food materials and other products and low moisture content [2]

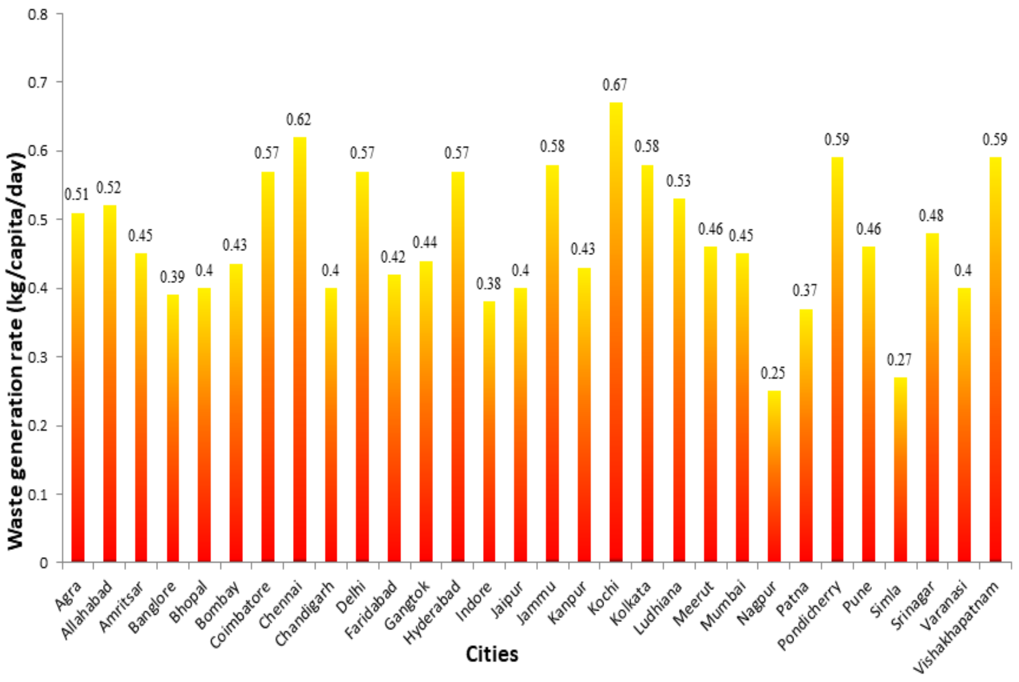


Figure 1.1: Per capita waste generation / day in some Indian cities

The data in the table showed that Indian cities generate waste which has more organic content (about 50%) and low calorific value in comparison to developed countries [4]. General features of MSW in developing countries include more density and moisture, larger organic component, and higher dust/dirt particles due to sweeping and open-dumping as compared to developed countries.

In general, MSW management comprises of the process / step as waste generation, storage, collection, transfer, transport, processing, disposal of waste. But only four activities out of these are in usual practice at most places, i.e., waste generation, collection, transportation and disposal. The primary requirement for managing the waste sustainably includes efficient infrastructure and upgradation of the processes/activities. However, due to rapid and unplanned urban growth, these requirements impose significant financial burden on existing system, as a result, the required services in terms of waste collection, processing and disposal are not met efficiently by municipal corporations in cities.

Table 1.2: Composition of Municipal Solid Waste (Indian cities and developed countries)

S. No.	**Components**	**% weight**	
		Indian cities (Developing countries)	Developed countries
1	Paper	5	33
2	Plastics	4	11
3	Metals/ Glass	5	16
4	Rags/clothes	7	2
5	Inert silt, construction waste	29	17
6	Biodegradable waste (Food waste, garden trimmings)	50	21

Source: [5],[6],[2]

MSW management is important to the national economy, health, and sanitation. There are numerous technologies and methodologies available for effective solid waste management and treatment, such as waste-to-energy conversion, incineration, gasification, pyrolysis, landfilling, and composting [7]. These are given in Figure 1.2. Each method has its own merits and demerits. No single solution has universal applicability. In majority of urban centers, sanitary landfills and open dumpsites are opted as the final disposal methods for almost every kind of waste generated from residences, markets, institutes, waste processing facilities and inorganic waste / inert materials which will not be used or recycled further. The dumping sites are chosen depending on their close vicinity to the collection points. Compaction and levelling of the waste and covering the waste with inert material are not practiced usually at most of dumping places. Untreated waste mixtures of organic / biodegradable and nonbiodegradable components remain for days / months / years at these dumping sites.

Further, the uncontrolled dumping at these sites often create overflowing and airless heaps of waste, which are not only difficult to reclaim because of the haphazard manner of dumping, but also have serious environmental implications in terms of ground/surface water pollution and contribution to global warming in absence of the leachate and gas collection systems [8],[9]. These sites represent the picture of open dump yard rather than sanitary landfill posing health risks associated with spread of vector-borne diseases like dysentery, typhoid, cholera, yellow fever, plague, etc. Dumpsites have been found to emit or produce toxic chemicals such as persistent organic pollutants (POPs) and heavy metals [10].

According to CPCB report (2015), about 48% of total methane emission of the country is produced by only seven Indian megacities due to improper waste disposal in the dumping sites. Since the waste generated presently is also not treated efficiently, it aggravates the problem. It is projected that 80 - 90% of municipal waste is disposed off in landfills without proper management practices, resulting in air, water, and soil pollution [5],[4]. All these issues necessitate a proper disposal and management system. Various impacts of improper waste disposal are depicted in Figure 1.3. The present trends in increase in solid waste generation would require more and more land in and around the cities. Due to restricted space for landfilling, stringent governmental waste disposal regulations and public awareness, these strategies have become more difficult and costly.

According to Solid Waste (Management and Handling) Rules 2016 by Ministry of Environment, Forest and Climate Change (MoEFCC), India, urban local bodies (ULBs) have the responsibility for any infrastructure development for MSW management. As per the rules, it has become mandatory to segregate waste at point of generation itself. This will facilitate the waste-to-wealth approach by implementing recovery, reuse and recycle. Further, it is clearly stipulated that the biodegradable waste should be processed and treated in-situ by a suitable combination of the bio-processes, i.e., composting, vermicomposting, anaerobic digestion, etc. The residual waste, if any, can be disposed off through waste collectors in line with the directions of local authority. Only the non-biodegradables, inert and other appropriately stabilized bio-wastes should find their way to landfill sites.

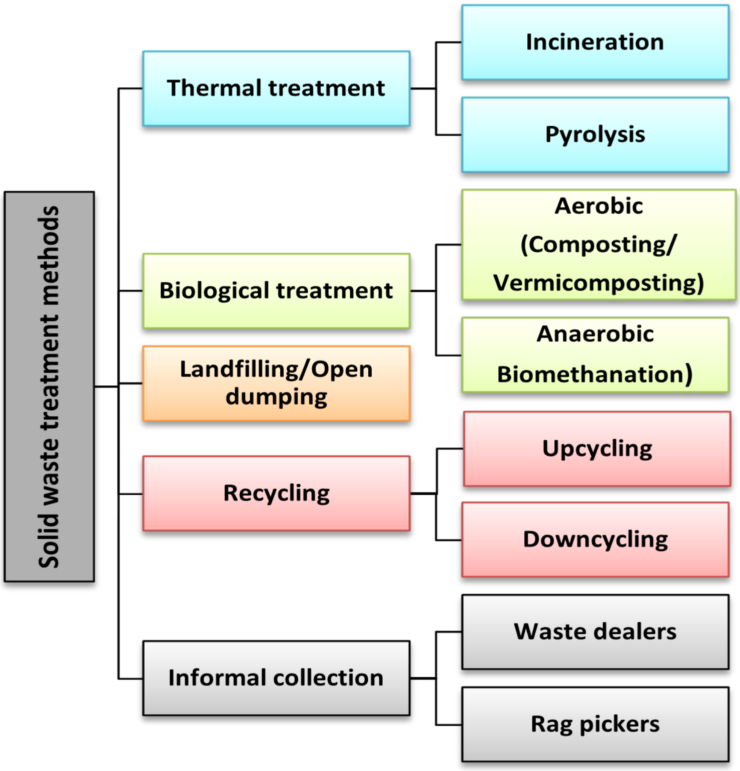


Figure 1.2: Solid waste management / treatment methods

This could significantly reduce the burden of solid waste management on urban local bodies. For sustainable MSW processing or technological solutions, the integrated solid waste management (ISWM) hierarchy as exhibited in Figure 1.4 can be adopted [3]. In this approach, the most preferred waste prevention strategies are waste minimization at the source and product reuse, followed by recycling the waste materials. Waste disposal in open dumpsites is the least preferred option. ISWM is useful for ULBs to ensure sustainable and eco-friendly solid waste management and promote resource recovery.

However, considering the environmental risks associated with the present solid waste disposal practices, source-segregation leading to separate non-biodegradable (to be recycled) and biodegradable fraction (for conversion into valuable products) may prove to be the best solution to waste disposal problems. The solid waste composition in India reveals that about 50% of the total waste consists of organic fraction which can be put to good use by bio - processes like composting and vermicomposting, thus, recovering resource and reducing waste. This practice leads to significant reduction in amount of waste to be land-filled, moreover, it will lead to substantial decrease in cost of transportation of waste.

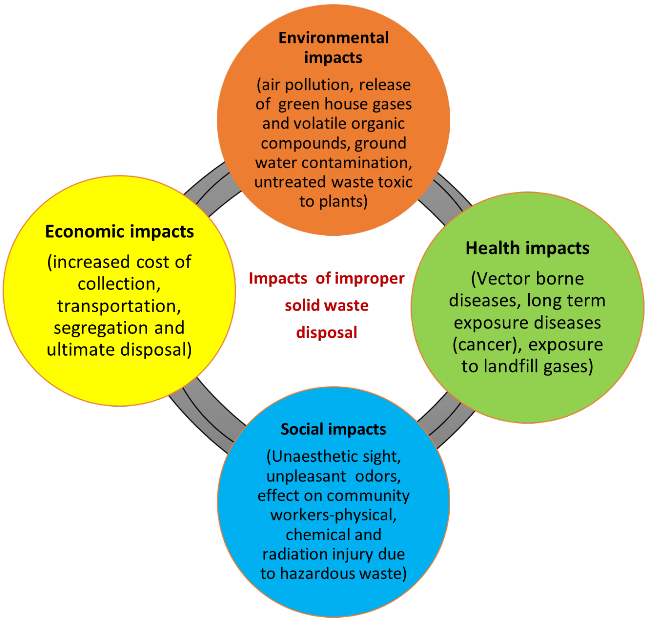


Figure 1.3: Impacts of improper solid waste disposal

In yester years, municipalities and private owners used biological processes for managing municipal solid waste and convert it into energy and biofertilizer. Aerobic composting/vermicomposting as well as waste to energy (biomethanation,etc.) are the two preferred strategies in India for treatment of waste. Among these, vermicomposting is emerging as an efficient, eco - friendly and low - cost technology for the degradation of biodegradable waste generated from domestic, agricultural and industrial areas.

In its simplified form, vermicomposting is a bio - technological composting process involving combined activities of earthworms and microbes for conversion of the organic waste into ”vermicompost” rich in plant nutrients. Almost any organic waste from agriculture, urban or industries may be utilized as feed substrate in vermicomposting provided it is non-toxic to earthworms. The worms complete bio-conversion of wastes into enriched compost in 2 - 3 months in an aerobic environment. Introduction of earthworms in organic waste speeds up the degradation process, converts waste into more stabilized humus like substance termed as vermicompost (Figure 1.5). Vermicompost is odour free, fragmented, porous, enriched with nutrients and microbially active [11], [12].

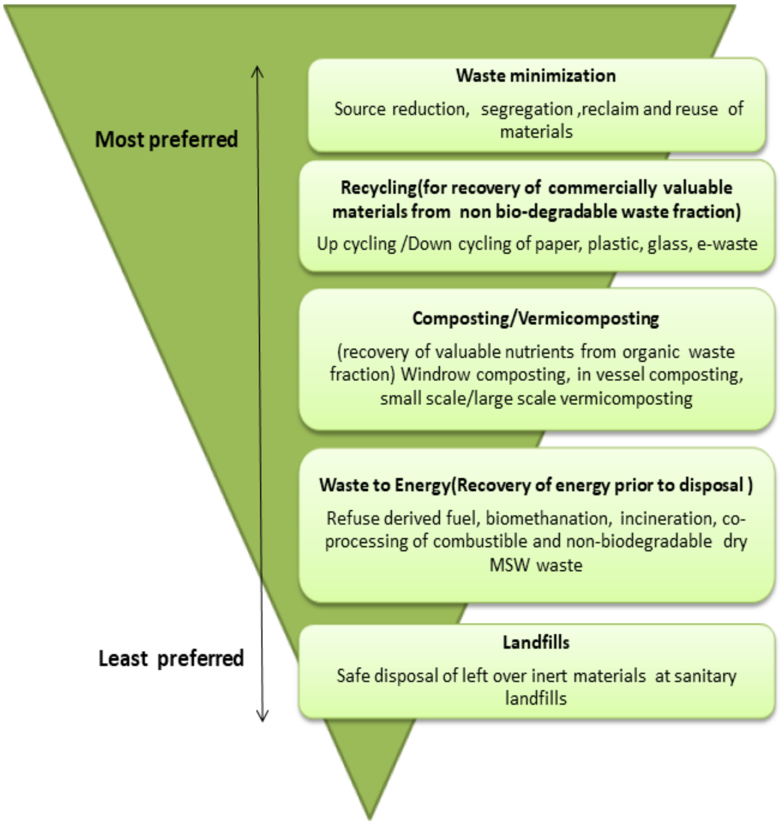


Figure 1.4: Integrated Solid Waste Management Hierarchy

Essential nutrients are present in plant-available forms in vermicompost, can be used as biofertilizer thus can be an alternative to chemical fertilizers. Vermicomposting produces a large amount of worm biomass because the worms multiply quickly during vermi - conversion. It is a valuable resource that is now finding new uses in the feed and pharmaceutical industries [13],[14]. It is well understood now that the manurial ability and carbon content of soil is continuously decreasing due to excessive utilization of chemical fertilizers. Therefore, it is required to add humus to the soil to enhance its fertility and water holding capacity. Studies by the Indian Council for Agricultural Research (ICAR) has shown that compost / vermicompost used with chemical fertilizers stipulate 15% increase in food production creating a strong case for its promotion.

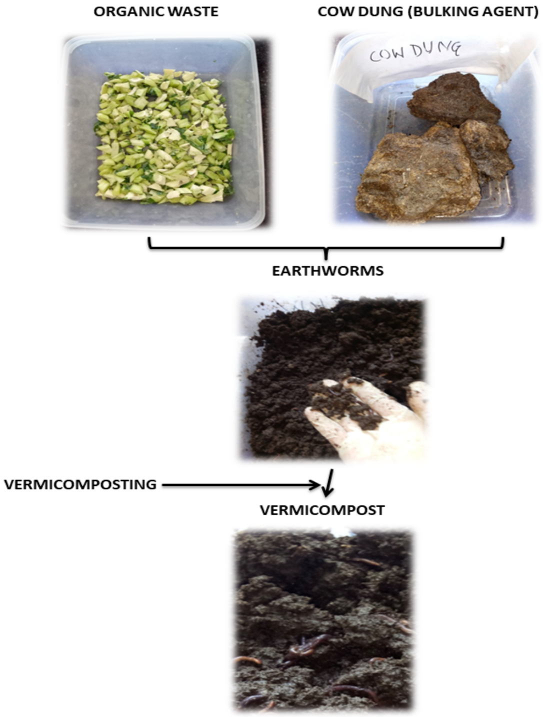


Figure 1.5: Vermicomposting process

Vermicomposting is being commercialized all over the world for mid to large scale vermi - conversion of most organic wastes (food and farm wastes and green wastes, as well as hazardous wastes like sewage sludge and fly-ash) from developed countries like the United States, Canada, the United Kingdom, Australia, Russia, and Japan to developing countries like India, China, Chile, Brazil, Mexico, Argentina, and the Philippines [15]. Some Indian states like Bihar, Punjab, Gujarat, and Tamil Nadu have numerous firms that produce and provide vermicompost throughout the country. The Karnataka Compost Development Corporation in India established the country's first vermi - composting unit to handle all the municipal urban solid wastes and produces 150 to 200 tons of vermicompost from city garbage every day [16]. Vermicompost is highly porous, aerated, humified and has high water holding capacity than traditional compost. Thus, use of vermicompost reduces the need of irrigation water by 30 - 40% . As vermicompost is produced at local level from organic waste, it is 70% less expensive than chemical fertilizers.

Further, vermicomposting could be accomplished at household, public or local levels. As source - segregated organic waste is composted through vermi - composting, decentralization of waste collection may result in economically viable and profitmaking vermi - composting. It is desirable to set up decentralized vermicomposting plants through public / NGO participation and centralized units through private sector participation. Alongwith the primary waste collection, vermicomposting may improve the unsustainable condition of waste management at community level, and reduces dependency on the poor MSW management services. In current study, the feasibility of vermi-technology for different streams of organic waste arising from different origins in an Indian city, Faridabad (Haryana) has been explored.

Faridabad, the most populated city of Haryana, India is a part of National capital region. It is located 284 kilometers South of the Indian capital city. It's population as per census 2011 is 18 Lakhs. Faridabad being a major industrial hub along with big shopping malls and institutions combined with rapid urbanization generates huge amount of waste. It is estimated that approximately 600 - 700 MT per day of municipal waste is produced by the city. The management of this waste is deficient as large parts of the population don't get proper waste collection services, as a result, a small percentage of waste produced gets collected and treated. With rising population, changing living standards and lack of citizen awareness, waste generation is on the rise at a fast pace. Due to lack of sufficient waste collection services from generation points, people often dump waste on the streets, vacant plots, railway tracks, roadsides, drains and water bodies that create unhygienic surroundings. Municipal Corporation, Faridabad (MCF) takes the responsibility for collection-transportation-disposal of MSW produced in cities. However, un-treated biomedical waste and hazardous-industrial waste is handled by their respective producers. MCF, Faridabad has given contract to waste collection agency Ecogreen Pvt Ltd, Gurgaon in 2017 for collection, handling and disposal of MSW from Faridabad city (Figure 1.6).

It includes collecting waste from households, institutions, market places, commercial areas, hotels & restaurants, construction and demolition work (primary collection). Then it is carried to collection points (secondary collection), transferred to transportation stations, compressed, compacted, packed in containers and finally moved to the landfill site situated in Bandhwari village (spread over an area of 30.5 acres) on Gurgaon-Faridabad highway, which was identified and established in 2009 to process the waste into compost and RDF. Small tipper trucks, vans, loaders and rickshaws are deployed for primary and secondary collection of waste. According to Haryana State Pollution Control Board's report on MSW management (2018 - 2019), $1/4^{th}$ of

Figure 1.6: Eco-vans for collection of solid waste in the city

Figure 1.7: Bandhwari Land fill site on Faridabad - Gurugram highway

Haryana's solid waste is generated by Faridabad and Gurugram city out of which 78% is sent to landfill, 17% is treated and 4.5% is not collected.

Bandhwari landfill receives more than 1000 tons per day MSW from Faridabad and Gurugram which has already about 35 lakh tons of untreated mixed waste accumulated over 12 years. It affects soil, air, groundwater, surface water bodies, animals and humans in the surrounding area. Each day, a heavy-loaded vehicle of garbage reaches Bandhwari and dump the waste in unsegregated form. Heaps of waste accumulated at the landfill site is shown in Figure 1.7.

Groundwater and other water bodies in the vicinity have been polluted due to release of leachate from the landfill site. It is difficult to breathe for the local residents due to foul odor dispersing from the site. Rag-pickers play an important role in the Indian MSW management scenario. However, their contribution to the waste management process is not weighed. They try their best to collect the recyclable items (paper, plastic, tin, etc.) from the waste dumping sites to get some income (Fig 1.8). As mixed waste is dumped in most of the landfill sites, most of the collected material has already lost its quality due to lack of source segregation of waste.

Figure 1.8: Waste salvaging by ragpickers / waste pickers at Bandhwari Landfill site

The MSW in Faridabad city is mainly produced by residences and institutions like public / private workplaces, commercial apartments, markets, hotels / restaurants, educational institutes, farm - houses, parks / gardens, water bodies etc. The solid wastes originating from multiple sources contain a significant organic proportion which has a potential to be used in vermicomposting process. Therefore, there is a need to find a suitable and cost-effective method for disposal of biodegradable portion of MSW. Unmanageable waste in form of piles in city (open dumpsites and road sides) is of immense concern related to public well-being and environment. Biodegradable fraction gets mixed with inorganic portion and looses its potential as resource. On several occasions, the segregated constituents became mixed up again during transportation and disposal due to improper handling. Thus focus on source segregation is fundamental factor for sustainable management of solid waste. For this, active participation of city dwellers is must so that substantial reduction in waste generated at household level can be achieved. Recovery of nutrients by conversion of biodegradable organic waste components into compost / vermicompost and applying it to agriculture will aid in the development of value addition facilities for improving soil fertility and generate profits for the uphold of the compost / vermicompost.

In present study, feasibility of vermicomposting technology in decomposition of different organic waste streams in municipal solid waste management of Faridabad city (India) has been investigated with a view to integrate vermicomposting of biodegradable fraction of municipal solid waste into overall waste management plan. In many parts of the country, composting has been included as a part of MSW management strategy at different scales. However, the studies on inclusion of vermicomposting technology in MSW management are very scarce. Vermicomposting of different organic wastes originating in Faridabad city have been explored that are left unattended viz. market fruit and vegetable wastes (mixed), urban leafy waste, industrial sludge, agricultural waste, household organic solid waste and weeds with the help of earthworm *Eisenia fetida* (red wriggler worm). Such wastes have been noticed to be often dumped openly and thus under-utilized. It was hypothesized that on one hand, vermicomposting of MSW will reduce the amount of waste for final disposal and treatment, but the manurial aspect of vermicompost would also be utilized in agriculture contributing to increase in food production. Further, the organic waste will be dealt locally instead of shifting the problem to another area.

From the literature survey, it was found that there are no extensive vermicomposting studies carried out in Faridabad city earlier. Therefore, the present study was formulated with the following objectives:

- To investigate and evaluate the vermicomposting of organic fraction of different solid wastes using *Eisenia fetida* individually and in combination of different wastes.
- To quantify the macro and micronutrients of vermicompost produced from different solid wastes.
- To study plant growth in vermicomposts obtained from different solid wastes (pot culture study).

Chapter 2

REVIEW OF LITERATURE

The expansion of the urban population has resulted in exaggerated waste generation subsequently making solid waste management a multifarious challenge. Municipalities and ULBs are struggling hard to manage this waste due to lack of finances, proper disposal systems and lack of comprehensive strategies in waste sector. Primary component of solid waste in India is wet (biodegradable) that can be segregated at source of generation for producing compost or vermicompost and another fraction of dry waste can be reused, recycled, as refuse derived fuel or another source of energy. It will ensure lesser waste to reach dumpsites / landfills ultimately. Aerobic composting and vermicomposting are two commonly used methods for treating biodegradable waste.

Composting is the natural aerobic process of degrading organic residues by microbes such as bacteria, actinomycetes, and fungi [17] producing CO_2, water and relatively stable organic end product, whereas,vermicomposting is the degradation of organic matter due to combined action of earthworms and microorganisms. It has emerged as a decent, environmentally sustainable and economically viable technology for handling organic waste burden and in return providing an excellent medium to grow vegetables and plants. The conventional compost is rich in ammonium, whereas, vermicompost is found to be enriched with nitrates in plant available form [18]. Earthworm's compost contain nutrients that are easily absorbed by plant roots and unlike chemical fertilizers it is 100% organic [19]. Waste to compost / vermicompost can efficiently minimize the use of inorganic fertilizers besides lessening the waste load on already over - burdened landfills. According to a study, vermicomposting can help diminish the emission of greenhouse gases along with enhancing the nutrient status [20].

In this chapter, a comprehensive review of vermicomposting technology is presented, encompassing types of earthworm, vermi-manure quality, applications and various literature studies on vermi-conversion of different types of organic waste.

2.1 VERMI-TECHNOLOGY: COMPOSTING USING EARTHWORMS

Earthworms and microorganisms synergistically and symbiotically act to decompose organic matter in an aerobic environment to produce nutrient enriched vermicompost and process is termed as “vermicomposting”. Vermicomposting is a physico-chemical process combined with biological activities that accelerate degradation of organic materials thereby forming stabilized humus-like black, odorless end product called vermicompost. The process has no negative effects and results in the formation of fine organic rich manure that can be applied to plants [21]. Compost worms consume partially degraded waste organics, kill pathogenic microbes, introduce gut microbes, and then push the digested matter to upper soil surface as vermicast [22].Vermicomposting requires the following important components to function properly and produce an efficient and valuable plant growth medium. These are organic substrates, optimal environmental conditions (temperature, moisture, pH, organic matter content), earthworm species and the design and operations to be carried out. Figure 2.1 exhibits scheme of a vermicomposting system.

While eating, earthworms turn and keep the substrate aerobic, as well as covering the surface of the substrate with vermicast produced, which reduces bad odors. As earthworms feed on organic wastes, their muscular gizzard of the digestive tract acts as a crusher, breaking up larger particles into finer ones, increasing the area of action and enhancing earthworm gut’s symbiotic microbes and enzymes. Approximately 5% of the ingested matter is assimilated during the process and rest is released as vermicast with many nutrients that are converted to plant - available forms (nitrate / ammonium nitrogen, exchangeable phosphorus and potassium in soluble forms).

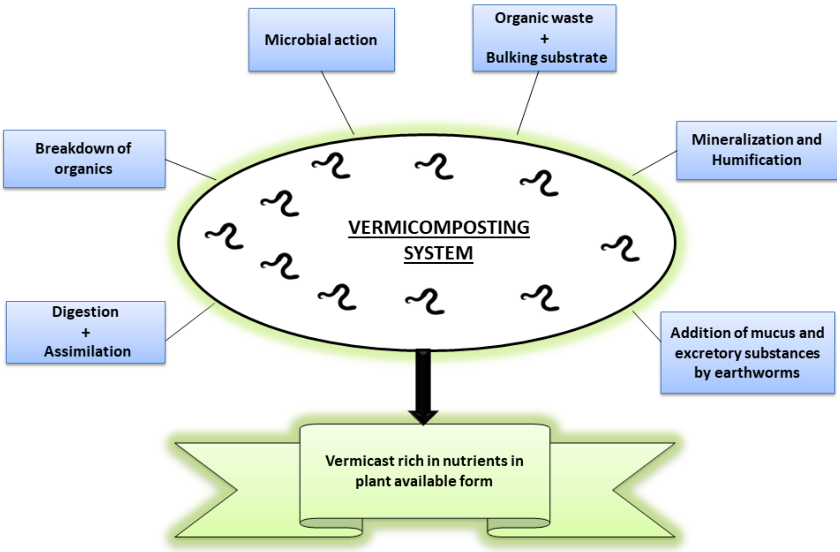


Figure 2.1: Schematic of a Vermicomposting system

Earthworms release plant available forms of phosphorus and potassium from their insoluble forms with earthworm casts [23]. Ultimately, vermicompost contains more nutrients in plant available forms than the wastes from which it was formed. Earthworms can be cultured in pits, containers, pots or tanks and used in the process of vermicomposting. Vermiculture is the cultivation of earthworms feeding on organic wastes / soil. It is gaining importance as end products and byproducts are both economically useful and environmentally sustainable. Earthworms degrade organic waste by secreting enzymes (amylase, lipase, cellulase, and chitinase) and engineering the growth of decomposer microbes in billions and trillions in a short period of time. They increase the aerobic activity of microorganisms by moving through materials and creating aerobic conditions [24],[25]. When fragmented organic matter passes through the worm's gut, it interacts with intestinal-associated bacteria and digestive enzymes, gets partially digested and enter the intestine as casts, at which point the microbes begin the decay phase and contribute to the maturation stage [26]. Organic materials get decomposed by earthworms and microorganisms (bacteria, fungi etc.) into a stabilized vermicast of improved nutrient quality.

Organic wastes (non-toxic to earthworms) originating from household, industrial and agricultural sector can be efficiently managed by vermicomposting technology. Fresh kitchen waste, poultry and pig manure all contain high level of inorganic salts / ammonia which are harmful to worms, therefore, composting should be performed to remove these prior to inoculation of earthworms into the system. A brief composting period can be used to treat the waste prior to vermicomposting process [27]. Pre treatment of organic waste via pre - composting typically take 15 - 20 days and results in thermal stabilization, prompting microbial decomposition, making organic material soft and more acceptable to be consumed by compost worms [28]. Maintaining aerobic conditions in the waste, along with optimal moisture and temperature conditions, is the key to maximum productivity. The advantages of biological waste conditioning via vermicomposting are reduced organic waste pollution, production of vermi-fertilizer (worm cast) for agronomic application, worms for vermi- related studies, vermi-protein to use as feed for poultry, fish, pigs, and other domestic animals.

2.2 VERMICOMPOSTING PROCESS

Organic materials from various points of generation (households, agricultural and industrial activities) and non-toxic in nature can be utilized as feed stocks for earthworms in vermi-conversion. Wide variety of organic wastes suitable for earthworm culture can be cow dung, buffalo dung, horse dung, manure from poultry, sheep, rabbit etc., kitchen wastes, distilleries, paper waste, mushroom residues, floral waste, leaf litter, fly ash, saw dust, municipal wastewater, coffee waste, sugarcane waste, coconut husk, weeds, etc. About 20 - 35 °C (mesophilic range) temperature is optimum for vermicomposting and the whole process is accomplished in 4 levels based on the activities of earthworms: Pre-composting /pre-degradation, addition /mixing of amendments; vermicomposting / vermi-conversion and vermicompost maturation.

Pre-composting / Pre-degradation of organic waste is critical to worm survival as well as to obtain vermicompost of good quality. Pre-degradation of wastes remove the components that might be toxic to the earthworms (volatile substances, excess heat and gases) and make the feed easily acceptable to earthworms.

Addition / mixing of amendments is recommended prior to vermicomposting so as to improve feed acceptability / palatability together with enhancement of nutritional content in the end product. Many industrial wastes are not suitable for the earthworms in their initial forms and require addition of amending materials before applying to vermiprocess. Various organic amendments have been utilized for different wastes in various studies.

Vermicomposting / Vermiconversion starts with the introduction of suitable earthworm species maintaining optimum moisture and temperature conditions. Earthworms accelerate the microbial activities in the feed stocks, speed up the degradation process (through enzymatic action) resulting in modification of physical, chemical and biological characteristics thereby conditioning the organic materials for bio manure formation. **Vermicompost Maturation** is the pivotal phase prior to its designated use and possess decent amount of nutrients in their plant available forms. Matured vermi-manure have decreased C:N and C:P ratios which indicate delayed release of nutrients. Earthworms and their vermicompost soften, makes the soil porous and maintains its physico-chemical and biologic characteristics, enhancing soil richness and plant production. Different physical, chemical, and biological parameters must be evaluated to determine the maturity of vermicompost. Maturity of vermicompost can be evaluated by estimating seed germination index and soil respiration assessment. Besides this, pot culture experiments can be conducted to access the feasibility of vermicompost obtained as biofertilizer. Trends in parametric change (increase / decrease) during the process of vermicomposting are depicted in Figure 2.2.

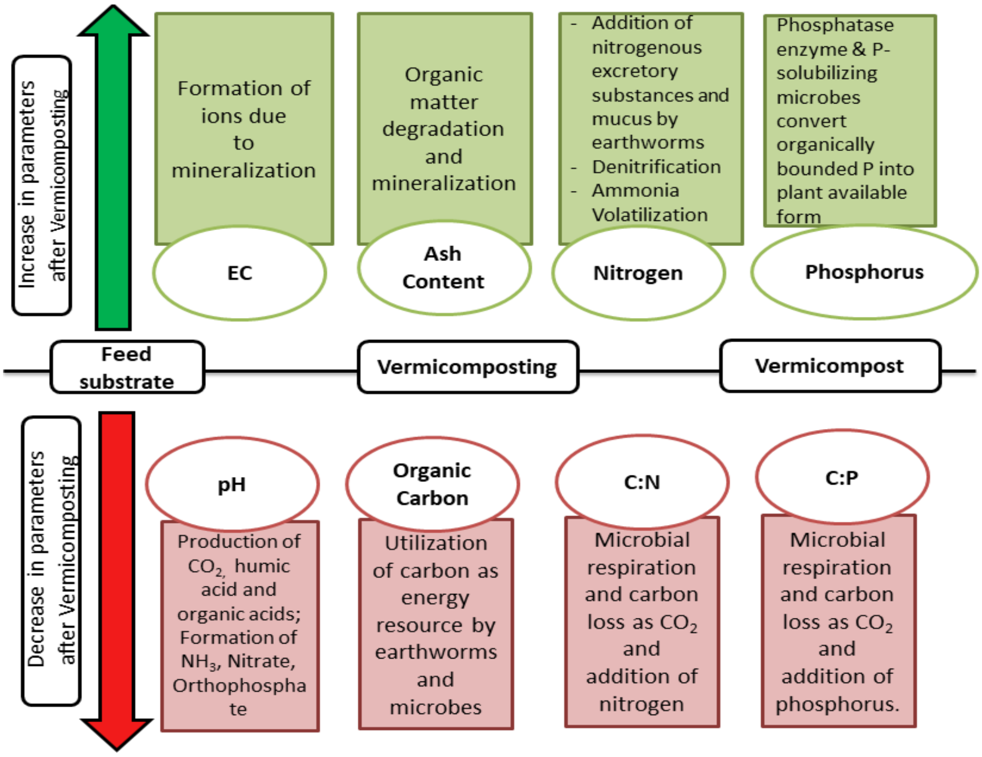


Figure 2.2: Parametric changes during vermicomposting process

2.3 EARTHWORMS INVOLVED IN VERMICOMPOSTING

Sir Charles Darwin referred earthworms as “unheralded soldiers of mankind” as well as ‘farmers’ friend. He further quoted “No other creature on the earth has performed such an important function in progression of life on the planet.” Earthworms perform many ecosystem functions viz. decomposition, nutrient cycling and climate regulation as well as considered as bioindicators of soil health and diversity [29]. They are widely recognized as nature’s best biological element for recovering vermi-fertilizer and vermi-protein from organic waste for use in the agro-ecosystem, aquaculture, and poultry industries. Earthworm is a physical aerator, crusher, mixer as well as a chemical degrader and biological stimulator in the decomposer system. The distribution of earthworms in the environment is affected by pH, moisture, C:N ratio and soil / water temperature. Earthworms / Crassiclitellata (class clitellata) are soil-dwelling terrestrial oligochaetes and classified as phylum Annelida. About 7,000 existing species of earthworms are known across the globe with different appearance [30]. Breathing in earthworms is carried out with skin. Earthworm’s body is extended, circular and symmetric covered with a fine carapace and contains 65% lysine-rich protein by dry weight. The earthworm gut is sectioned into three parts, namely the foregut, midgut, and hindgut, connected with number of digestive glands [22]. The earthworm body has no bones, with bristles named as setae which regulates its movement in the soil [31]. These are sexually dimorphic in nature, clitellum appearance denotes reproductive age.

Highest enzyme activity was found to be in the earthworm’s foregut and midgut [32]. Earthworm burrowing, casting, grazing, and dispersal activities alter the physical and biochemical properties of waste [33]. Earthworm body fluid contains antibacterial properties that kill harmful microbes in the feed material, at the same time promoting the growth of healthy microbes. On basis of morpho - ecology, earthworms are classified into three categories (Table 2.1) [34]. *Eisenia fetida*, *Eudrilus eugeniae*, *Perionyx excavatus* and *Lumbricus rubellus* are some compost worms which have gained importance nationally and internationally in vermicomposting process.

Table 2.1: Classification of earthworms on the basis of morpho - ecology

Earthworm category	**Features**	**Feeding habits**	**Burrowing habits**	**Species in each category**
Epigeic worms	• Small sized, pigmented, high fecundity and growth rate • Efficient waste consumption and conversion, produce granular castings on surface. • Aids in decomposition of organic wastes	Feed on leaf litter, plant debris, animal excreta, decaying organic matter	• Do not make permanent burrows, produce burrows in soil for feed. • Surface burrows 3-10 cm	*Eisenia fetida*, *Eudrilus euginaeae*, *Eisenia andrei*, *Perionyx excavatus*, *Lumbricus rubellus*
Endogeic worms	• Medium sized, less/absence of pigments, low fecundity and growth rate • Moderately efficient waste conversion, aids in soil formation, thick castings under the ground • Aids in soil formation	Feed on soil enriched with organic matter	• Make continuous, horizontal burrows • Medium burrows 10 -30 cm	*Allolobophora aliginosa*, *Octochaetona thurstoni*, *Aporrectodea caliginosa*, *Drawaida barwelli*
Anecic worms	• Large sized, lightly pigmented, medium fecundity and growth rate • Not efficient in waste conversion, loose, granular castings on soil • Aids in distribution of organic matter in soil	Feed on leaf litter and soil (comes to surface for feeding)	• Construct and live in permanent burrows • Deep burrows 30 -90 cm	*Lampito mauritii*, *Lumbricus terrestris*, *Apporrecctodea longa*

Indeed, *Eisenia fetida* and *Eisenia andrei* are the frequently used earthworm species in vermicomposting and vermi-culture facilities worldwide due to their widespread prevelance, inherent colonization of variety of organic wastes, withstand a range of temperature and moisture conditions as well as resilient and simple to manage [35]. These are tiny in size with a small life span and greater rate of reproduction. *Eisenia fetida* (Savigny) is also known as "compost worm", "manure worm", "redworm", and "red wiggler" and has excellent waste conversion efficiency. End products obtained are compost enriched with nutrients and earthworm biomass. Based on the literature studies, it has wide acceptance to various environmental factors as well as high rate of waste digestion and assimilation [36]. It consumes a variety of organic materials, reducing their mass by 40 - 60%. About 5 - 10% of waste matter can be assimilated by *Eisenia fetida* (0.5 - 0.6 g) and excretes about 50% waste consumed as vermicast that is fine and granular [37]. Earthworm *Eisenia fetida*, an epigeic worm has been used in the present vermicomposting experiments.

2.4 IMPORTANT PARAMETERS AFFECTING THE VERMICOMPOSTING PROCESS

Compost worms require a hostile living environment in form of bedding, a food source, adequate moisture, sufficient oxygenation and safe guarding against thermal extremities [38]. Vermicomposting, earthworm growth, cocoon production and microbial activity relies on different factors such as pH, ambient weather conditions / ambient temperature, moisture, aeration, feedstock nature, daylight, carbon to nitrogen ratio, bulking substrate, worm density, enzymes.

1. pH: Earthworm activity is favored at pH range of 5.5 - 8.5 and preferably neutral or near neutral. pH of the medium is essential for earthworms and microorganisms throughout vermicomposting along with its soil application for plant growth [39]. pH of vermicompost is also affected by the type of substrate used. pH shift occurs due to bio transformation of organics to organic acids and formation of humic and fulvic acids by microbial action [40]. Microbial decomposition mineralizes nitrogen, phosphorus to nitrites / nitrates & ortho-phosphates and alkaline pH tends to move towards acidic. Moreover, organic decomposition produces a variety of organic acids, humic acids, and ammonium ions as by products and the combined effect of both determines the final pH in the process. Several authors have reported decrease in pH as the process proceeds in forward direction [41].

2. Ambient Temperature: Temperature influences the activities of earthworms. The vermicomposting system should have winter temperatures > 10 °C and summer temperature < 35 °C. Earthworm's food intake decreases significantly at low temperatures and reproduction and metabolic activity begins to decline. At high temperatures microbial activity increases indirectly diminishing oxygenation, thus, negatively influencing earthworm's action. According to various reports, earthworm activity increases between 10 and 35°C [42]. According to Edwards [11] *Eisenia fetida* thrives well at temperature of 25°C, with the acceptable limit of 0 - 35°C.

3. Moisture Content: The function of earthworms and microorganisms is dependent on the vermicomposting system's adequate moisture content as they breathe through their skin. Earthworm activity requires 60 - 80 % moisture content [36]. Clitellum development is hampered at reduced levels of moisture [22].

4. Aeration: Earthworm respiration rate decreases when oxygen content is low and slows down food ingestion. In view of high temperature, microbes consume oxygen thereby reducing its availability for earthworms. Excess of moisture in vermicomposting system reduces aeration and thus oxygen provision [43]. Manually turning the waste materials aerate the vermicomposting system.

5. Quality of Feed Stock: Feed quality is critical for growth and production of worms in the course of vermicomposting process.The feed rate is affected by the amount of organic materials, particle size, moisture levels, salt content, C:N ratio, and other factors [44]. Feed substrate should have salt levels of $< 0.5\%$ [45].

6. Light: Earthworms are photosensitive. Because they lack eyes, earthworms sense light through their skin specially light cells concentrated at the anterior end [46]. Earthworms avoid direct sunlight as both short time as well as long duration of light harms them. When the earthworm's skin becomes too dry on exposure to heat, it loses its ability to breathe.

7. C:N Ratio: Greater or lower C:N ratio slows down the process of waste degradation. Earthworm growth and reproduction rate is favored when feed substrate has C:N ratio of 30:1.Effective vermicomposting relies on ideal C:N ratios, amount of nitrogen containing substances and carbon for body metabolism [47]. Earthworms ingest feed material, hastens decomposition, microbial respiration results in CO_2 loss and low carbon to nitrogen ratio. Simultaneously, earthworms add nitrogen in form of mucus and nitrogenous substances thereby decreasing C/N ratio. C:N ratio (25 - 20:1) is prerequisite for affirming vermicompost maturity as a plant utilizes mineral nitrogen at this ratio. As vermicomposting proceeds, carbon-nitrogen ratio gets reduced and further decreased C:N can result in ammonia toxicity [48],[49].

8. Bulking Substrate: Organic waste can be converted into vermicompost by using a good bulking substrate. Feed material should promote microbes and thus growth and fecundity of earthworms. To condition the waste, a bulking agent is used. Cow dung, sheep manure, cattle dung, sewage sludge, biogas plant slurry, poultry droppings and other bulking agents are used in the vermicomposting process [50], [51]. Kouba et al. [52] used wheat straw as a bulking agent in an aquaculture system using the earthworm *Eisenia andrei* to stabilize sludge. Table 2.2 shows different types of bulking substrates and species of earthworms involved in the process.

9. Worm Density: In a vermicomposting system, earthworms influence microbial communities and nutrient dynamics. Earthworm population influences rate of feed ingestion, fecundity, respiratory and burrowing activities. Copulation frequency of earthworm is high at low population density. Higher population densities increase mortality while decreasing growth rate and cocoon production. Effect of stocking density was studied previously by earlier authors [53],[51]. Maintaining optimal earthworm density is critical for achieving highest population growth in less time, resulting in conversion of organic substrate into worm castings [22].

10. Enzymes: Cellulase, amylase, phosphatase, protease, lipase, and other digestive enzymes secreted from earthworm gut and microbes aid in the degradation of organic matter components such as starch, lignin, cellulose, hemicellulose etc. [54].

Table 2.2: Different type of wastes, bulking substrates and earthworm species involved in vermicomposting

Organic waste	**Bulking substrate**	**Compost worm**	**Reference**
Municipal Solid waste	Cow dung	*Metaphire posthuma*, *Eisenia fetida*	[55]
Vegetable processing waste	Cow dung	*Eisenia fetida*	[56]
Fresh fruit & vegetable waste	Soil + vermicompost of cow dung	*Eisenia fetida*, *Eudrilus eugeniae*	[57]
Fruit & vegetable waste	Cow dung, fruit & vegetable waste	*Eisenia andrei*	[58]
Green waste	Cow dung	*Lumbricus rubellus*	[59]
Apple pomace waste	Beef manure	*Eisenia fetida*	[60]
Food & vegetable waste	Buffalo waste	*Eisenia fetida*	[61]
Grape marc	Cow dung	*Eudrilus Andrei*	[62]
Vegetable market solid waste	Cow dung	*Eisenia fetida*	[63]
Rice husk & market refused fruit	Cow dung	*Eudrilus eugeniae*	[64]
Bakery sludge	Cow dung	*Eisenia fetida*	[65]
Tomato fruit waste	Sheep manure	*Eisenia fetida*	[66]
Fruit & vegetable waste	Soil, Excess activated sludge	*Eisenia fetida*	[67]
Fruit & vegetable waste, pruning waste	Cow dung	*Eisenia andrei*,*Eisenia fetida*	[68]
Silk industry waste	Cow dung, sludge	*Eisenia fetida*	[69]
Palm mill fruit waste	Cow manure	*Eudrilus eugeniae*	[19]
Kitchen waste, paddy straw	Cow dung	*Eudrilus eugeniae*, *Perionyx excavatus*	[70]
Parthenium weed	Cow dung	*Eudrilus eugeniae*	[71]
Tomato plant waste	Paper mill sludge	*Eisenia fetida*	[72]
Wheat residue	Cow manure	*Eisenia fetida*	[48]

2.5 BENEFITS / SIGNIFICANCE OF VERMICOMPOSTING

Earthworm vermicompost works as an excellent biofertilizer, providing 30-40% higher crop yields than chemical fertilizers and has 5 - 7 fold nutrient content as compared to conventional composts. Plant growth regulators like auxins, gibberlins and cytokinins released by soil microbes are present in gut or castings of worm. It also improves the farm soil's ability to hold water. Vermicompost enhances seed germination and promote plant growth. The most remarkable social and economic benefit is that the food produced is organically pure as well as free of chemicals. Further, the amount of vermicompost used in the future may be gradually reduced as soil productivity is maintained for the long time. Raw material degradation/digestion improves the fundamental nutrient bioavailability. Vermicompost's beneficial effects on plant growth are attributed to improvement in aggregation of soil particles, porous nature and capacity to retain water along with growth regulating substances, control of disease causing microbes and availability of nutrients in their available forms. Slow release of nutrients from vermicompost has a long-term impact on agriculture [73]. Various benefits of vermicomposting have been displayed in Figure 2.3.

2.6 VERMICOMPOSTING STUDIES

For the purpose of study, various research papers were reviewed to understand the process and work done in the concerned field. Table 2.3 shows some fruit and vegetable vermicomposting studies. During the course of vermicomposting, there is a change in parametric values and the final vermicompost value decides the fate of organic waste material as manure. Table 2.4 exhibits changes in physico-chemical parameters in vermicompost in various studies and table 2.5 represents changes in heavy metals in vermicomposts obtained from different organic substrates. Concentration of micronutrients/heavy metals increase as a result of reduced mass and volume / nutrients released from their bindings [74] or decrease due to bioaccumulation of metals into earthworm's body/ formation of metal complexes [75],[76].

Figure 2.3: Benefits of Vermicomposting

Some experimental studies on growth of plants and /seed germination were also reviewed as: Belda et al. [77] conducted experiments to study the growth of vermicomposts prepared from tomato waste on ornamental plants - *Calendula officinalis* and *Viola cornuta* and found that seed germination was not affected while plant growth was decreased at high dose of vermicompost application. Hussain and Abbasi [78] investigated the effect of parthenium (*Parthenium hysterophorus*) vermicompost (upto 40%) on the germination of green gram (*Vigna radiata*), ladies' finger (*Abelmoschus esculentus*), and cucumber (*Cucumis sativus*) and found that VC germination was improved and promoted early growth. Moreno et al. [79] investigated vermicomposting of coffee silver skin and spent coffee grounds amended with mature horse manure for 60 days using the earthworm *Eisenia andrei* and hybrid wheat seeds were germinated to test the toxicity levels.

Table 2.3: Fruit and vegetable waste vermicomposting studies

S. No.	Waste	Vermicomposting study	Vermicomposting period	Reference
1.	Fruit waste, vegetable waste, leaves	FVW + bedding (cow dung, mango leaves and sawdust) in ratio of 1/1	60 days	[59]
2.	Pre-consumer vegetable processing waste	Vegetable waste + cow dung	105 days	[56]
3.	Food and vegetable waste	Vegetable waste + buffalo dung	90 days	[61]
4.	Apple pomace waste	Apple pomace +straw + beef manure in 4/1 ratio	30 days	[60]
5.	Grape marc	Grape marc + mature vermicompost	15 days	[62]
6.	Fresh fruit and vegetable waste (FVW)	FVW composting (without earthworms) and vermicomposting systems studied separately and compared	35 days	[57]
7.	Wet fruit and vegetable waste	Excess activated sludge + wet fruit and vegetable waste and effect on decomposition was studied	30 days	[67]
8.	Tomato fruit waste	Tomato waste + sheep manure	150 days	[66]
9.	Fresh fruit and vegetable wastes	FVW + bedding materials (soil + vermicomposted fruits and vegetables) with three layers - substrate, bedding and leachate collecting layer	35 days	[57]
10.	Fresh fruits and vegetables	Five different types of fruits and vegetables + Bedding material (cow dung + prepared vermicompost)	60 days	[80]
11.	Vegetable market waste	Vegetable waste + cow dung	80 days	[81]
12.	Banana stem	Banana stem waste + cow dung	60 days	[49]
13.	Green manure plant	Sesbania +cow dung	50 days	[82]

Table 2.4: Change in physico - chemical parameters in vermicomposts obtained from different organic substrates

Organic substrate	pH	EC (Final range or % increase)	TOC (Final range or % reduction	TKN (Final range or % increase)	TAP (Final range or % increase)	TK (Final range or % increase)	C/N (Final range or % reduction)	References
Apple pomace +rice straw	5.9 - 6.9	1.6–4.4	33%	2.8%	0.85%	2.3%	13-14	[60]
Ligno-cellulosic waste+cow manure	7.54 - 7.70	3.25–3.78	268–320	90-96%	46–66%	8.0-12.4	12.26-16.85	[83]
Ageratum conyzoids + cow dung	7.11-7.56	30.5-36.5%	27.3 - 35.3%	59.6-69.9%	53.8-148.7%	32.2-92.43%	9.35-18.92	[84]
Duck weed + cow dung	7.09-7.87	28.5 – 86.04%	33.54–38.25%	18.2–42.4%	137–187%	7.76–79.4%	43.6–56.6%	[85]
Potato plant biomass+ cow dung (5:1)	6.63-6.93	1.9 fold	71.2-75.6%	3.8–4.4-fold	5–5.6-fold	upto1.6 fold	92.5–94.4%	[86]
Weed *Ageratum conyzoides*+cow dung	6.7-7.4	3.5-3.8	32.37-38.58%	2.26- 2.67%	9.06-10.75g/kg	3.18-3.93%	12-17	[87]
Food & vegetable processing waste+ buffalo dung	7.56-6.55	48.25-23.54%	23.54–34.03%.	7.82-20.73	4.80-11.74	7.43-12.75	24.11-39.74%	[61]
Rice straw + kitchen waste	–	–	38.24-43.49%	9.01-32.52%	31.38-55.89%	33.40-63.15%	58.55-71.96%	[88]
Bakery industry sludge +cow dung	6.5- 6.9	1.6–2.2	26.1–42.8%	2.0-3.5 fold	1.2-1.9 fold	1.2-1.4 fold	65.4-83.5%	[65]
Lawn waste+ kitchen waste+ buffalo dung	Alkaline to 6.54	147.5-212.9	21.89-29.0%	0.88-1.89 fold	48.2-142.5%	30-35%	11.65-37.87	[89]
Citronella bagasse + paper mill sludge	6.45	1.89-3.00	86%	1.6 fold	121.1%	43.5% increase	91.1%	[90]
Press mud+cow dung	6.9- 7.2	4.5-5.8	323.2-389.4 g/kg	20-24.8 g/kg	——	—-	14.2-19.4	[7]
Sea weeds	7.38	1.97	22%	1.01 g/kg	—	—-	21.07%	[91]
Milk processing industry waste +cow dung	6.2-6.8% reduction	24.6-37.2%	16.8-37.9%	23-46%	39-47%	26.6-40.6% increase	23.8-97.9%	[92]
Weed *Ipomoea* +cow dung	0.55-6.41% reduction	20.74 - 54.48%	10.65- 21.41%	5.84-41.38%	27.9-75.21%	57.7-115.8%	55.25-84.22%	[39]

*values are given as final value/ range (EC in mS/cm; TOC, TKN, TAP and TK in g/kg) of final values or percent/fold change.

Table 2.5: Change in micronutrients / heavy metals in vermicomposts prepared from different organic substrates

Organic substrate	Earthworm species	*Total Fe	Total Zn	Total Cu	Total Mn	Total Cr	Total Pb	References
Milk processing industry sludge +cow dung	*Eisenia fetida*	—	—	+32.7-44.6	+23.9-36.3	+30.9-40.6	+32.6-42.9	[92]
Sewage sludge +vermicomposts	*Eisenia fetida*	-36-59.6	-22.9- 57.8	- 40.7-130	-33.3-81.8	-25.8-111	—	[31]
Duck weed + cow dung	*Eisenia fetida*	+1.1-6.97	+7.06-15.41	+11.58-26.43	+4.75-12.75	—	—	[85]
Rice straw +Paper waste	*Eisenia fetida*	+31-136	+66.80 - 151	+39–132	—	—	+51–150	[93]
Milk industry sludge	*Eisenia fetida*	—	—	+32.7-44.6	-23.9-36.3	-30.9-40.6	-32.6- 42.9	[94]
Pre-consumer vegetable processing waste	*Eisenia fetida*	-53.0- 56.8	-29.7-44.3	-48.3-56.1	-33.3- 81.8	—	-34.4 - 44.4	[56]
Bakery industry sludge +cow dung	*Eisenia fetida*	+27.3-31.0	+7.5-32.8	-1.7-40.8	+7.1-51.6	+28- 80	—	[65]
Potato crop biomass	*Eisenia fetida*	+1.15 fold	+1.23 fold	-1.04 fold	+1.2 fold	+1.11 fold	—	[86]
Press mud and fly ash	*Eisenia fetida*	—	-5.62-36.08	-6.88-34.0	—	-3.01-47.0	-10.86-28.58	[89]
Weed *Ipomoea staphylina*	*Eudrilus eugeniae*	—	+97.3-212.42 mg/kg	+18.63-26.36 mg/kg	—	+1.78-4.62 mg/kg	+28.17-43.56%	[39]
Sewage sludge	*Eisenia fetida*	-25	-44	-84.1	-28	-24.7	-17.7	[53]

*+ (percent/fold increase in concentration); – (percent/fold decrease in concentration).

Karwal and Kaushik [89] studied bio-conversion of kitchen waste and lawn grass waste with buffalo dung into valuable humus-rich manure. The 2:1:2 ratio of buffalo dung, kitchen waste, and lawn waste produced vermicompost with high germination index for tomato plant. Sangwan et al. [95] performed pot culture experiments with vermicomposts prepared from sugar mill waste water with horse manure and cow dung vermicompost on marigold plants. Pot soil mix with 30% cow dung vermi-manure produced maximum numbers of flowers and soil without blending showed minimum production of flowers. The pot soil mixed with 40% of sugar mill sludge vermicompost had maximum flower diameter. The presence of vermicompost was having positive influence on growth and flowering of plants.

Many literature studies reveal that although work done in this field is enormous still there is lack of its practical use with locally available materials (menace as waste at urban levels). As every city produces waste of its kind, it is imperative to estimate the amount of waste generated, its organic fraction load as well as recyclable portion so that nutrients can be regained and useful materials can be recovered. Vermicomposting of organic part of waste can minimize the extra load on landfills along with the conscious efforts of individuals towards managing waste at their own level. In view of this, the present work was performed to vermicompost different kinds of waste from various origins at city level (yet not explored for vermicomposting in the city) that can act as potential feed substrate for earthworms and their feasibility for the plant growth / germination can be evaluated. A small effort has been made in the form of development of prototype four bin vermicomposter to manage household waste at the source of generation and diverting it away from the landfills.

Chapter 3

MATERIALS AND METHODS

The present evaluation “Assessment of Vermi-Technology in Solid Waste Management” was conducted at Department of Environmental Sciences (J.C. Bose University of Science and Technology, YMCA) in city Faridabad (Haryana) in India. Detailed methodology as well as materials used for the study have been given in the following chapter.

3.1 MATERIALS

3.1.1 Earthworm Culture

Prior to vermicomposting experiment, earthworm cultures were developed using *Eisenia fetida* as a combination of clitellated worms (adults) and hatchlings in rectangular plastic boxes/containers under lab conditions. Initially, earthworms were collected from Guru Jambheshwar University, Hisar and TERI, Gurugram (Haryana) at different times and cultivated in cow dung /cow excrement. Cow dung (free from urine) was collected from local dairy, New Industrial Town - 5 and village Kheri, Faridabad city (India) and left for 15 - 21 days for sun drying before using in experiments. Four vermi-culture boxes (vermi-culture I–IV) were established in similar manner. Mini holes were made in the vermi-culture boxes for maintaining aeration and top most side was covered with jute cloth protecting them from light and predators. Moisture content up to 70 ± 10% water retaining capacity was sustained by showering water in requisite amount.The care was exercised not to put the feed material in large heaps that cover the whole surface of the matrix. *E. fetida* young adults (clitellated)/hatchlings on random basis were picked from the prepared culture and used in various experiments as per requirement to achieve the proposed objectives.

3.1.2 Collection of Organic Wastes

Different types of raw waste / substrate were collected from their respective source of generation viz. Household Solid Waste, Fruit and Vegetable Waste, Agro-industrial waste - Cabbage Leaf Waste and Cauliflower waste, Bakery Industry Sludge, Agricultural waste/crop residue - Banana leaf biomass, Rice residue, Leaf litter and Rice Weed (*Echinochloa crus-galli*). Figure 3.1 represents different kind of organic wastes used as feed materials in vermicomposting experiments and their collection sources.

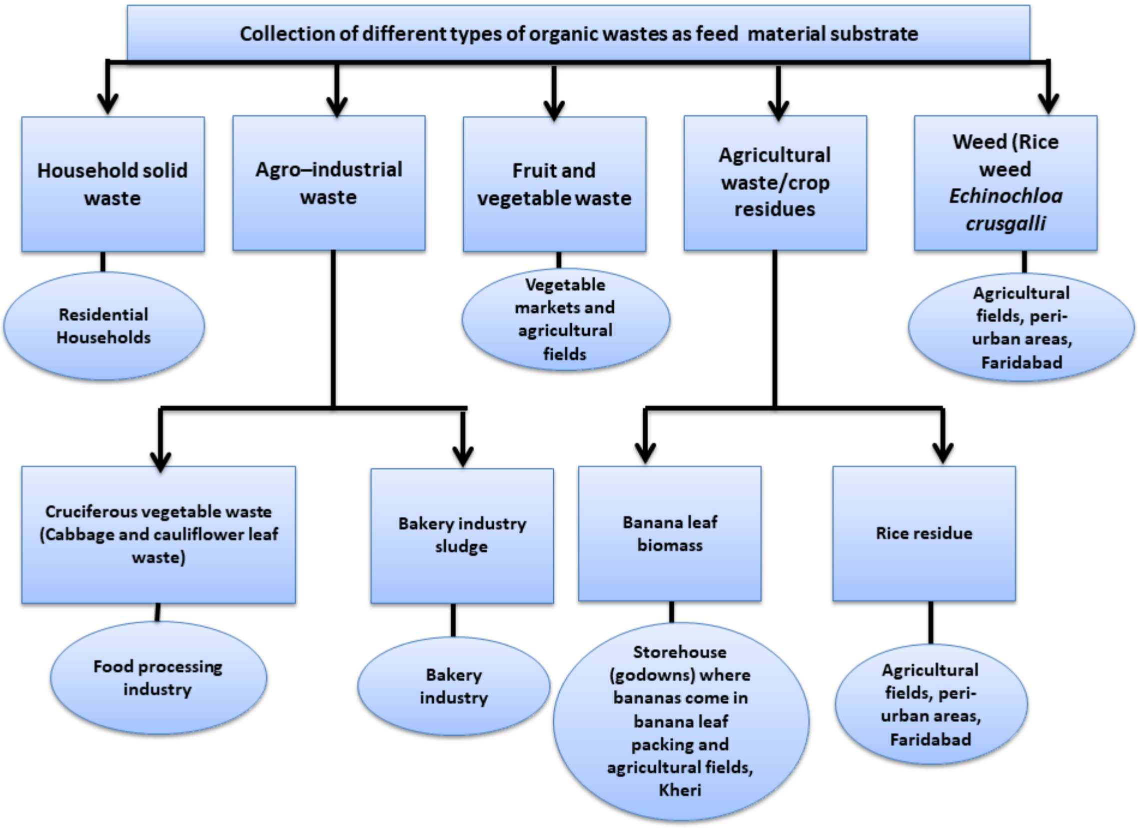


Figure 3.1: Different types of organic wastes used in Vermicomposting experiments in the study

3.2 EXPERIMENTAL DESIGN

Various experiments were designed for selected organic wastes during the course of study and conducted following a generalized plan (Figure 3.2). Solid wastes were collected and segregated into biodegradable & non-biodegradable portions. Organic part was used for vermicomposting experiments after shredding/grinding into small parts to facilitate biological activity by increasing surface area. Cow dung was added as bulking substrate in different ratios as it is favourable feed material for earthworms. Organic amendments (Fruit and vegetable waste, Leaf litter) were used in varying proportions in some experiments to reduce the quantity of cow dung used. Different vermicomposting units / vermireactors were established with varying feed composition along with 100% cow dung / cow excrement as control.

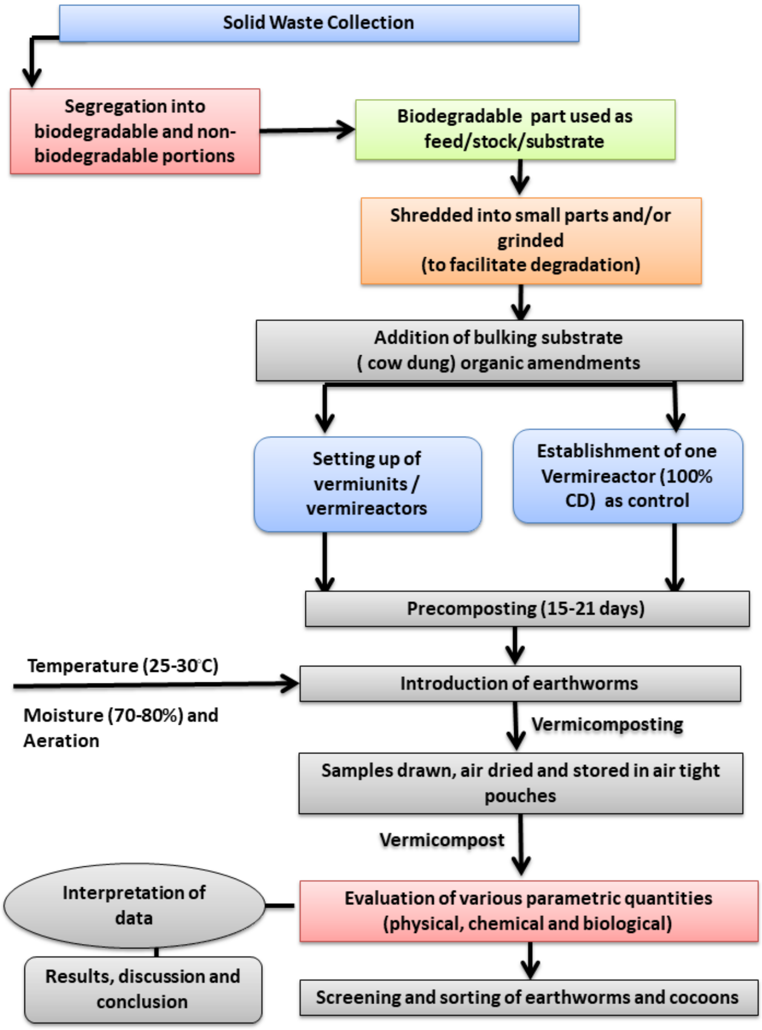


Figure 3.2: General methodology and experimental design of the study

Pre-composting of waste mixtures was done for elimination of offensive odours and volatile waste materials to increase feed acceptability by earthworms. A specific number of earthworms (depending upon the weight of initial waste material) were introduced into vermireactors and proper conditions of temperature, moisture, aeration were sustained during vermicomposting period. Samples from vermireactors were drawn, dried in air, grounded and stored in air-sealed pouches to further analyze physico-chemical characteristics, nutritional quality, micronutrients, stability parameters and biological parameters. Screening and sorting of earthworms and cocoons was performed after accomplishment of vermicomposting using a sieve /providing light stimuli. At the end of experiments, feed waste materials were converted into homogeneous, granular brown/dark brown-coloured organic manure - vermicompost.

Generally, two sets of experiments were conducted during vermicomposting of different organic wastes:

(i) Evaluation of manurial quality of vermicomposts obtained.

(ii) Assessment of earthworm growth along with fecundity in the course of vermicomposting.

Figure 3.3 outlines different parameters evaluated during the study.

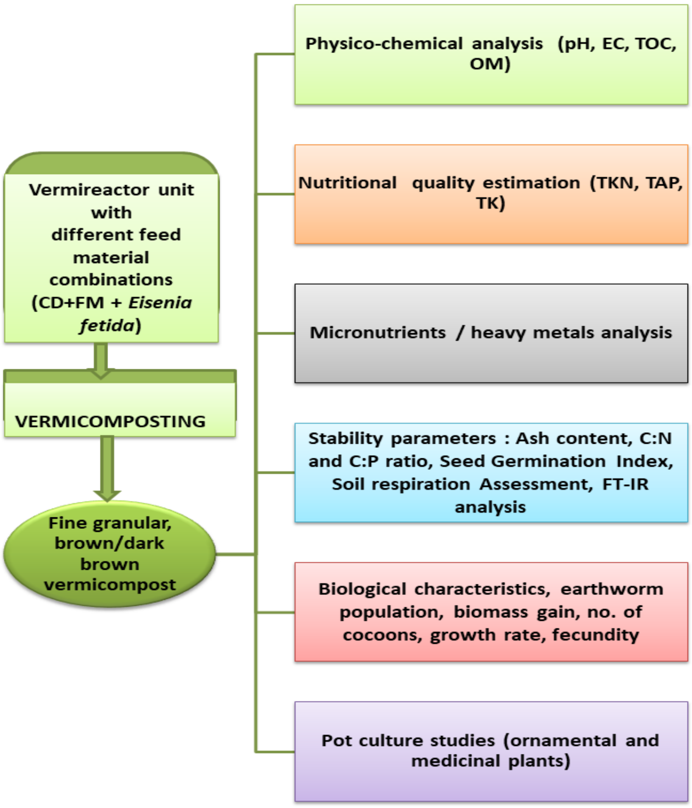


Figure 3.3: Different parametric quantities analyzed during the study

3.2.1 Evaluation of Manurial Quality of Vermicomposts Obtained

Organic wastes were collected from their respective sources of generation and diced into pieces if required to raise the surface area for speeding up degradation. Then the waste was intended for pre-decomposition of 15-21 days for eliminating stinky odors, thus making them palatable to earthworms. Cow dung was also pre-decomposed to remove volatile gases that produce odors. Plastic boxes (rectangular) were named according to experiments and used to contain pre-weighed waste material (dry basis). A specific number of earthworms (depending upon the weight of initial waste material) were introduced into these bins. Experiments were performed in triplicates, and one reactor was taken as control (100% cow dung as feed material). Vermi-bins were kept at an ambient temperature $\approx$25-30ºC and frequently turned to provide earthworms with an aerobic environment. During the experimental time, moisture levels of 70 - 80% was maintained. All the vermi boxes were covered with wet jute bags for maintaining moisture levels and preventing mosquitoes, pests as well as odors. Experiments were performed in triplicates. The samples were taken out of every bin at various time periods during vermicomposting experiments. The earthworm and cocoon free samples after drying in air and grounded were stored in air sealed vials prior to further analysis. The earthworms were separated into adults and hatchlings by hand. Gain in earthworm biomass was measured at various time intervals and the number of cocoons was also recorded.

Parameters such as, pH, electrical conductivity, TOC content, TKN, TAP, TK levels & micro nutrients / trace metals were estimated in initial feed/raw materials and vermicomposts obtained for assessing physical and chemical characteristics. Vermicompost maturity was affirmed by evaluating stability parameters such as ash content, C:N ratio, C:P ratio, germination index, soil respiration assessment and FT-IR analysis.

3.2.2 Assessment of Earthworm Growth Along with Fecundity during Vermicomposting

Biological analysis was performed after specific time intervals to estimate the growth rate, increase in biomass gain and fecundity (cocoon/worm) of earthworms during vermicomposting period. Worm growth response was determined by measuring biomass of earthworms with time. Samples were taken out and piled up on a plastic mat. Hand sorting was used to separate earthworms and cocoons from the feed materials in each vermireactor, washed with water and dried with paper towels. After that, worms and coccons were counted manually. Earthworms were weighed on weighing balance without removing their gut contents. In the study, no data was corrected for gut content. After that, worms and cocoons as well as feed waste were put back in their original vermi boxes. During the course of study, no extra feed substrate was added.

Individual earthworm mass, earthworm population, gain in biomass and cocoon number along with earthworm growth as well as fecundity were determined for each waste material.

3.3 ANALYTICAL METHODS

a **Reagents**

All the experiments were performed using chemicals of analytical reagent grade (AR) without the need for further purification. Glassware used was made up of alkali resistant borosilicate. Double distilled water was used in analysis.

b **Stoichiometry**

Samples from different organic wastes and vermicomposts obtained were used on dry weight basis. Wet waste sample of 100 g was heated to consistent mass inside an hot air oven at 90 °C. Dried sample was weighed and final weight was noted.

$$Dry \quad weight(g/kg) = \frac{W \times 1000}{100} \tag{3.1}$$

Where W = Final weight (g)

Moisture content (%) = 100 – Final weight (g)

3.3.1 pH (Electrometric Method)

5 g homogenized sample (dried in air) and 50 ml distilled water were mixed in 1w: 10v ratio. Suspension was shaken on an orbital shaker for half an hour. Calibration of pH meter was done with pH buffers of 4.0, 7.0, and 9.2. Supernatant was collected and pH was recorded by digital pH meter (E.I. Model 101).

3.3.2 Electrical Conductivity (EC)

5 g sample (dried in air) was dissolved with 50 ml distilled water in ratio of 1w:10v. Suspension prepared was shaken on orbital shaker for half an hour. Calibration of electrical conductivity meter was done with 0.1M standard KCl solution. Supernatant was collected and EC was recorded using digital EC meter (E.I. Model 601).

3.3.3 Total Organic Carbon (TOC) and Ash Levels

Dry combustion method [96] was used to estimate ash content and Total organic carbon content. In a silica crucible (pre - weighed), 0.5 g of waste sample (dried in air) was placed and ignited into the muffle furnace at 550 °C for an hour. Let the furnace cool before weighing the ash obtained.

$$Ash \quad content(\%) = \frac{\text{Wt. of sample left after ignition}}{\text{Wt. of sample taken}} \times 100 \tag{3.2}$$

TOC was calculated using formula:

$$Total \quad Organic \quad carbon \quad (\%) = \frac{\mathit{100 - ash\ percentage}}{1.724} \tag{3.3}$$

3.3.4 Organic Matter (OM)

Organic matter was determined using the formula

OM (%) = (100 - Ash content %)

Alternatively, organic matter % can be calculated using conversion factor of 1.724 (derived from 100/58)

OM (%) = TOC (%) × 1.724

Organic carbon relates with organic matter in a way that 58% of the mass of organic matter exists as carbon.

3.3.5 Total Kjeldahl Nitrogen (TKN)

Micro-Kjeldahl method [97] was adopted to analyze Total Kjeldahl Nitrogen.

a) Reagents

- i Digestion mixture: Digestion mixture was prepared by mixing $10K_2SO_4$: 4: $CuSO_4$: $1SeO_2$ (TiO_2). K_2SO_4 increase the boiling point of sulphuric acid whereas $CuSO_4$ and SeO_2 increase the rate of digestion.
- ii Digestion acid mixture: Concentrated sulphuric acid and perchloric acid was mixed in ratio of 9v: 1v (9 H_2S0_4: $1HClO_4$) to prepare digestion mixture.
- iii Indicator solution:
  - 20g of boric acid and 700 ml warm distilled water was mixed to prepare a solution, that was cooled and transferred to 1 litre volumetric flask (having 20 ml mixed indicator solution)

- Mixed indicator: 100 mg bromo-cresol green along with 50 ml methyl red was dissolved in ethanol(100 ml) followed by dilution with 1 litre distilled water.
- Boric acid is preferred as it prevents loss of ammonia by volatilization by capturing ammonia gas forming ammonium borate complex.

iv 0.02 N HCl for titration:
200 ml of 1N HCl was mixed in 800 ml of distilled water for preparation of 0.02 N HCl.

v Anhydrous Na_2CO_3: 0.6625 g of anhydrous Na_2CO_3 was prepared with 250 ml distilled water for standardization of 0.02 N HCl.

vi 40% NaOH: 40g NaOH pellets were added in distilled water (100 ml) for preparing 40% NaOH.

b) Sample Digestion

i In 100 ml digestion flask with 1g digestion mixture , 0.5g of air dried and powdered solid waste was added followed by addition of 10 ml digestion acid mixture .

ii Mixture was digested on a hot plate at $<$ 150 °C until clear.

iii Sample was allowed to cool and distilled water was added to make final volume in 50 ml.

c) Distillation

i To Kjeldahl assembly with 10 ml of 40% NaOH, 10 ml aliquot of digested sample was supplied.

ii A flask of boric acid indicator (5ml) was placed below Kjeldahl apparatus with the tip of condenser dipped into the indicator. The distillation was started by connecting the assembly until 50 ml of condensate was collected. Prior to end of distillation, flask was taken off so that back sucking can be prevented. Color of the indicator converted to greenish-blue as nitrogen gets dissolved in form of ammonia.

d) Titration

The condensate was titrated with 0.02N HCl (phenolphtalein added as an indicator). Greenish-blue colour changes to permanent light pink.

e) Calculation

$$TKN(\%) = \frac{(a-b) \times N \quad of \quad HCl \times 1.4}{S} \times Dilution \quad factor \tag{3.4}$$

a = HCl volume used with sample (ml)

b = HCl volume used with blank (ml)

S = sample weight taken (g)

N = HCl Normality (after standardization)

Dilution factor (D.F) = 5 (10 ml aliquot of 50 ml sample was taken for distillation)

3.3.6 Total Available Phosphate (TAP)

Total Available Phosphate was determined by Beers Method.

a) Reagents

i Sulphomolybdic acid:

A. To 20 ml distilled water, 2.5 g Ammonium Molybdate had been added.

B. 40 ml of distilled water had been mixed with 28 ml of concentrated sulphuric acid. After cooling, both the solutions were mixed and made up to 100 ml with distilled water.

ii Stannous chloride ($SnCl_2$): To 100 ml glycerol, 2.5 g $SnCl_2$ had been added followed by heating on water bath for dissolution of contents.

iii Standard Phosphate stock solution: 4.388 g anhydrous Potassium dihydrogen phosphate (KH_2PO_4) was mixed with 1000 ml of distilled water. 1 ml contained 1 mg of PO_4-P. Standards were made out of the phosphate stock by appropriate dilution.

iv 0.002N Sulphuric acid: 0.1N sulphuric acid was prepared from concentrated sulphuric acid. It was standardized against 0.1N Na_2CO_3 solution and further diluted to 0.002N sulphuric acid.

b) Extraction

To 0.5 g solid waste sample (in 100 ml flask), 50 ml of 0.002 N sulphuric acid was added. Then it was shaken on an orbital shaker for half an hour followed by filtration through Whatman no. 42 filter paper.

c) Calibration Curve

To 50 ml of standards (known concentration) and samples, added 2 ml of sulphomolybdic acid along with 0.5 ml / 4 - 5 drops of $SnCl_2$ solution. Once the blue coloration developed, absorbance was read at 690 nm by UV-Vis spectrophotometer (E.I. Model 2371) and a calibration curve was prepared for concentration versus absorbance.

d) Calculation

Conc. = Absorbance/graph factor = A mg/l

$$\text{TAP} \quad (\text{mg/kg})(\text{as} \quad {PO_4}^{-3}) = \frac{A(mg/l).V(ml).1000}{W(g).1000} = Bmg/kg \tag{3.5}$$

Where V = Vol. of sample taken (ml)
W = Wt. of solid waste sample taken (g)
TAP (g/kg) (as PO_4^{3-}) = B/1000 g/kg

3.3.7 Total Potassium (TK)

Total K was estimated by Flame Photometric method.

a) Reagents

i Mixture of diacid : To prepare mixture of diacid, conc. Nitric acid & Perchloric acid were blended in 9:1 (v/v) ratio.

ii Stock Potassium: 10 meq/l of K Standard stock solution was prepared by mixing 0.746g of pure dry KCl in one litre of distilled water.

b) Sample Digestion

In 100 ml digestion flask, 0.5g dried waste sample was mixed with 10 ml diacid mixture and digested on hot plate till colourless. To dilute the sample, 30 ml of distilled water was added.Solution was filtered,then shifted to a 50 ml volumetric flask. To make up to 50 ml volume, finally distilled water was added.

c) Calibration Curve and Sample Readings

By making use of the stock solution, 0.5, 1.0, 1.5, 2.0 and 2.5 meq/l standard solutions were made from 10 meq/l stock. Standard solutions were used to calibrate Flame photometer and then sample readings were taken. Standard curve was prepared (using standard methods). Readings obtained from flame photometer (ELICO, Model 378) was compared with standard curve and concentration of potassium in solid waste samples was determined.

d) Calculation

TK Conc. = A meq/l (as obtained from the standard curve) = (A x 39) mg/l

$$TK(mg/kg) = \frac{A.39(mg/l).V(ml).1000}{W(g).1000} = Bmg/kg \tag{3.6}$$

Where V = Vol. of sample taken (ml)
W = Wt. of solid waste sample taken (g)
TK (g/kg) = B/1000 g/kg

TOC content was divided by TKN and TAP to calculate C:N and C:P ratio, respectively.

3.3.8 Micronutrients / Heavy Metals Analysis

Samples were digested using diacid digest prepared: $4HNO_3$v: $1HClO_4$v. Heavy metals (Total Cu, Fe, Mn, Zn, Cd, Pb, Ni and Cr) of feed materials and vermicomposts were quantified using ICP-MS (Thermo Scientific Model iCAPQc). Standard solutions used were of AR grade.

3.3.9 Benefit Ratio (BR)

Benefit Ratio for heavy metals was calculated as reported by Sahariah et al [55].

$$Benefit \quad Ratio \quad (BR) = \frac{\text{Average conc. (105 Days) – Average conc. (0 Day)}}{\text{Average conc. (0 Day)}} \tag{3.7}$$

(Where conc. = concentration)

3.3.10 Seed Germination Index

Seed Germination Index was calculated as reported by Zucconi [98]. 5g sample of final vermicompost was added to 50 ml distilled water. Contents were subjected to agitation for 60 minutes at 150 rpm followed by filtration. Petri plates were lined with filter paper and 20 - 25 plant seeds were placed along with addition of vermicompost extract(10 ml). For 5 days, the petri plates were kept in darkened atmosphere at 25 °C. Double-distilled water was used as control. Seeds germinated were counted along with root length estimation for the control and experimental petri dishes. Germination Index (%) was estimated as:

Germination Index (%) = RSG/RRG × 100

RSG and RRG stands for Relative Seed Germination and Relative Root Germination, respectively.

3.3.11 Soil Respiration Assessment

Soil Respiration Assessment (measured as mg $CO_2kg^{-1}VC48hr^{-1}$) was determined by method of Oliveira and Ferreira [99]. 10 g vermicompost sample was added to a closed gas jar containing 10 ml NaOH and incubated for 48 hrs. Back titration of NaOH was performed with $BaCl_2.2H_2O$ with phenolphthalein as an indicator to determine CO_2 dissolution .

3.3.12 FT-IR analysis

Fourier Transform-Infrared Spectroscopy (FT-IR) analysis for waste materials and vermicomposts was performed by Diamond Cut Technology (Cary630, Agilent Technologies) using finely grinded samples. Spectrum was observed in the infra range of 4000 - 400 nm.

3.4 DETERMINATION OF GROWTH AND FECUNDITY OF EARTHWORMS

The methods to determine the growth and fecundity of earthworms are discussed below.

3.4.1 Biomass Gain and Biomass Gain / Unit Feed Mixture

The net biomass gain can be estimated by subtracting initial biomass from final biomass attained.

The net biomass gain and feed material used per vermi reactors were related as:

$$Biomass \quad gain \quad / \quad feed \quad mixture \quad (mg/g) = \frac{b_2 - b_1}{w} \tag{3.8}$$

w = waste mass (g)
b_1 and b_2 stand for initial and final worm biomass (mg),respectively.

3.4.2 Growth Rate (mg/worm/day)

The growth rate was estimated by dividing the net biomass gain by the no. of worms introduced and no. of days to achieve maximum biomass during the time of experiment.

$$G = \frac{b_2 - b_1}{t \times n} \tag{3.9}$$

G stands for Growth rate as mg/worm/day
b_1 and b_2 stand for initial and final worm biomass (mg), respectively.
t stands for the time of attaining maximum biomass and n for no.of worms introduced.

3.4.3 Fecundity

Fecundity was calculated by formula:

$$F = \frac{C}{E} \tag{3.10}$$

Where,
F = Fecundity rate
C = Number of cocoons produced
E = Number of earthworms introduced

3.5 STATISTICAL INTERPRETATION OF DATA

Statistical investigation was carried out using IBM-SPSS Statistics 21 tool to find the comparison of vermicomposts obtained and feed waste mixtures. The mean value of triplicates as well as standard error of mean (Mean ± SEM) were estimated. Significant difference between various vermicomposting units/vermi reactors was determined using ANOVA (Analysis of Variance) considering physico-chemical and biological factors along with nutrient dynamics. Maturity parameters viz. seed germination and soil respiration rate were also introduced to statistical analysis for checking significance levels among all the vermi-units. Tukey’s HSD post hoc test was executed to determine statistical significance at ($p < 0.05$).

Some photographs during the experimental study are as below:

Cow dung

Eisenia fetida

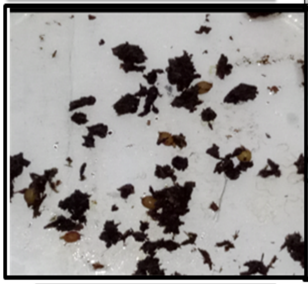
Pre decomposition of cow dung

Earthworms in cow dung

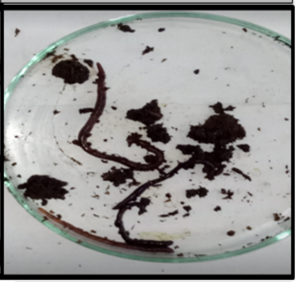
Earthworm culture

100% cow dung (control)

Vermi -reactor covered with jute bag



Cocoons



Earthworm Hatchlings

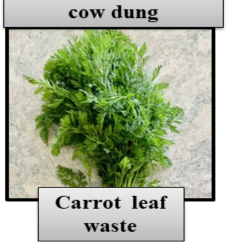

Cabbage leaf waste


Cauliflower waste


Cabbage leaf waste + Cow dung


Cauliflower waste+ cow dung


Banana leaf waste


Carrot leaf waste


Echinochloa crus-galli


Fruit and Vegetable waste

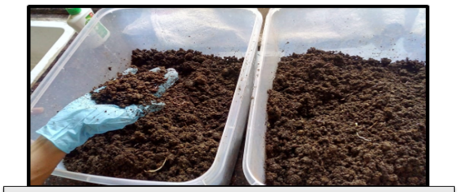

Rice residue


Raw substrates used in vermicomposting experiments

Vermicomposting experiments conducted at EVS Lab

Vermi reactors established for different organic wastes

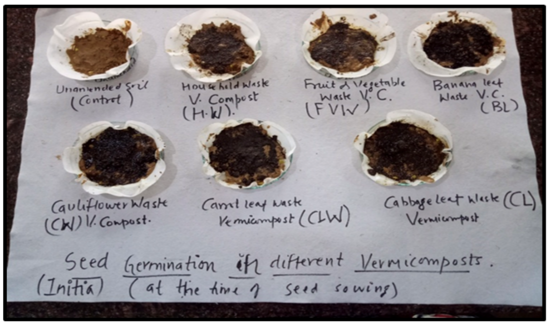
Samples drawn from vermi reactors for analysis



Vermicompost produced after 84 days of HSW Vermicomposting

Vermicomposting - From waste to worth

Vermicompost used for growing plants



Seed germination in Cabbbge leaf waste and Cauliflower waste vermicompost

Chapter 4

HOUSEHOLD SOLID WASTE MANAGEMENT BY VERMICOMPOSTING TECHNOLOGY

With the increasing population and urban development, there has also been an increase in generation of solid waste from various sectors like domestic, public places, private services, institutions, commercial activities, etc. These wastes form the intrinsic part of municipal solid waste and their safe and hygienic disposal is becoming a complicated task for the concerned authorities all over the country. Efficient solid waste management system has been a challenge faced by the urban centers of the developing world due to wide difference between the rate at which solid waste is generated and actually collected. As a result, most of the waste generated is openly dumped or landfilled at places. Improper disposal of solid waste causes health, sanitation and environmental issues, on the other hand, significantly contributes to global warming as waste decomposition produce methane and carbon dioxide along with formation of leachates contaminating groundwater sources [8]. Unscientific disposal sites become the breeding ground for disease causing vectors and emit offensive odours. Therefore, effective strategies should be adopted for solid waste management that will ultimately reduce pressure on municipalities and landfill sites.

Waste management system in its formal form initiate from households ending up in the landfills in the mixed form as decentralization of waste treatment is not implemented at most of the places [100]. Municipalities hold responsibility and cost of waste collection increases due to transportation of waste to dumpsites thereby putting pressure on our fossil fuels too. Therefore, there is utmost need to manage wastes near their point of generation. Mixing of waste creates a series of problems for any of the technique to be followed for its treatment. Even recycling of waste becomes cumbersome. Source segregation is the primary step in effective waste management as it leads to organic waste management, waste processing and recovery of useful materials. Prior to waste management plan, it is pre-requisite to evaluate the amount and composition of waste generated in a city on basis of per capita waste generation. In a developing country like India, where a large portion of waste generated is organic / bio-degradable in nature, biological methods involving renowned technologies such as composting and biogas generation can have potential along with decentralizing the waste management system. Decentralization of solid waste management at an individual / societal level can be a sustainable option and for this, categorization of solid waste is necessary to know the trend of waste reuse / recycling.
In view of this, the present chapter is divided into following sections:
4.1 Characterization and Composition analysis of Household Solid Waste in Faridabad City
4.2 Management of Household Solid Waste by vermi-technology
4.3 Effect of worm stocking rate and seasonal temperatures on vermicomposting of Household solid waste
4.4 Designing of a prototype Four-bin vermicomposter for Organic Waste Management

4.1 CHARACTERIZATION AND COMPOSITION ANALYSIS OF HOUSEHOLD SOLID WASTE IN FARIDABAD CITY

4.1.1 Introduction

In the present study, the objective was to characterize and perform composition analysis of waste generated, evaluate the effect of income status and size of households and assess the potential of household waste for recycling / recovery of valuable resource in study area. In addition to this, a survey was conducted to assess the waste generation habits of households, behaviour towards waste segregation, disposal and management, awareness level and willingness to adopt biological methods of managing waste at home. These findings can be incorporated in all-inclusive waste management strategy of the city to streamline municipal solid waste management process.

4.1.2 Methodology

The study was conducted in residential areas of New Industrial Town - 5 of Faridabad city (India) during October 2016 - December 2017. Random households in this locality were selected for waste generation studies based on a detailed map of the study area. A self - designed questionnaire was prepared to conduct survey on 120 households (on random basis) to determine waste generation, methods of waste disposal and awareness about waste disposal methods. Annual income status and size of household family were taken into account to assess their effect on solid waste generation in a household. Total 100 households have been considered in the results as at least seven samples could be collected from these houses and 20 houses were dropped out as these houses were not able to provide seven days waste consecutively in due course of time. On a final note, 700 solid waste samples from 100 households for seven days were collected and results were obtained for the same sample size. Each house was asked to segregate their waste into wet and dry parts. The samples were weighed and their contents were categorized into three broad groups: Biodegradable waste (organic), Recyclable waste and Non-recyclable waste that were further divided into their sub-components. Simple statistical calculation was performed for the collected data and per capita waste generation was estimated. Waste generation rate was assessed using the formula:

Waste generation rate (kg/capita/day) = Amount of solid waste generated (kg/day) / Population

The focus area was as follows:

- Survey on household solid waste generation
- Solid waste characterization and composition
- Estimation of waste generation in relation to annual income and family size of households
- Estimation of per capita solid waste generation in study area

4.1.3 Results and Discussion

The components of HSW collected during the study have been presented in Table 4.1. The sampled households were categorized into three groups on the basis of annual income, viz., low - income, medium - income and high - income group (Table 4.2). On the basis of household family size, i.e., number of persons in a family, the sampled houses were grouped into small, medium and large family as presented in Table 4.3.

In the present study, the amount of HSW generated in different households for 7 days has been given in Figure 4.1. The HSW collected from different houses ranged between 0.32 kg - 6.5 kg. Table 4.4 depicts composition analysis of HSW generated in the city in terms of amount and percentage of waste having vermicomposting potential, market utility and non- recyclable fraction. Furthermore, these components were bifurcated into sub-components. The biodegradable component stood out to be the highest fraction (47.2%) among all components. Further splitting the biodegradable components, food waste (fruit & vegetable peels and leftover food material) constituted the highest fraction with 41.2% followed by 4.88% garden waste and 1.12% soiled paper items. The recyclable component accounted for 17.45 % of waste generated. The trend of different fractions was: plastic (6.81%) > paper (5.3%) > glass (2.7%) > rags (1.71%) > metals (0.93%). The fraction which can't be recycled included sanitation waste, stones, bricks, miscellaneous waste such as dust and stones (23.6%) as the highest fraction.

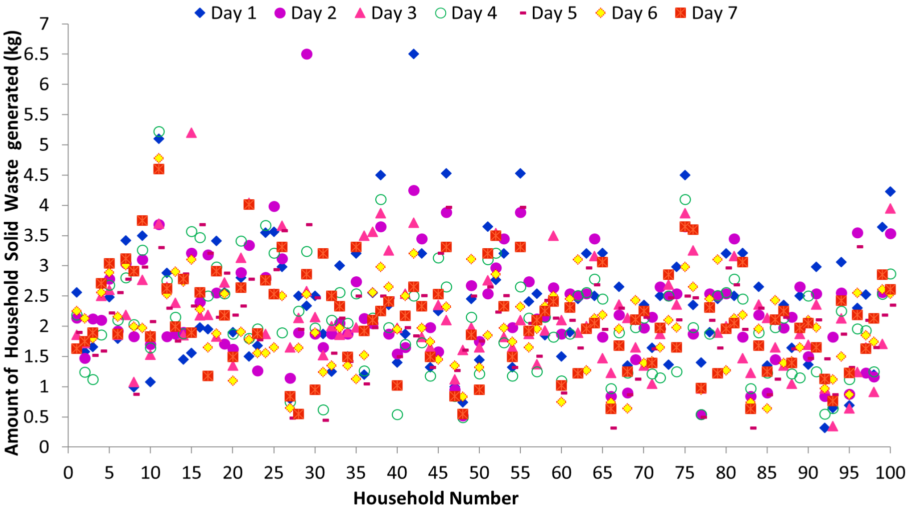


Figure 4.1: Household Solid waste generation by households in 7 days

Table 4.1: HSW categorization for determining its composition

S. No.	Category	Components
1	Biodegradable waste	a) Food waste (Fruit and vegetable peel off, left-over food)
		b) Garden waste (grass, leaves, twigs, etc.)
		c) Soiled paper/paper items
2	Recyclable waste	a) Paper
		b) Plastic/polythene bags
		c) Glass
		d) Metals
		e) Clothes/rags
3	Non-recyclable waste	a) Sanitation waste
		b) Dust and stones
		c) Ceramics and brick pieces
		d) Misc. mixed waste (glass, plastic, etc.)

Table 4.2: Household income Status and no. of houses sampled in each income category

S. No.	Income Status	Annual Income categorization (Rs.)	Number of sampled houses
1.	Low-income	$<$ 2 Lakhs	33
2.	Medium-income	2-5 Lakhs	47
3.	High-income	$<$ 5 Lakhs	20
	Total		100

Solid waste generated at household level forms the major part of municipal solid waste and ultimately reach to landfills in absence of suitable waste segregation practices. As depicted in Table 4.4, biodegradable proportion (47.20%) is the largest fraction of HSW, which at present finds its way to open dumping or unstructured landfill sites leading to under-utilization or sheer wastage of valuable organic resource.

Table 4.3: Household Family size and no. of sampled houses in each household category

S. No.	Family Size	Number of persons in Family	Number of sampled houses
1.	Small	2 – 4	33
2.	Medium	5 – 6	46
3.	Large	> 6	21
	Total		100

Being organic and non-toxic in nature, this fraction of waste can be recycled/recovered by biological methods like composting and vermicomposting processes. It was observed that the recyclables (plastic, paper, polythene etc.) could not be potentially recovered due to lack of proper segregation practices at generation point, although some portion is collected by local rag pickers in an unorganized and decentralized manner. If the waste is segregated at the point of generation, then recovery of market utility fraction of HSW can be enhanced than the present rates and eventually their fate in reaching landfills can be avoided.

Figure 4.2 presents waste generation/capita/day by households in present study. Per capita/day waste generation ranged in between 0.256 - 0.748 kg in various households in the study, however, mean values for waste generation was found 0.448 kg/capita /day. Based on the earlier research studies, it has been observed that waste generated from one city differs in composition and volume from another cities. The difference is due to variation in consumeristic patterns, population matrix, social, economic, cultural levels and climate. Figure 1.1 shows per capita waste generation rate of different cities. If this data is compared with the per capita waste generation of the present study, it was found to be greater than some cities and comparable to some big Indian cities. Population growth and urban development have contributed significantly in increasing waste generation during recent decades.

Table 4.4: Composition analysis of solid waste collected in Faridabad city

Waste Category	**Amount of waste produced (kg)**	**Recyclable (%)**		**Nonrecyclable (%)**
		Market utility	Vermicomposting Potentiality	
Biodegradables				
Food waste	618.90		41.20	
Garden waste	73.30		4.88	
Soiled paper items	16.82		1.12	
Recyclables				
Paper	79.61	5.30		
Plastic	102.29	6.81		
Metal	13.97	0 .93		
Glass	40.55	2.70		
Clothes/Rags	25.68	1.71		
Non-Recyclables				
Sanitary waste	5.55			0.37
Dust and Stones	354.51		23.60	
Ceramics and Brick pieces	52.42			3.49
Misc. mixed waste	71.35			4.75
Others	47.16			3.14
Total	1502.2	17.45	47.20	35.35

Various socio-economic factors influence waste generation rates, out of these, income status and family size of households were taken into account in the present study. Table 4.5 shows waste generation (per family/day) in various income categories. Solid waste generation rate was estimated on basis of income status to analyze how living standards of people affect waste generation. The waste generation per family/day in low-income category varied from 0.58 to 2.80 kg with an average of 1.79 kg/family/day. The households in medium-income category generated waste in range of 0.77 to 4.08 kg with an average of 2.28 kg/family/ day. The waste generation rate was in range of 0.89 to 4.58 kg with an average value of 2.43 kg/family/ day in high-income category. It is clear from the results that as the income level increases, there is widening of the range of waste generation rate by each family. Also, the average rate of waste produced / family increases with increase in income level of families. Further, per capita waste generation accelerated with increased income status and registered to be 0.364 kg/capita/day (low-income category); 0.472 kg/capita/day (medium-income category) and 0.537 kg/capita/day (high-income category). Income status and waste generation are directly correlated as depicted in Figure 4.3. Direct relationship was observed between household income status and rate of waste generation by several authors too in their studies [101],[102],[103]. According to study conducted by Kamran et al. [102], lower income groups generated 0.39 kg/capita /day; middle income group produced 0.56 kg/capita /day and higher income category generated 1.1 kg/capita /day of waste. Some studies have shown that income status might not influence waste generation directly [104],[105], however, food waste was the significant portion of waste generated.

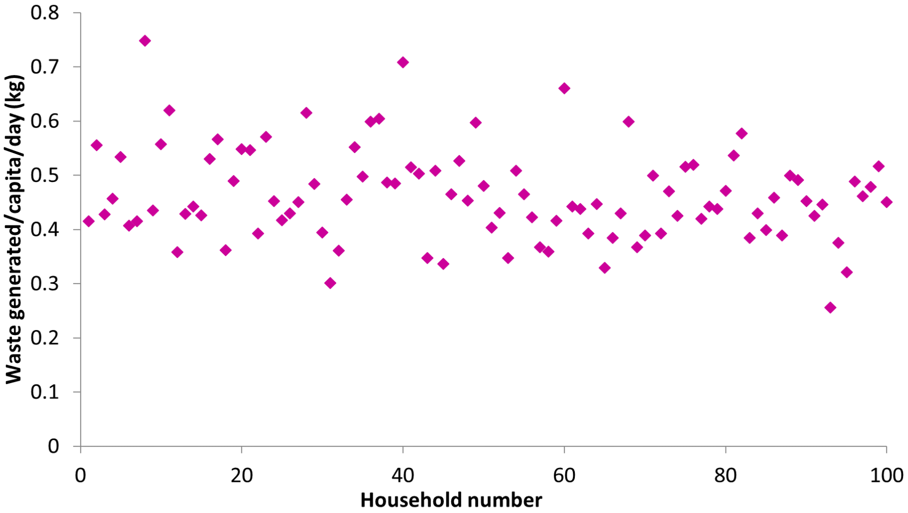


Figure 4.2: Per capita waste generation by households in the study

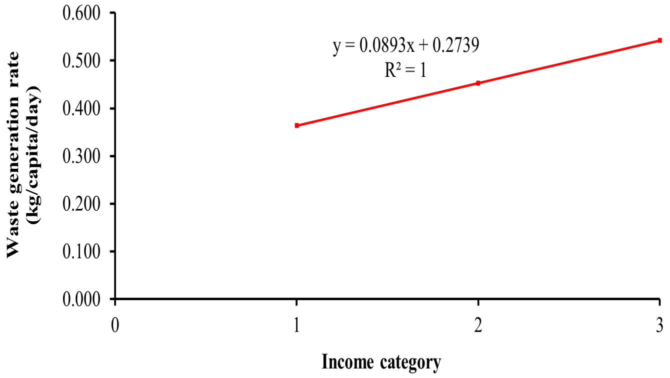


Figure 4.3: Relationship between Income group and waste generation rate

Household family size was another important factor studied to analyze waste generation by each household (Table 4.6). It was evident from the findings that per capita waste generation was not directly impacted due to number of persons in a family, however, amount of waste generated might increase with increase in number of persons. Per capita waste generation per family showed somewhat erratic pattern with the increase in the number of persons in households. Direct relation of no. of persons in family with per capita waste generation was not found (R^2=0.3768) as shown in Figure 4.4.

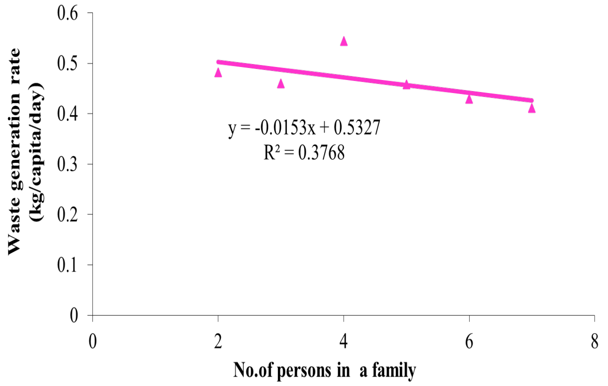


Figure 4.4: Relationship between No. of persons in households and waste generation rate (kg/capita/day)

The overall status of waste generation rates in the present study in Faridabad city have been exhibited in Table 4.7 and Figure 4.5. The waste generation rates ranged from minimum of 0.256 to maximal 0.748 kg/capita/day in households and mean values for waste generation came out be 0.448 kg/ capita/ day. Biodegradable waste constituted the highest proportion as 47.2%, followed by recyclables having market utility (17.45%). The remaining portion of waste generated is of non-recyclable nature (35.35%). Due to lack of sufficient waste collection facilities, all the waste find its way to landfills without any processing.

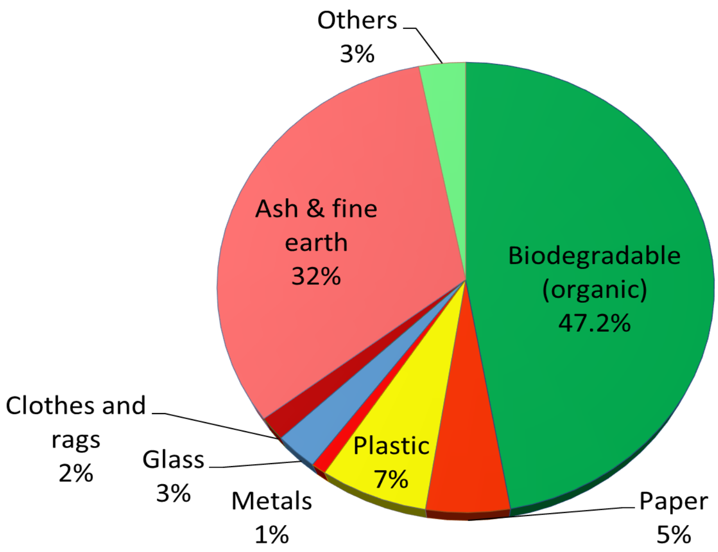


Figure 4.5: Composition of solid waste in the study area

Table 4.5: Solid Waste Generation/family/day in household income category in Faridabad city

Income group	**No. of sampled houses**	**No. of persons in households**	**Waste generation family^{-1} day^{-1} (Kg)**		
			Minimum	Maximum	Mean
Low-income	33	162	0.58	2.80	1.79
Medium-income	47	227	0.77	4.08	2.28
High-income	20	90	0.89	4.58	2.43

Faridabad city is facing the problems related to municipal solid waste management, viz., limited space for landfills and waste dumping in the Aravalli ranges near Gurgaon-Faridabad road resulting in poor environmental quality in surroundings. Therefore, a suitable waste management plan is required so that the amount of waste reaching the landfills can be reduced. The source - segregation of waste into biodegradables, recyclables and non-biodegradables will surely bring about significant changes in overall system. This will also prevent the mixing of waste of different nature, for example, if kitchen waste is mixed with toxic wastes such as dyes, acids, batteries, etc., the former will also turn toxic. The quality of recyclable wastes such as paper bags and plastic items may be reduced if they get mixed with wet organic waste.

Table 4.6: Solid waste generation by Number of persons in a family in Faridabad city

S. No.	No. of persons in a family	No. of sampled houses	Waste generated /day (kg)	Waste generated / capita/day
1.	2	14	13.52	0.482
2.	3	14	19.32	0.460
3.	4	05	10.88	0.544
4.	5	28	64.12	0.452
5.	6	18	46.34	0.429
6.	7	21	60.42	0.411

Table 4.7: Estimation of per capita per day Solid Waste generation in Faridabad city

Total no. of household studied	100
Total no. of persons in the household	479
Total no. of HSW samples collected	700 (7 samples for each household)
Total quantity of waste generated	1502.2 kg
Per capita per day waste generation	0.448 kg
Maximum	0.748 kg
Minimum	0.256 kg

Source-segregation of waste would provide good opportunities for waste disposal in a scientific way. As obvious from the findings of study, HSW is a significant fraction of overall waste generated, below-given points can be considered in order to improve the solid waste disposal system of the city:

- The biodegradable organic fraction (47.2%) dominates the whole HSW stream. This fraction can be significantly used in the bio-processes like vermicomposting.
- The recyclable fraction (17.45%) included paper, plastic, etc. These items may be handled by strengthening recycling markets.
- Left-over waste (35.35%) can't be recycled and consisted of dust particles, soil etc. This waste may find its way to landfill sites.

Owing to scarcity of land/space and increasing concerns about environmental quality, it would be difficult to acquire more land areas for waste disposal in future. This demands more research on the possible uses of HSW.

Responses collected during the survey indicated:

- About 34% of the households segregate their waste into dry and wet waste, whilst, 66% do not practice source segregation. Out of these, some people from both categories revealed that segregated waste was mixed prior to disposal during their collection by eco-vans employed by Municipal Corporation. Therefore, many of the households discontinued the practice of segregation.
- About 76% of households gave their waste to Municipal garbage collectors and 24% of them disposed household waste on their own either by throwing in open places / street corners / nearby plots where garbage was pre - thrown hardly caring about the menace they are creating.
- About 81% of people used polythene bags for storing and disposing household waste whereas 19% used paper bags / compostable bags. 96% of people often gave their old books/ newspapers and other recyclables to local vendors; only 4% burn them.
- 79% of households were aware that organic wastes can be managed by composting while 21% of them showed ignorance about composting method. On asking whether they were interested in household waste (organic waste) composting, 86% of people were in favor of adopting this method but 14% of households refused due to time constraint, space requirement and efforts involved.
- On asking about the most preferable mode of composting, 38% showed interest in backyard composting whereas comparable responses were recorded for vermicomposting (32%) and conventional composting (31%).
- Participants were asked to separate HSW into wet and dry; some of them found it difficult to segregate the waste while others end up mixing the waste, therefore, 20 houses were not able to give seven days waste as required in the study. Lack of awareness, willingness, time and space constraint were some limitations / excuses for giving organic fraction of total waste.

4.1.4 Conclusions

Household solid waste (HSW) quantity estimation and composition analysis is a basic parameter for developing strategies of municipal solid waste management in a city. Waste sampling and analysis at the source of generation provides a better idea about the composition of solid waste generated. Due to lack of scientific waste disposal landfill sites in Faridabad city, there is an utmost requirement to reduce the quantity of solid waste going to the landfill site. This can be achieved only by segregation of the waste at the point of generation and processing the waste before final disposal. Present study signified the importance of managing organic proportion of solid waste generated at household level.

- Per capita waste generation in Faridabad city was found to be 0.448 kg per capita/day.
- Waste generation rate (kg/capita/day) was directly proportional to the annual income of households but per capita per day waste generation was not proportional to the family size although family size somehow affected waste generation.
- The biodegradable/organic component in the HSW was the highest (47.20%) that can be used as potential feed substrate in vermicomposting. Biodegradable (compostable) and recyclable components (17.45%) in the household waste can be segregated at the source thereby reducing the waste load on landfills. By proper segregation of the HSW at the source itself, a significant portion ($\approx$65%) of the solid waste (biodegradable and recyclable) can be diverted from the landfills for the final disposal.

Inefficient waste disposal and management in Faridabad city has led to open dumps, choked drains and littered waste everywhere. This necessitates the obligation for active participation by public in the form of waste segregation at household levels, managing organic portion through composting / vermicomposting and giving recyclable fraction to local vendors. Also, there is a need of integrated solid waste management system at urban levels to achieve 100% waste segregation at household levels, proper door to door collection by Municipal Corporation, Faridabad followed by waste processing, establishing community waste bins and composting / vermicomposting bins. Thus, a shift from conventional waste management to sustainable management is call of present time where waste is not considered as waste any more, in fact, a worthy resource as organic manure and recovered / recycled materials and changing mindset of thinking waste as others' problem to our own responsibility that we should perform; thus a step ahead to make Faridabad a waste-wise city.

4.2 MANAGEMENT OF HOUSEHOLD SOLID WASTE USING VERMI-TECHNOLOGY

4.2.1 Introduction

As mentioned in previous section, biodegradable organic waste makes a significant portion of overall waste stream in the city and has a potential to be utilized in biological processes like vermicomposting. Therefore, this chapter represents the feasibility of vermi-technology for decomposition of HSW. Extensive studies have reported the use of earthworms in decomposition of organic wastes and epigeic forms of earthworms enhance the rate of composting to a significant extent with production of nutrient enriched vermicompost. The household solid waste in Faridabad city has a significant percentage of organic matter which can be used as a substrate in vermicomposting process.

4.2.2 Methodology

a) Materials

Household Solid Waste was collected from the residential area of New Industrial Town 5 in Faridabad city. The organic component of HSW comprised of kitchen waste, fruit and vegetable peels, paper products, garden waste and other organic materials. Raw waste was shredded into small parts for use in vermicomposting experiments. Cow dung (CD) was used as an amendment in the process. It was obtained from a local dairy farm. Physico-chemical characteristics of HSW and CD prior to start of the experiment are presented in Table 4.8. *Eisenia fetida* earthworm employed in vermicomposting experiment was taken from stock culture prepared in lab.

b) Experimental Setup

One kilogram of feed mixture was maintained in triplicates in five vermireactors (on dry weight basis) with varying ratios (20 - 60%) of HSW and CD including 100% CD for 90 days (Table 4.9). All vermireactors were kept for pre-composting of twenty-one days to eliminate offensive odors. 20 individuals of *E. fetida* (150 and 200 mg each) were released into each vermireactor after 21 days. Water was sprinkled regularly in the feed mixtures to maintain moisture content at 70 ± 10%. The vermireactors were covered with jute cloth to provide congenial dark environment to the photo-sensitive earthworms. Homogenized samples from each vermireactor were collected at regular intervals. Physico - chemical quality of vermicomposts obtained from HSW + CD was evaluated. Different growth parameters were recorded at different time intervals to assess the potentiality of household solid waste as feed substrate for earthworms.

Table 4.8: Initial physico - chemical characteristics of raw substrate used in different Vermireactors (Mean ± SEM of three replicates)

S.No	Parameters	Cow dung (CD)	Household Solid Waste (HSW)
1.	pH	8.3±0.02	7.3±0.03
2.	EC (dS/m)	1.32±0.03	1.98 ±0.05
3.	Ash content (g/kg)	211±2.26	148±4.6
4.	TOC (g/kg)	458±3.42	494.1±2.89
5.	OM (%)	78.9±1.48	85.2±2.02
6.	TKN (g/kg)	8.5±0.15	12.6±0.01
7.	TAP (g/kg)	7.3±0.2	5.1±0.06
8.	TK (g/kg)	9.2±0.38	13.6±0.28
9.	C: N ratio	53.9± 2.08	39.2±1.90
10.	C:P ratio	62.7±1.76	97.0±1.03
11.	Moisture content (%)	80±1.28	76.2±1.89
12.	Fe (mg/kg)	1488±11.2	711±2.05
13.	Zn (mg/kg)	98.8±5.6	54.06±1.12
14.	Cu (mg/kg)	82.6±1.28	129.1±4.52
15.	Mn (mg/kg)	104.3±2.08	49.4±1.16
16.	Pb (mg/kg)	1.46±0.04	1.12±0.03

Table 4.9: Composition of raw substrate (Cow dung and Household Solid waste)

Vermireactors	CD + HSW	CD (%)	HSW (%)
V1 CD_{100}	1000g	100	–
V2 HSW_{20}	800g+200g	80	20
V3 HSW_{40}	600g+400g	60	40
V4 HSW_{50}	500g+500g	50	50
V5 HSW_{60}	400g+600g	40	60

c) Physico - chemical and Biological Analysis

The following parameters were analyzed in the study using standard methodology (Chapter 3): pH, electrical conductivity - EC, total organic carbon-TOC, ash content, total kjeldahl nitrogen - TKN, total available phosphorus - TAP, total potassium - TK, soil respiration rates, seed germination index, total iron - Fe, copper - Cu, zinc - Zn, manganese - Mn and lead - Pb. Biological parameters were also evaluated using methods mentioned in Chapter 3.

d) Statistical Analysis

Statistical analysis of data was done as mentioned in chapter 3, where statistical significance was denoted as $p < 0.05$.

4.2.3 Results and Discussion

During the course of vermicomposting, organic matter contained in raw substrate gets mineralized and exhibit changes in physico-chemical characteristics – pH, EC, TOC, ash content, macronutrients (TKN, TAP, TK) and micronutrients (Total Fe, Cu, Zn, Mn and Pb) (Table 4.10). These findings have been exhibited in this section. Further, vermicompost obtained from different combinations of household solid waste had shown about 3.7 - 4.8 times reduction in mass during the course of vermi-conversion. The trend of mass reduction was: CD_{100} (4.8 times) $>$ HSW_{20} (4.7 times) $>$ HSW_{40} (4.5times), HSW_{60} (3.7times). Lalender et al. [106] also reported reduction in mass followed by vermicomposting of cow dung and food waste.

a) Change in pH, EC, TOC and Ash Content

A decrease in pH was recorded in all vermireactors, which ranged from initial values of 7.62 - 8.36 in feed mixtures to 7.09 - 7.56 in final vermicomposts after 90 days. The pH decline was statistically different for vermireactors ($p < 0.05$). Highest decrease in pH was reported in HSW_{40} (9.77%) and least in feed mixture HSW_{60} (6.9%) which suggests better mineralization of oranic matter in former end product. The trend of pH decrease was $HSW_{40} > HSW_{20} > CD_{100} > HSW_{50} > HSW_{60}$. In the present study, initial increase in pH values may be attributed to nitrogen and phosphorus mineralization, organic matter degradation and CO_2 and NH_3 formation [107] (Figure 4.6).Researchers have reported final pH fall in near neutral range in vermicomposts due to humic and fulvic acid production as a result of earthworm and microbial activities [67]. Further, pH drop during the process of vermicomposting is dependent upon raw substrate employed in the study [108].

EC estimates the amount of salts in organic material and is considered significant for assessing the suitability of vermicomposts for agronomic use. EC values were found to be increased in all the vermireactors irrespective of variation in raw substrate combinations. Initially, EC values were in between 1.36 dS/m - 1.96 dS/m in different feed combinations and accelerated in the range 2.67 - 3.53 dS/m with time during 90 days of vermicomposting (Figure 4.7). All vermireactors were significantly different from each other for increase in EC values ($p < 0.05$). The trend of percent increase in EC was: HSW_{40} (101.2%) $>$ HSW_{20} (100.6%) $>$ CD_{100} (96.3%) $>$ HSW_{50} (83.5%) $>$ HSW_{60} (80.1%).

The findings of the present study showed that vermicomposting of HSW_{40} and HSW_{20} resulted in more increase in EC than control (CD_{100}) and rest of the feedstock combinations which may be attributed to effective organic matter degradation and presence of nutrients in more available forms in these combinations. However, all the vermicomposts produced had EC < 4.0 dS/m which is the recommended limit for agronomic applications as manure. EC increase might be due to the production of soluble salts, change of organically bind nutrients into accessible forms and inorganic ions accumulation along with organic matter degradation [109].

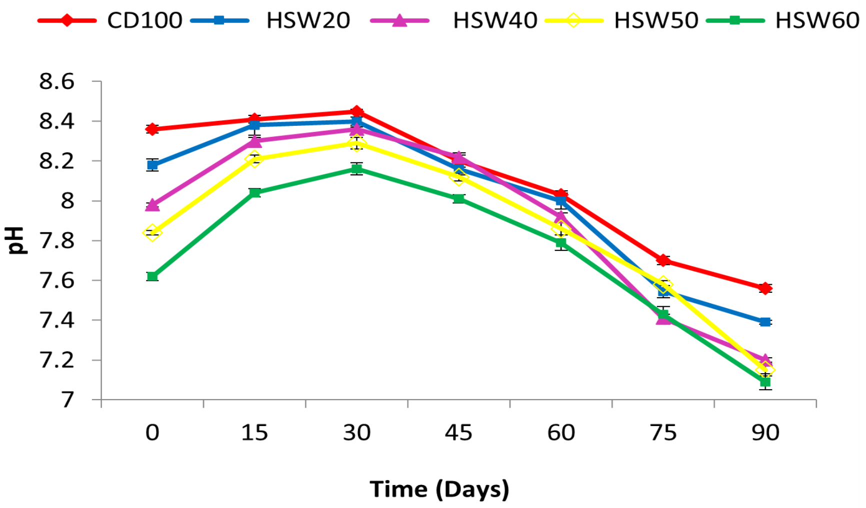


Figure 4.6: Change in pH level in different vermireactors with time

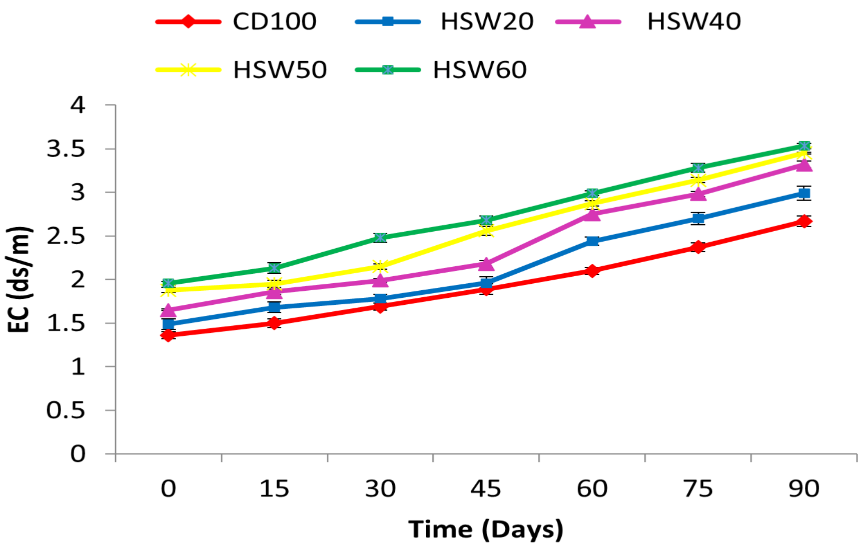


Figure 4.7: Change in EC level in different vermireactors with time

TOC content reflects organic waste degradation and reduced significantly in final vermicomposts as compared to initial feedstocks. TOC ranged from 458 ± 3.45 - 495 ± 2.14 g/kg in initial feedstocks and decreased to 334.4 ± 2.98 - 272.6 ± 3.56g/kg at the end of process (Figure 4.8). Significant difference was recorded in all the vermireactors for reduction in TOC content ($p<0.05$). The trend of TOC reduction was as follows: CD_{100} (40.0%) $>$ HSW_{40} (39.4%) $>$ HSW_{20} (38.8%) $>$ HSW_{50} (35.0%) $>$ HSW_{60} (32.4%).

Table 4.10: Physico-chemical characteristics of raw substrate and vermicompost produced in different vermireactors (Mean ± SEM of three replicates)

Vermi-reactors	pH	EC (dS/m)	TOC (g/kg)	Ash Content (g/kg)	TKN (g/kg)	TAP (g/kg)	TK (g/kg)	C/N	C/P
Initial raw substrate									
CD_{100}	8.36±0.02e	1.36±0.04a	458±3.45a	211±3.20e	8.5± 0.03	7.4±0.03	9.2±0.01	53.8±1.14	61.8±1.14
HSW_{20}	8.18±0.03d	1.49±0.06b	469±2.34b	191±4.15d	9.34±0.02	7.1±0.01	9.8±0.01	50.2±1.18	66.0±1.21
HSW_{40}	7.98±0.01c	1.65± 0.01c	479±3.80c	173±5.08c	9.87±0.01	6.2±0.01	10.6±0.03	48.5±1.09	77.1±1.26
HSW_{50}	7.84±0.01b	1.88±0.03d	488± 4.02d	158±4.10b	10.3±0.04	5.4±0.01	11.8±0.02	47.3±1.80	90.3±1.37
HSW_{60}	7.62±0.02a	1.96± 0.02e	495±2.14e	146±2.11a	11.5±0.02	5.1±0.02	12.9±0.04	43.0±1.56	99.0±.2.42
Final Vermicompost									
CD_{100}	7.56±0.02e	2.67±0.06b	274±3.56a	526±5.20d	16.8±0.05	12.2±0.06	21.02±0.02b	16.3±0.98	22.3±1.02
HSW_{20}	7.39±0.01d	2.99±0.08d	287± 1.2b	505±4.87c	19.8±0.08	11.8± 0.07	23.5±0.03d	14.4±1.75	24.2±1.11
HSW_{40}	7.20±0.01c	3.32±0.04e	290±1.45c	500±3.64c	22.3±0.18	11.0± 0.04	24.6±0.02e	13.0±0.78	27.1±1.08
HSW_{50}	7.15±0.03b	3.45±0.01c	317±3.87d	454±4.32b	20.3± 0.20	8.64± 0.02	22.4±0.02c	15.6±1.08	36.6±1.20
HSW_{60}	7.09±0.04a	3.53± 0.03a	340±2.98e	413±2.28a	17.8±0.09	6.85±0.03	20.8±0.03a	19.1±0.67	49.6±1.18

Different alphabets in each parameter shows statistically significant difference (ANOVA, Tukey's HSD test $p \leq 0.05$)

The fast reduction of TOC content in feedstocks of HSW exhibited that the worm *E. fetida* efficiently degraded and stabilized the feedstocks. The reduction in TOC content in the organic feedstocks was due to utilization of carbon pool as energy source in microbial respiration and degradation of organic matter by earthworms [110]. Earlier works also suggested TOC decline in vermicompost samples up to different extents [93],[111].

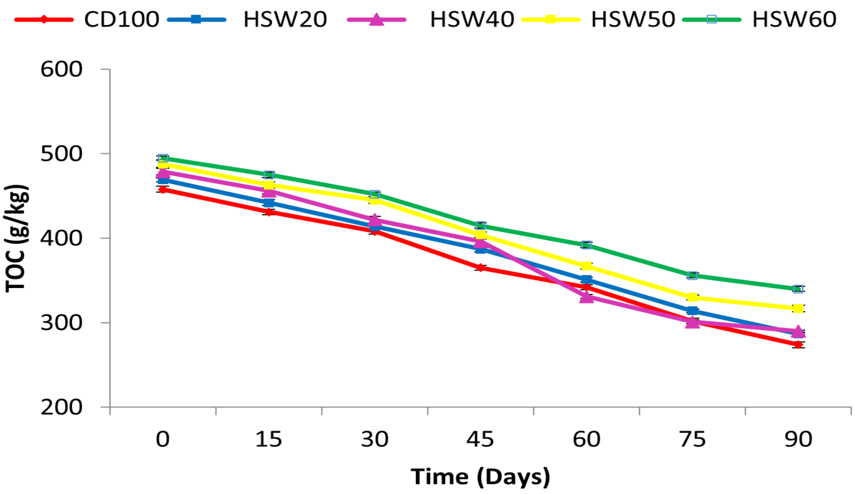


Figure 4.8: Change in TOC content in different vermireactors with time

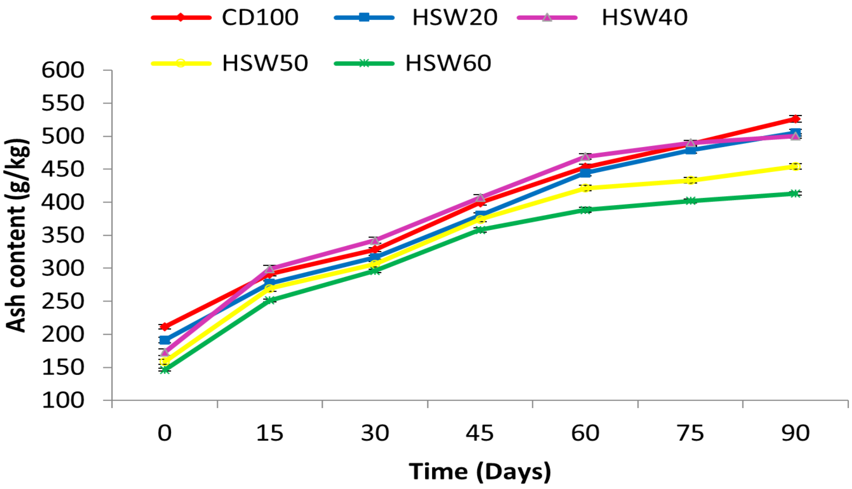


Figure 4.9: Change in Ash content in different vermireactors with time

Increase in ash content suggests efficient decomposition and mineralization of raw substrate, henceforth, vermicompost maturation. Present experiment showed trends of increase in ash content towards the completion of vermicomposting process. Significant increase in ash content from initial levels of 146 - 211 g/kg to final values in range of 413 - 526 g/kg was noted. The study showed increment of 149.5- 188.0% in final vermicomposts from varied proportions of HSW with time (Figure 4.9). Earthworms efficiently degraded and mineralized raw waste which resulted in increase of ash level in final vermicomposts [86]. Significant difference was found among different vermireactors for ash content increase (ANOVA; Tukey's HSD test, $p<0.05$) although HSW_{20} and HSW_{40} were significantly indifferent.

b) Change in TKN, TAP and TK Levels

Nitrogen is an essential macro-nutrient for plant growth and its enhancement during vermicomposting evidences the importance of earthworm activity. After 90 days of degradation by earthworms, all the vermireactors have shown enhanced TKN levels in the range of 16.8 - 22.3g/kg as compared to 8.5 - 11.5 g/kg in initial raw wastes. Remarkable increase of 1.54 - 2.25 fold was recorded in all the vermireactors with highest increase in 40% HSW vermicompost (Figure 4.10). The trend of TKN increase was in the order: $HSW_{40} > HSW_{20} > CD_{100} > HSW_{50} > HSW_{60}$. Further, nitrogen content in vermireactors varied significantly in all waste mixtures ($p < 0.05$). TKN augmentation is associated with initial nitrogen level of waste mixture, mucus, excretory substances, hormones, enzymes and body fluids of earthworms in final vermicomposts [28]. Fu et al. [112] have suggested that some microflora along with earthworms enhance the release of enzymes which directly increase the nitrogen and phosphorus content in final vermicomposts.

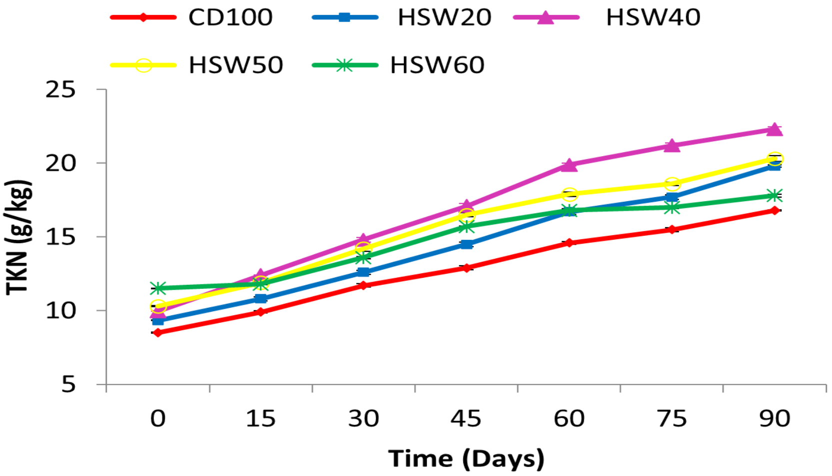


Figure 4.10: Change in TKN in different vermireactors with time

Phosphorus is an essential nutrient required for plant growth. TAP content enhanced from the values 5.1 - 7.4 g/kg in all the raw substrates to variable extents (6.85 - 12.2 g/kg) in final vermicomposts (Figure 4.11). TAP increase was found to be 1.34 - 2.10 fold more than initial values in raw substrate and may be linked to combined activity of earthworms & microbes leading to phosphorus mineralization and organic substrate degradation [113]. The trend of percent increase in TAP content was: $HSW_{40} > HSW_{20} > CD_{100} > HSW_{50} > HSW_{60}$. TAP increase was statistically different in all the vermireactors ($p < 0.05$). Phosphatase enzyme and phosphate-solubilizing bacteria in earthworm's gut release phosphorus in soluble forms thus exaggerating TAP in final vermicompost [114]. TAP increase was also recorded in previous reseach studies [88],[93],[89].

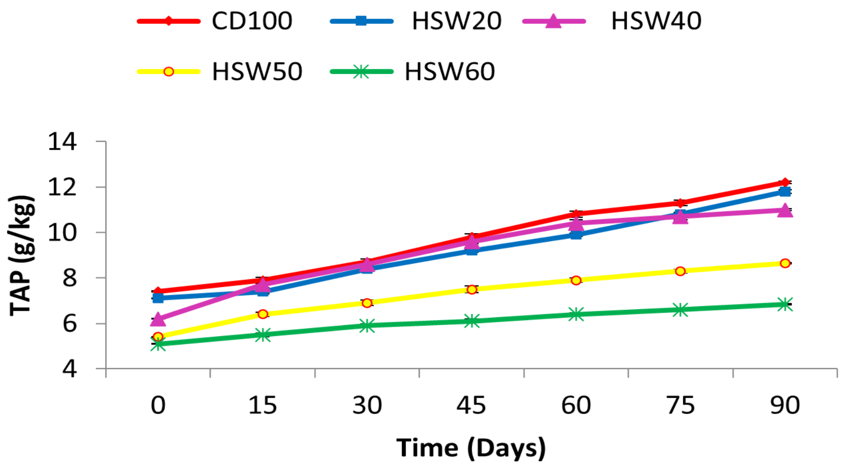


Figure 4.11: Change in TAP in different vermireactors with time

A remarkable increase in TK was observed in all the feedstock combinations after completing 90 days vermicomposting with 1.61- 2.39 fold increase in vermireactors. TK augmentation was of the order: $HSW_{20} > HSW_{40} > CD_{100} > HSW_{50} > HSW_{60}$ (Figure 4.12). Potassium content was statistically significant for different vermi reactors ($p<0.05$). Earlier experimental studies also suggested higher potassium content in the end product [86]. Effective breakdown of raw substrates with production of exogenic/endogenic enzymes due to increased microbial action in presence of earthworms had resulted in TAP increase. Organic matter depletion and surge in exchangeable potassium ultimately raised potassium levels in final vermicompost [90],[115]

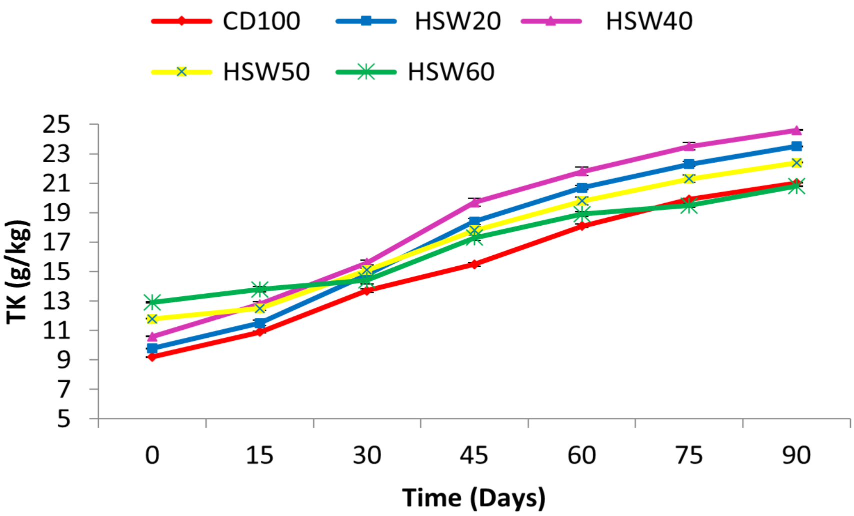


Figure 4.12: Change in TK in different vermireactors with time

c) Change in Carbon to Nitrogen / Phosphorus Ratios

C:N ratio is used for determining the vermicompost maturity and stability for its agronomic use. Remarkable decrease of 55.5 - 73.1% was shown by all the vermireactors after 90 days of vermicomposting. The C:N values in raw wastes was in the range of 43.0 - 53.8, whereas it was decreased in the end products and the range was 13.0 - 19.1. Highest percent decrease in C:N values was recorded in HSW_{40} (73.19%) and it was minimum in HSW_{60} feedstock (55.58%) (Figure 4.13). The percent decline was: $HSW_{40} > HSW_{20} > CD_{100} > HSW_{50} > HSW_{60}$. As evident from the findings, vermireactor HSW_{40} and HSW_{20} showed more decrease in C:N ratio as compared to control CD_{100} indicating more organic matter degradation by earthworms due to addition of HSW in cow dung. All the vermireactors statistically varied from one another ($p < 0.05$) with respect to C:N levels. With loss in carbon levels as CO_2 and nitrogen loss to lower extents, effective degradation of organic wastes take place resulting in C:N ratio drop. Decrease in C:N levels can be ascribed to organic matter decomposition and depletion of carbon pool as well as augmentation of nitrogen [116]. The C:N value < 20 determines vermicompost stability [117],[118] and < 15 notify its value as an organic manure [90].

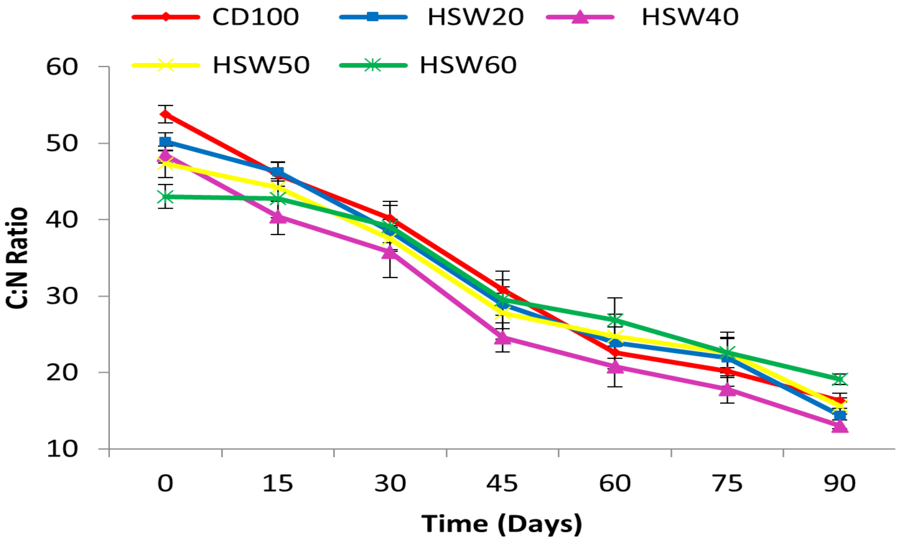


Figure 4.13: Change in C:N ratio in different vermireactors with time

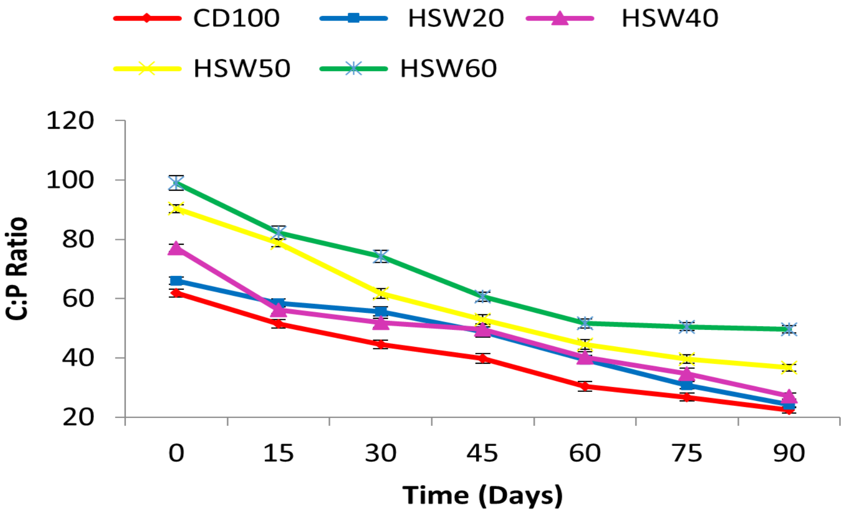


Figure 4.14: Change in C:P ratio in different vermireactors with time

C:P ratio also showed a declining trend in various vermireactors after 90 days. C:P ratio varied from 61.8 - 99.0 at the onset of experiment and declined in the range of 22.3 - 49.6 as the process reaches completion. The percentage decrease was in order of $HSW_{40} > HSW_{20} > CD_{100} > HSW_{50} > HSW_{60}$ (Figure 4.14). Decrease in C:P ratio suggested effective raw substrate degradation and hence vermicompost stability. C:P ratio drop was significantly different among different combinations($p<0.05$). C:P drop during vermicomposting process was also registered by some previous researchers [119],[115].

d) Soil Respiration Rate and Germination Index

Respiration rate is measured as $mgCO_2kg^{-1}VC48h^{-1}$ and considered as an important parameter for assessing vermicompost stability [120]. At the onset of experiment, large source of carbon is present as a part of organic waste which accelerates respiratory action of microoganisms. As soon as this source gets depleted due to accumulating microbes, a drop in respiration rates can be noticed in all the vermireactors up to different extents [84]. Respiration rate was in range of 178 - 212 mg $CO_2kg^{-1}VC48h^{-1}$ at the onset of the process and accelerated upto 45th day owing to presence of plenty of raw waste for degradation in all the vermireactors (Figure 4.15). At 90th day, respiration rate declined to 60 - 114 $mgCO_2kg^{-1}VC48h^{-1}$. Final respiration rates in vermireactors were in the permissible limits of <120 $mgCO_2kg^{-1}VC48h^{-1}$ [121] that is reflective of vermicompost stability. TOC and C:N ratio decrease also suggests utilization of carbon source during the course of vermicomposting. Final Respiration rates varied significantly from each other in the study ($p < 0.05$). Previous findings also recorded a significant decrease in respiration rates of different organic wastes [122]. Thus, it can be further suggested that household solid waste can provide a suitable habitat for microbes and earthworm to produce a stable vermicompost.

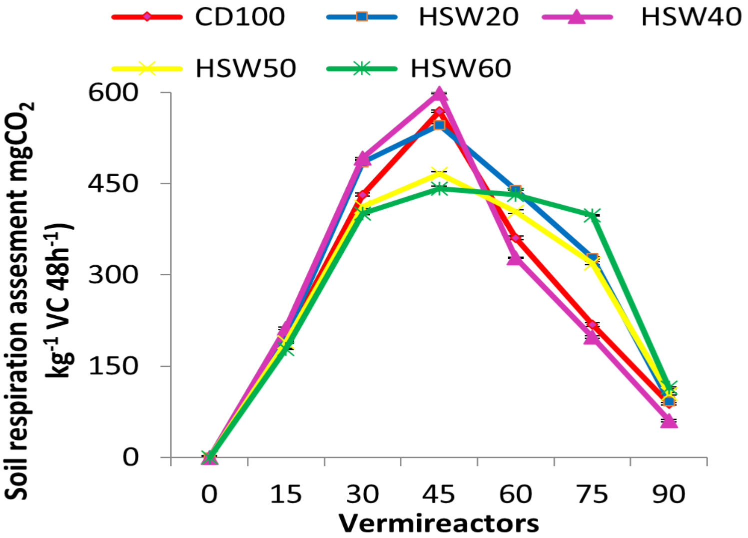


Figure 4.15: Change in Soil respiration rate in different vermireactors with time

Germination Index (GI) is an indicative of vermicompost maturity as it establishes suitability of manure produced. GI value > 80% suggests non-toxicity of vermicompost [98]. Relative seed and root germination in raw wastes were estimated to find Germination Index for *Vigna radiata* (moong bean). Initially the feed stocks had GI values varying from 26 - 59% in raw wastes and were not suitable for plant use. GI in all vermireactors were recorded in range of 98 - 168%. GI trends mark the stability of vermicompost upto variable extents in the study: $HSW_{40}(168\%) > HSW_{20}(145\%) > CD_{100}(129\%) > HSW_{50}(105\%) > HSW_{60}(98\%)$ (Figure 4.16). GI $> 80\%$ was achieved in all the vermireactors and varied significantly from each other ($p<0.05$). The vermicompost prepared from 40 % Household Solid waste possessed higher GI as compared to cow dung vermicompost. GI for different seeds with different vermicomposts have been reported earlier also: 98 - 162% for *Lycopesicon esculentum*, 48 - 81% for *Daucus carota* [54], 86.9 - 98.25% for maize [123], 89.5 - 115.32% [84]; 95 - 150% [84] for *Brassica campestris*; 98 - 138% for *Vigna radiata* [115].

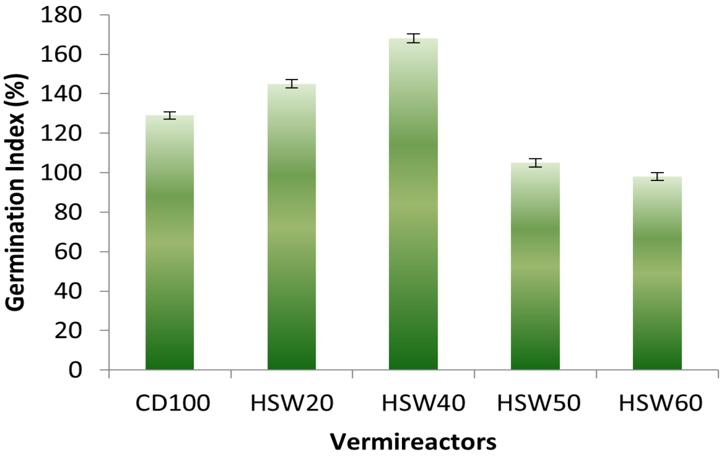


Figure 4.16: Germination Index in different vermireactors

e) Change in Micronutrients (Fe, Zn, Cu, Mn and Pb)

Micronutrients viz. Fe, Zn, Cu, Mn and Pb are important for plant growth in trace amounts. They are uptaken by plants from soil and may result in various health issues of animals and humans through consumption [124]. In the present study, five heavy metal contents (Fe, Zn, Cu, Mn and Pb) were analyzed in initial feedstocks and final vermicomposts. Micronutrients enhanced in the vermireactors and were not related to their mixing ratios and initial values as shown in Table 3. Metal contents Fe, Zn, Cu, Mn and Pb had shown manifold increase towards the end of the experiment as 1.25 - 1.55 fold, 1.90 - 2.47 fold, 1.16 - 1.95 fold, 1.27 - 1.78 fold and 2.13 - 2.21 fold, respectively. Total Fe content in final vermicompost varied from 995 ± 8.2 - 1759 ± 11.4 mg/kg from initial values of 794 ± 7.4 - 1128 ± 11.2 mg/kg. Total Zn concentration instigated from the initial values of 62.9 ± 1.87 - 94.4 ± 3.42 mg/kg to 119.7 ± 3.0 - 234.1 ± 5.63 mg/kg after 90 days vermicomposting.

Table 4.11: Micronutrient content in raw waste and vermicompost produced in different vermireactors (Mean ± SEM of three replicates)

Vermi- reactor	**Total Fe (mg/kg)**	**Total Zn (mg/kg)**	**Total Cu (mg/kg)**	**Total Mn (mg/kg)**	**Total Pb (mg/kg)**
Initial raw substrate					
CD_{100}	1128±11.2e	94.4±3.42d	49.7±0.97e	56.8±0.80d	1.46±0.09e
HSW_{20}	1044±10.7d	88.7±2.87c	45.3±0.90d	47.9±0.31c	1.40±0.08d
HSW_{40}	962±8.8c	74.1±3.11b	40.9±1.14c	40.1±0.09c	1.36±0.1c
HSW_{50}	885±9.1b	69.8±1.82a	30.8±0.56b	33.3±1.01b	1.32±0.05b
HSW_{60}	794±7.4a	62.9±1.87a	26.4±0.32a	26.9±0.05a	1.28±0.06a
Final Vermicompost)					
CD_{100}	1759±11.4e	234.1±5.63e	97.4±1.18e	95.4±1.87e	3.11±0.12d
HSW_{20}	1584±12.2d	189.2±3.45d	84.6±1.07d	82.6±1.56d	3.12±0.09d
HSW_{40}	1398±10.8c	159.6±2.28c	66.8±1.10c	69.4±0.75c	3.09±0.13c
HSW_{50}	1170±9.9b	134.2±2.08b	49.8±0.08b	59.6±1.02b	2.96±0.07b
HSW_{60}	995±8.2a	119.7± 3.0a	30.8±0.04a	34.4± 0.07a	2.91±0.06a

Different alphabets in each parameter shows statistically significant difference (ANOVA, Tukey's HSD test $p \leq 0.05$)

Total Cu concentration was in the range of 26.4 ± 0.32 - 49.7 ± 0.97 mg/kg initially and raised to 30.8 ± 0.04 - 97.4 ± 1.18 mg/kg in final vermicomposts. Significant variation was observed between all the five vermireactors for incremental changes in Total Fe, Zn and Cu contents ($p<0.05$). Total Mn levels were found to be more (34.4 ± 0.07 - 95.4 ± 1.87 mg/kg) in vermicomposts in comparison to initial values (26.9 ± 0.05 - 56.8 ± 0.8 mg/kg) irrespective of raw waste combinations. Total Pb content was in the range of 1.28 ± 0.06 - 1.46 ± 0.09 in initial combinations and reached to 2.91 ± 0.06 - 3.12 ± 0.12 in final vermicomposts. Difference among various vermicomposts was significantly variable for increased Mn levels ($p < 0.05$) while statistical variation was not observed for Pb increment. Earlier researches have also reported an increase in heavy metal content after vermicomposting which may be attributed to loss of organic matter and decrease in volume and quantity of the final waste mixtures [125],[24],[126],[92],[127].

Change in the heavy metal content depends on the composition and nature of initial substrate used for vermicomposting. According to Swati and Hait [128], the enzymes present in earthworms degrade and mineralize the wastes and form short chain organic acids. These organic acids bind with metals and form stable metal complexes. Metals easily accumulate in the earthworm tissues and result in reduced concentrations. The enhancement of metals in the end product in the current research indicated that enhanced level effect due to mineralization surpassed the accumulated concentration of metals in earthworms. Although metals in the final products were found to be augmented, but final metal contents were within range according to International Standards for Compost [129], thereby making them suitable for potting media / manure in the agricultural crops.

f) Changes in Earthworm Population, Biomass, Growth and Fecundity

Biological parameters were analyzed to assess waste mixture as potential feed for earthworms during vermicomposting and are presented in Table 4.12. Earthworms are driving agents in forwarding the vermicomposting process and producing bio-manure in form of vermicompost [41]. HSW bulked with CD provides progressive ambience for earthworms, thus enhanced population was evidenced in all the vermireactors and the trend of increase was: CD_{100} (78 ± 3.0) $>$ HSW_{20} (74 ± 2.8) $>$ HSW_{40} (67 ± 3.8) $>$ HSW_{50} (56 ± 2.2) $>$ HSW_{60} (42 ± 2.6).

Table 4.12: Biological characteristics of raw waste and vermicompost produced in different vermireactors (Mean ± SEM of three replicates).

Vermireactor	**Earthworm population**		**Individual earthworm biomass (mg)**		**Biomass gain (mg)**	**No. of cocoons**	**Biomass achieved (days)**	**Fecundity (cocoon /worm)**	**Growth rate /worm /day (mg)**
	Feedstock	VC	Feedstock	VC					
CD_{100}	20	78±3.0e	162±2.6a	986±2.2c	824±6.3c	280± 4.8e	56	3.6	14.7±1.02c
HSW_{20}	20	74±2.8d	196±3.1c	970±3.4c	774±5.6b	236 ± 3.6b	56	3.2	13.8±1.05c
HSW_{40}	20	67±3.8c	188±2.2b	853±2.5b	757± 6.8b	207±4.2c	56	3.1	11.2±0.98b
HSW_{50}	20	56±2.2b	191±3.4bc	775±2.12a	620± 4.8a	123±3.2b	63	2.2	9.8±0.23a
HSW_{60}	20	42±2.6a	167±2.8a	768±2.26a	601±5.1a	71±2.5a	63	1.7	9.5±0.08a

Values expressed are mean ± SEM. The different alphabets between treatments within each group differ significantly at $p \leq 0.05$ by Tukey's HSD test.

Statistically significant difference was observed in HSW_{40}, HSW_{50}, and HSW_{60} ($p<0.05$) whilst vermireactors HSW_{20} and CD_{100} were statistically insignificant from each other ($p>0.05$). Other authors also suggested an increase in earthworm population towards the completion of vermicomposting process [90],[84]. Earthworm biomass gain, growth rate, fecundity and cocoon production are pivotal factors of feed acceptance by earthworms and obtaining good vermicompost. Live earthworm biomass was found to vary from 162 ± 2.6 to 196 ± 3.1 mg/worm in initial waste combinations and enhanced to 768 ± 2.26 to 986 ± 2.2 mg/worm with maximum biomass achieved in CD_{100} followed by HSW_{20} and HSW_{40} after 90 days of vermicomposting. All the vermireactors varied significantly from each other for maximum live biomass ($p<0.05$). Biomass gain depends on type of raw substrate and marks good survival rate as well as fecundity [83]. In the present study, 100% CD had shown biomass gain of 824 mg/worm owing to its high palatability by earthworms. HSW also favored earthworm growth due to microbial colonization, good palatability and a decent amount of organic matter upto a suitable extent, thenafter, higher concentrations of HSW affected growth. Previous experimental studies also documented biomass gain due to readily consumable raw substrates [62],[89],[130].

Mean difference for cocoon production was significantly different for all the vermireactors ($p<0.05$). Maximum number of cocoons were notified in CD_{100} (280 ± 4.8) followed by HSW_{20} (236 ± 3.6), HSW_{40} (207 ± 4.2), HSW_{50} (123 ± 3.2) and HSW_{60} (71 ± 2.5). Fecundity (cocoon/worm) followed the order: CD_{100} (3.6 ± 0.02) $>$ HSW_{20} (3.2 ± 0.01) $>$ HSW_{40} (3.1± 0.01) $>$ HSW_{50} (2.2 ± 0.01) $>$ HSW_{60} (1.7 ± 0.01). No significant variation was found among the vermireactors for earthworm fecundity rate ($p<0.05$). Growth rate/day/worm is an important parameter to assess earthworm growth in raw substrates and depends on nature of initial substrate as well as bulking material like cow dung [93]. Highest growth rate (mg/worm/day) was registered in cow dung preceded by HSW_{20} and HSW_{40} that might be owed to better level of nutrients and organic matter as well as reduced total carbon and organic matter. HSW_{60} possessed least growth rate that might be owed to less amount of bulking material in vermireactor. Addition of 20 - 40% HSW in vermireactors favored earthworm growth and fecundity. Different vermireactors showed growth rate trends in following order: $CD_{100} > HSW_{20} > HSW_{40} > HSW_{50} > HSW_{60}$. Statistically significant difference was found in vermireactors CD_{100}, HSW_{20} & HSW_{40} for comparison of growth rates ($p<0.05$) while rest of the vermireactors were significantly indifferent.

4.2.4 Conclusions

Present study establishes the use of household solid waste as potential substrate for its vermiconversion into value added product and recovery of nutrients. All the vermireactors had substantial amount of nutrients (NPK) and optimum physico-chemical characteristics such as low TOC (334.4 - 272.6 g/kg), C:N ratio (13.0 - 19.1), C:P ratio (22.3 - 49.6) and increased electrical conductivity & ash contents. It was inferred from the study that 20 - 40% household solid waste can be efficiently used as feed for earthworms as these wastes favored decent growth (9.5 - 14.7 mg) and fecundity (3.1 to 3.6). As far as nutrient levels are concerned, a significant amount of macro nutrients (TKN:16.8 - 22.3 g/kg; TAP: 6.85 - 12.2 g/kg; TK: 20.8 - 24.6 g/kg) were recorded in all the five vermireactors. This can provide a basis for effective management of household solid waste that tends to become unavoidable part of municipal solid waste management system. Finally household waste can be converted into value added product at the source of generation by vermicomposting, thereby managed by the waste owners. Overall inclusion of vermicomposting in our waste management systems will not only provide sustainable solution for the large amount of waste produced, but also can be potentially used for the nutrient recovery from the wastes produced at an individual level.

4.3 EFFECT OF WORM STOCKING RATE AND SEASONAL TEMPERATURES ON VERMICOMPOSTING OF HOUSEHOLD SOLID WASTE

4.3.1 Effect of Worm Stocking Density on Household Solid Waste Vermicomposting

a) Introduction

Vermicomposting process relies on earthworms' performance in waste decomposition which in turn depends on quality and quantity of feed substrate, moisture, temperature, pH, C:N ratio and ofcourse number of proliferating earthworms. The feed material quality decides the fate of earthworms' growth as well as vermicompost quality. Luxuriant growth of worms in feed environment is indicative of feed acceptability and its efficient conversion into usable manure. Earthworm population is regulated by availability of resources like food and space [131]. Worm density in feed substrate influence the process of vermi-conversion and quality of vermi manure produced [132]. It was suggested by Jicong et al. [133] that an average earthworm consumes half of its body weight organic waste in a day and worms should be added in feed mixtures accordingly. Thus prior to vermicomposting, it is pre-requisite to decide how many worms should be employed in the process to have maximum growth and fecundity in short period of time. Limited studies Fayolle et al. [134]; Hait and Tare [135]; Suthar [136]; Yadav and Garg [137] are available on effect of stocking density on growth and fecundity as well as nutrient levels and stability of vermicompost. In view of this, an experimental study was done on household solid waste amended with cow dung in different proportions to assess the effect of worm stocking density on earthworms' biological characteristics, manurial status and vermicompost stability (C:N and C:P).

b) Materials / Methods

HSW and CD was collected as mentioned earlier in household solid waste vermicomposting chapter. Earthworm *Eisenia fetida* was reared in lab and used in the experimental study. The physical and chemical parameters of CD and HSW are presented in Table 4.13.

Table 4.13: Initial physico-chemical characteristics of raw substrate used in different vermi setups (Mean ± SEM, n=3)

S. No.	Parameter	VS1 100%CD	VS2 80%CD+20%HSW	VS3 60%CD+40%HSW
1	pH	8.2±0.03	8.18±0.02	8.06±0.04
2	TOC (g/kg)	450±3.21	456±2.45	462±2.32
3	OM (%)	77.5± 3.2	78.6±2.21	80.6 ±2.10
4	TKN (g/kg)	8.4±0.42	8.6±0.40	8.8±0.28
5	TAP (g/kg)	7.6±0.34	7.1±0.22	6.7±0.46
6	TK (g/kg)	8.6±0.31	8.9±0.41	10.0±0.35
7	C:N ratio	53.5±2.12	53.0±1.87	52.5±1.60
8	C:P ratio	59.2±1.81	64.2 ±1.12	68.9±1.67

Three kilogram of raw substrate in form of cow dung and HSW (on wet basis) was mixed in 80:20 ratio and 60:40 ratio along with one setup of 100% cow dung - VS1 - 100% CD, VS2 - 80% CD + 20% HSW and VS3 - 60% CD + 40% HSW. After 21 days, non-clitellated earthworms were introduced into different vermi setups at different stocking densities (20, 40, 60, 80, 100 and 120) to find the effect of number of earthworms on decomposition of 3 kg of raw waste. The research experiment was performed for 84 days in triplicates for each stocking density and no extra feed material was introduced into vermisetups during this time.

The biological parameters were monitored after every 12 days interval in each raw substrate during the experimental time. Earthworms / cocoons were separated by taking them out from waste mixture, hand-sorted, washed with water, counted and weighed. Finally, earthworms, cocoons and feed substrate were placed back in their respective reactors. The physical and chemical parameters of the raw substrate and end products at different stocking densities were analyzed and presented according to standard methods mentioned in Chapter 3.

c) Results / Discussion

i Effect of Stocking Density on Earthworm Growth and Fecundity

No mortality was seen in any of the feed combinations at any stocking density. Individual growth of *Eisenia fetida* in different feed substrates with respect to stocking density is depicted in Figure 4.17 - 4.19. For the stocking density of 20 worms per vermi setup, the individual worm biomass increased for 60 days in 100% CD, 72 days in 80% CD + 20% HSW vermi setups and it started decreasing after 60 days in 60% CD + 40% HSW vermi setup. Fewer number of earthworms render less competition for feed substrate and hence long growth period in these vermi setups. Figure 4.17 showed that maximum biomass achieved was inversely proportional to the stocking density in feed substrate. The maximum mean worm biomass was obtained at the stocking density of 60 worms (1542 ± 92 mg/earthworm) and minimum biomass (974 ± 52 mg/earthworm) at stocking density of 120 worms in VS1 (100% cow dung). Maximum biomass was noted on 36^{th} day for 120 worms whereas on 60^{th} day for 20 worms after which biomass decrease was observed (Figure 4.17). Earthworms at the lower stocking density possessed higher biomass than higher stocking density individuals that achieved low biomass. It was observed that at higher stocking rates, maximum biomass was obtained in less period of time when compared to low density individuals. Yadav & Garg [137] and Suthar [136] had also reported maximum biomass at comparatively low densities.

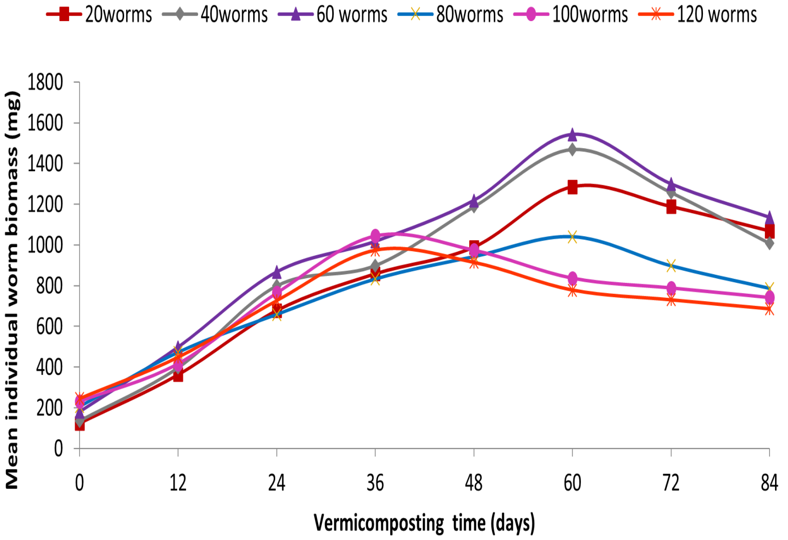


Figure 4.17: Growth of *Eisenia fetida* in 100% Cow dung with time

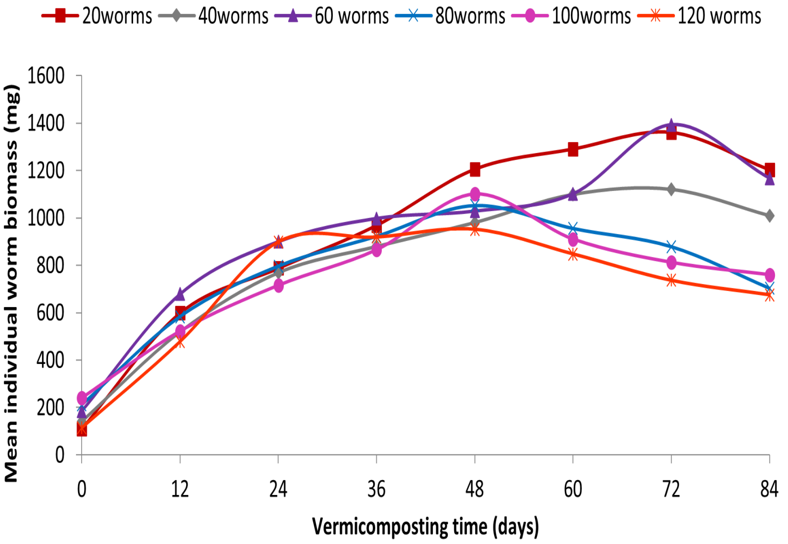


Figure 4.18: Growth of *Eisenia fetida* in 80% Cow dung + 20% HSW with time

In VS2 (80% CD + 20% HSW), maximum mean worm biomass was achieved at the stocking density of 60 (1392 ± 102 mg/earthworm) on 72^{nd} day and minimum (951±48 mg/earthworm) at the stocking density of 120 on 48^{th} day (Figure 4.18). Trend of maximum worm biomass at different stocking densities was in order: 20 worms > 60 worms > 40 worms > 80 worms > 100 worms > 120 worms. Maximum and minimum biomass gain at stock rate of 20 earthworms and 120 earthworms per vermisetup were 1295 ± 94 mg/earthworm and 915 ± 58 mg/earthworm on day 60 and 24, respectively in VS3 (80% CD + 20% HSW) (Figure 4.19).

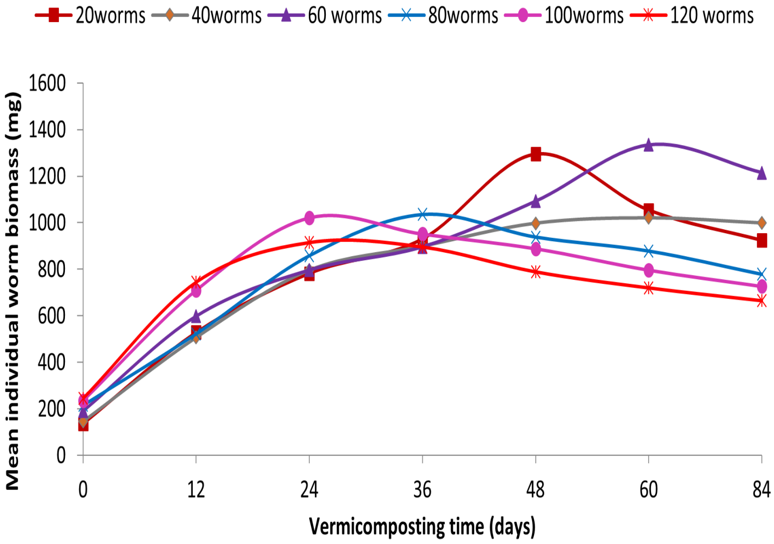


Figure 4.19: Growth of *Eisenia fetida* in 60% Cow dung + 40% HSW with time

The order of maximum biomass obtained at different stocking densities was: 60 worms > 20 worms > 40 worms > 80 worms > 100 worms > 120 worms. A decrease in net worm biomass gain (mg/earthworm) was noticed with an increase in stocking density in all the three vermisetups (Table 4.14). It might be due to worm population rush and scarcity of food for accumulating earthworms in vermi setups. Findings corroborated with previous studies by Ndegwa et al. [138]; Klok [131] and Hait & Tare [135]. Earthworm growth was fast at low stocking density in comparison to higher ones. Net worm biomass gain was statistically significant at different stocking densities in all the three vermi set ups ($p < 0.05$). Also, it was inferred that stocking density of 60 worms demonstrated maximum net worm biomass in all the three feed substrate combinations (VS1 : 1362 ± 7.2; VS2 : 1207 ± 5.9 and VS3 : 1144 ± 7.5).

Table 4.14: Net worm biomass gained (mg earthworm^{-1}) in different vermi setups at different stocking density (Mean ± SEM, n=3)

Stocking density	VS1 (100%CD)	VS2 (80%CD+20%HSW)	VS3 (60%CD+40%HSW)
20	1160±7.4d	1250±8.8f	1160±6.9f
40	1335±8.1e	980±4.6d	875±5.4d
60	1362±7.2f	1207±5.9e	1144±7.5e
80	840±5.8c	842±7.3b	820±6.1c
100	810±4.5b	860± 6.2c	746±4.2 b
120	779±3.42a	826± 5.54a	670±3.67a

Mean values followed by different letters in same column are statistically different (ANOVA; Tukeys's test, $p \leq 0.05$)

The overall worm biomass gain was maximum with 120 worms per vermi setup as feed consumption was fast at high worm density. Maximum worm biomass gained was 93.4 ± 2.04, 99.1 ± 3.10 and 80.4 ± 1.38 g in 80% CD + 20% HSW, 100% CD and 60% CD + 40% HSW, respectively (Table 4.15). Quality of feed substrate as well as density affects the worm growth. Overcrowded worm beds affect the rate of reproduction and individual biomass. Therefore, to attain maximum growth and reproduction and / or waste decomposition, it is essential to optimize the number of earthworms to be added in the vermi-setups.

Findings of the experiment indicated that a stocking density of 60 worms for 3 kg of feed substrate was found to be suitable for attainment of maximum net biomass. Once the highest density is attained by earthworms in vermi setup, their tendency is to decrease activities and stabilize their number [139]. The net biomass gain per unit feed mixture was in the range of 7.7 ± 0.50 to 31.16 ± 0.14 mgg^{-1} in 100% CD, 8.3 ± 0.80 to 33.0 ± 0.15 mgg^{-1} in 80% CD + 20% HSW and 7.7 ± 0.6 to 26.8 ± 0.19 mgg^{-1} in 80% CD + 20% HSW (Table 4.16). Significant difference was observed in all the vermi setups for different stocking densities ($p < 0.05$). Maximum net biomass gain/unit waste mixture was obtained at the highest stocking density and lowest stocking density possessed minimum biomass per unit feed substrate. Table 4.17 represents number of cocoons produced at different stocking densities in different feed combinations.

Table 4.15: Maximum worm biomass gained (g) in varied vermi setups at different stocking density (Mean ± SEM, n=3)

Stocking density	**VS1 (100%CD)**	**VS2 (80%CD+20%HSW)**	**VS3 (60%CD+40%HSW)**
20	23.2± 0.7	33.0±0.8	23.2±0.9
	84 days*	84 days	63 days
40	53.4±1.12	39.2±0.87	35.0±1.23
	60 days	72 days	48 days
60	81.7±1.89	72.4±1.15	68.6±0.99
	48 days	60 days	60 days
80	67.2±1.20	67.3±1.26	65.5±1.22
	48 days	48 days	60 days
100	85.2±1.99	86.0±2.34	74.6±1.45
	36 days	48 days	36 days
120	93.4±2.04	99.1 ±3.10	80.4 ±1.38
	24 days	24 days	24 days

Days* indicate number of days on which maximum biomass was achieved.
Mean values followed by different letters in same column are statistically different (ANOVA; Tukeys's test, $p \leq 0.05$)

Earthworms showed good fecundity rate in all the vermi-setups, however, cocoon production was initiated at later stage at low stocking rates, but it lasted longer as compared to high densities. Total number of cocoons produced in different vermi-setups was directly proportional to the stocking density. Maximum cocoons were produced (830 ± 26.22) in 100% CD at the stocking density of 120 worms whilst minimum cocoons (42 ± 3.20) were found in 80% CD + 20% HSW at the stocking density of 20 worms. Significant difference was observed in all the three combinations for cocoon production ($p<0.05$). Stocking density of 60 worms exhibited highest rate of cocoon production in VS1 followed by VS2 and VS3.

Table 4.16: Net worm biomass per unit feed substrate (mg g^{-1}) in different vermi setups (Mean ± SEM, n=3)

Stocking density	**VS1 (100%CD)**	**VS2 (80%CD+20%HSW)**	**VS3 (60%CD+40%HSW)**
20	7.7±0.50a	8.3±0.80a	7.7±0.6a
40	17.8±0.72b	13.0±0.91b	11.6±0.15b
60	27.24±0.81d	24.1±0.16d	22.8±0.71d
80	22.4±0.71c	22.4±0.14c	21.8±0.56c
100	27.0±0.12d	28.6±0.20e	24.8±0.32e
120	31.16±0.14e	33.0±0.15f	26.8±0.19f

Mean values followed by different letters in same column are statistically different (ANOVA; Tukeys's test, $p \leq 0.05$)

ii Effect on Physico-chemical Parameters and Manurial Quality of End Products

The physic0 - chemical parameters of feed substrates used have been presented in Table 4.13. The pH values in all three feed combinations were alkaline (8.0 to 8.2). pH shifted towards neutrality in vermicomposts from their initial values in all the feed substrates (Table 4.17). The pH shift was more at the stocking density of 40 and 60 worms (13.4% and 14.6% for VS1; 11.9% and 10.7% for VS2; 9.42 % and 9.1% for VS3). However, pH at stocking density of 40, 60, 100 and 120 worms were not significantly different from each other in all the three vermi-setups ($p < 0.05$). pH reduction was also noted by Sharma and Garg [83], Mago et al.[140], Balachandran et al.[111] and can be owed to organic acids and intermediates formed during the bioconversion of wastes [141],[117]. Remarkable reduction in TOC was observed in all the three feed compositions at varying population of earthworms although maximum descend was foreseen in vermi setups with high worm density.

Table 4.17: Total number of cocoons /worm in different vermi setups at different stocking density (Mean ± SEM, n=3)

Stocking density	**VS1 (100%CD)**	**VS2 (80%CD+20%HSW)**	**VS3 (60%CD+40%HSW)**
20	55±5.88a	42±3.20a	50±11.90a
	60^{th} day*	60^{th} day	60^{th} day
40	120±9.32b	99±12.16b	66±12.20b
	48^{th} day	48^{th} day	48^{th} day
60	270±12.95c	251±14.82c	161±12.81c
	36^{th} day	48^{th} day	48^{th} day
80	520±28.80d	402±15.60d	242±14.58 d
	36^{th} day	36^{th} day	48^{th} day
100	770±15.60e	544±14.31e	452±27.2e
	24^{th} day	36^{th} day	48^{th} day
120	830±26.22f	782±5.6f	591±25.6f
	24^{th} day	24^{th} day	24^{th} day

Day* refers to day of maximum cocoon count.
Mean values followed by different letters in same column are statistically different (ANOVA; Tukeys's test, $p \leq 0.05$)

Organic matter degradation and consumption of organic carbon by earthworms and microbes result in TOC decrement [78],[140]. TOC decrease ranged from 21.7 - 45.7% in VS1; 21.9 - 46.0% in VS2 and 21.2 - 44.8 % in VS3. More number of worms in feed substrate bring about fast and efficient decomposition towards the end of vermicomposting process. Results are supported with earlier findings by Aira & Dominguez [142] and Yadav & Garg [137].

Organic matter (OM) reduction increased with the an increase in the stocking density in all the three combinations (Table 4.18).

Table 4.18: pH, Total Organic Carbon and Organic Matter in vermicomposts obtained at different stocking densities (Mean ± SEM, n=3)

Stocking density (no. of worms)	**VS1 (100%CD)**			**VS2 (80%CD+20%HSW)**			**VS3 (60%CD+40%HSW)**		
	pH	TOC (g/kg)	Organic Matter (%)	pH	TOC (g/kg)	Organic Matter (%)	pH	TOC (g/kg)	Organic Matter (%)
20	7.9±0.01b	352±1.34c	60.7±0.03c	7.9±0.02b	356±1.78c	61.5±1.08c	7.7±0.02b	364±1.18d	62.8±0.87c
40	7.1±0.01a	272±1.16b	47.0±0.43b	7.2±0.01a	263±1.56b	45.5±1.21b	7.3±0.01a	286±1.45c	49.4±0.90b
60	7.0±0.01a	266±1.11b	45.9±1.02b	7.3±0.02a	267±1.28b	46.1±0.86b	7.32±0.01a	282±1.26c	48.7±1.12b
80	7.3±0.01a	247±1.34a	42.6±0.98a	7.5±0.03a	249±1.30a	43.0±0.54a	7.2±0.01a	262±1.19b	45.2±0.78a
100	7.4±0.01a	245±1.45a	42.3±0.56a	7.6±0.03a	247±1.78a	42.6±0.50a	7.1±0.02a	256±1.31a	44.2±0.87a
120	7.5±0.02a	244±1.49a	42.1±0.56a	7.6±0.04a	246±1.66a	42.5±0.50a	7.1±0.03a	255±1.39a	44.0±0.87a

Mean values followed by different letters in same column are statistically different (ANOVA; Tukeys's test, $p \leq 0.05$)

Percent reduction in organic matter ranged from 21.6 - 45.6 % in 100%CD (VS1), 21.7 - 45.9% in 80%CD + 20%HSW (VS2) and 22 - 45.4% in 60%CD + 40% HSW (VS3). OM reduction at the stocking density of 40 & 60 worms and 100 & 120 worms was significantly indifferent ($p>0.05$). Less reduction in organic matter was found in low stocking density vermi setups due to undecomposed feed material left.

Manurial quality of vermicomposts (in terms of nitrogen, phosphorus and potassium) obtained at different stocking densities are presented in Table 4.19. Total Kjeldahl Nitrogen increased from 65 - 75% in vermi setups with 40 worms and 52 - 64% for stocking density of 60 worms in all the three feed substrates. TKN content of vermicomposts at stocking density of 40 worms was statistically indifferent from that of 60 worms, however, different from initial substrates and other stocking densities ($p<0.05$). Earthworms and microbes jointly bring about organic matter mineralization and transform it into plant absorbable forms [61],[109],[141]. Stocking density of 20 worms showed 5.5 to 14.2% increment in nitrogen after 84 days of experimentation. Comparatively lesser increase in nitrogen was found at highest stocking densities. An optimum stocking density of 40 - 60 worms for 3 kg of household solid waste (wet basis) was required to carry out vermicomposting.

Increment in Total phosphorus levels was positively correlated with the increase in number of worms in various feed combinations but no significant difference was observed at stocking density of 60, 100 and 120 worms ($p< 0.05$). Organic matter degradation brings about an increase in phosphorus values in final vermicompost [143],[115]. Total Potassium in vermicomposts showed only slight incremental change from the initial feed combinations (Table 4.19). Organic matter decomposition together with production of metabolites enhance potassium concentration in its plant available forms in final product [49]. There was no statistical difference among different stocking densities for increased potassium in final vermicomposts ($p>0.05$).

Table 4.19: Nutrient profile (NPK) of vermicomposts obtained at different stocking densities (Mean ± SEM, n=3)

Stocking density (no. of worms)	VS1 (100%CD)			VS2 (80%CD+20%HSW)			VS3 (60%CD+40%HSW)		
	TKN (g/kg)	TAP (g/kg)	TK (g/kg)	TKN (g/kg)	TAP (g/kg)	TK (g/kg)	TKN (g/kg)	TAP (g/kg)	TK (g/kg)
20	9.6±0.8a	10.3±0.32a	9.8±0.52a	9.5±0.60a	10.2±0.1b	9.9±0.65a	9.3±0.12a	9.9±0.65a	10.4±0.67a
40	14.7±0.12c	11.3±0.16b	9.82±0.23a	14.2±0.56c	11.4±0.16bc	10.2±0.34a	14.6±0.67c	10.1±0.45b	10.4±0.53a
60	13.8±0.10c	12.4±0.20c	9.73±0.34a	13.1±0.67bc	12.8±0.34c	10.3±0.23a	13.4±0.34bc	10.9±0.37bc	10.3±0.32a
80	12.7±0.1b	12.3±0.12c	9.72±0.45a	12.7±0.34b	13.1±0.12c	9.91±1.20a	12.6±0.25b	11.4±0.26c	10.3±0.75a
100	12.8±0.14b	12.2±0.18c	9.70±0.21a	13.0±0.47bc	12.2±0.17c	9.90±0.32a	12.9±0.31b	12.0±0.32d	10.2±0.31a
120	12.7±0.12b	12.1±0.28a	9.71±0.19a	12.9±0.56bc	12.0±0.11c	9.89±0.22a	12.8±0.25b	12.2±0.2dd	10.1±0.22a

Mean values followed by different letters in same column are statistically different (ANOVA; Tukeys's test, $p \leq 0.05$)

Table 4.20: C: N and C:P ratio of vermicomposts obtained at different stocking densities (Mean ± SEM, n=3)

Stocking density (no. of worms)	VS1 (100%CD)		VS2 (80%CD+20%HSW)		VS3 (60%CD+40%HSW)	
	C:N ratio	C:P ratio	C:N ratio	C:P ratio	C:N ratio	C:P ratio
20	36.6±2.02b	34.1±2.87b	37.4±2.68b	34.9±2.45e	39.1±1.76b	36.7±2.28b
40	18.5±1.88a	24.0±1.35a	18.5±1.89a	23.0±2.4d	19.5±1.26a	28.3±1.66a
60	19.2±1.90a	21.4±1.89a	20.3±1.56a	20.8±1.67c	21.0±0.87a	25.8±0.98a
80	19.4±1.78a	20.0±1.08a	19.6±1.87a	19.0±1.17a	20.7±1.01a	22.9±0.80a
100	19.1±1.58a	20.0±1.48a	19.0±1.46a	20.2±1.27a	19.8±1.32a	21.3±1.78a
120	19.2±1.60a	20.3±1.52a	19.0±1.67a	20.5±1.34a	19.9±1.28a	20.9±1.65a

Mean values followed by different letters in same column are statistically different (ANOVA; Tukeys's test, $p \leq 0.05$)

Stocking densities also affected C:N and C:P ratios in different vermi setups (Table 4.20). C: N and C:P ratio drop marks the degree of organic waste stabilization during vermicomposting process. A decrease of 20.9 - 65% in C:N ratio was observed in different vermi setups at different stocking densities. Higher stocking densities displayed more reduction in C:N ratio of initial substrates. C:N values at stocking density of 40, 60, 100 and 120 worms showed no statistical difference in different feed combinations ($p>0.05$) However, vermi-setups with stocking density of 60 worms had least C:N ratio in comparison to other stocking densities after 84 days of vermicomposting. This also affirms that it is necessary to add at least up to 60 worms for 3 kg of the feed (on wet basis) during vermicomposting. C:N ratio dropped with an increase in stocking density but after a certain limit, no further stabilization was achieved with more increase in the number of earthworms. C:P decline was 42.30 - 69.6% in all the feed combinations at varying stocking densities and is suggestive of vermicompost maturity. As phosphorus increased with an increase in stocking density in general, C:P ratio decreased subsequently in different feed combinations. There was no significant difference in different stocking densities for C:P decline.

The findings of present study exhibited that earthworm population play a major role in decomposition rate of organic wastes. Vermi setups stocked with high density had not exhibited any noticeable change/increase in manure quality of vermicomposts obtained so far. Thus, it makes sense of adding 40 - 60 worms in 3 kg of organic waste as it demonstrates efficient earthworm growth and fecundity besides good nutrient status.

d) Conclusions

Stocking density plays an important role in vermicomposting process besides temperature, moisture and amount as well as nature of feed substrate. An ultimate number of worms should be sustained in vermi setups to achieve good growth and development. Experimental findings indicated that earthworm growth in different feeds was inversely related to stocking density. Earthworms at low stocking rate attained more biomass, however, they possessed less biomass at high stocking rates. Earthworm maturation was directly impacted by accumulating population in vermi setups. Higher number of cocoons were produced in different feed compositions at higher population density. Biomass production was favoured at low stocking density whereas better mineralization and stabilization were achieved at higher worm densities. Findings suggest that stocking density of 40 - 60 worms was ideal for vermiconversion of 3 kg of organic waste and manifested decent growth in earthworms along with efficient degradation and astounding nutrient profile.

4.3.2 Effect of Seasonal Temperature on Vermi-conversion of HSW

a) Introduction

Environmental conditions like pH, temperature, aeration and moisture content play significant role in earthworm activities during vermicomposting. Earthworms' body temperature vary with ambient temperature and affects activity, growth, density, metabolism, respiration, and reproduction of earthworms [12]. Temperature variations sensitize different earthworms up to different extents, while most appropriate temperature range lies between 20 - 30ºC [144]. Earthworm growth gets affected at temperature more than 25ºC and as the temperature exceeds 35ºC, worm activity gets severely affected [13]. Vermicomposting performance is effective at temperature 15ºC while temperature 20ºC favors reproductive activities and extreme temperatures can affect earthworm activity. Higher temperatures also affect metabolic rate of earthworms. Species like *Allolobophora caliginosa* and *Eisenia fetida* has wide tolerance for high and low temperatures as these lower down their body temperature in former condition and lives at depth near to optimum temperature in later conditions [145]. Among the earthworm species, *Eisenia fetida* is tolerant to wide range of temperatures and the most commonly used species in vermiconversion [49]. Feeding activities get affected at temperatures below 10°C and temperature above 40°C affects cocoon production [12]. Different earthworms have variable temperature ranges and have different tolerance for different temperatures: *Eisenia fetida* (10 - 35ºC), *Eudrilus eugeniae* (20 - 25ºC), *Perionyx excavates* (25 - 30ºC), *Lampito mauritii* (18 - 30ºC), *Drawida willsi* (20 - 25ºC) [146],[147].

Effect of temperature cannot be ignored as water evaporates through body surface leading to dehydration and hence less earthworm activity [148]. Earthworm population decreases with the increasing temperature[149]. Seasonal variations in the growth and activity of earthworms was observed with change in temperature [150],[151],[149]. Studies compared biomass growth of *Eisenia fetida* and *Lampito mauritii* at different temperatures and found significant change in biomass with change in temperature as *E.*

fetida and *L. mauritii* had optimum temperature of 25 and 30°C, respectively.
This chapter studies the effect of temperature variation on earthworms' physico-chemical and biological performance during household solid waste vermicomposting.

b) Materials / Methods

HSW and CD were collected as mentioned earlier in this chapter. Table 4.21 defines the physico-chemical characteristics of household solid waste (collected during different seasons) and cow dung.

Table 4.21: Physico-chemical characteristics of initial Feed mixtures (Mean ± SEM, n=3)

S.No	Parameters	Cow dung (CD)	Household Solid Waste (HSW)	
			Winter	Summer
1.	pH	8.3±0.01	7.8±0.03	7.9±0.12
2.	EC (dS/m)	1.30±0.02	1.98±0.04	2.11±0.10
3.	Ash content (g/kg)	221±2.12	149±6.4	172±10.9
4.	TOC (g/kg)	451.8±2.48	493±4.2	480± 3.5
5.	OM (%)	77.9±1.32	85.1±1.84	82.8±1.69
6.	TKN (g/kg)	8.2±0.12	8.8±0.18	9.1±0.17
7.	TP (g/kg)	7.1±0.06	3.4±0.16	3.7±0.13
8.	TK (g/kg)	9.0±0.25	12.5±0.36	12.8±0.23
9.	C: N ratio	55± 2.18	56.0±0.68	52.7±0.41
10.	C: P ratio	63.6±1.64	145±4.24	129.7± 2.89

Eisenia fetida was taken from the stock culture developed in laboratory. Effect of temperature was studied by conducting vermicomposting experiments in winter (October to December, 2016) and summer (June to August, 2017). Five vermireactors of feed mixtures HSW and CD were set up in one kg each on dry weight basis (Table 4.22).

Table 4.22: Composition of raw substrate (Cow dung and Household Solid waste)

Vermireactors	CD + HSW	CD (%)	HSW (%)
V1 CD_{100}	1000g	100	–
V2 HSW_{20}	800g+200g	80	20
V3 HSW_{40}	600g+400g	60	40
V4 HSW_{50}	500g+500g	50	50
V5 HSW_{60}	400g+600g	40	60

After 21 days, 20 earthworms (weighing 150 - 200mg) were introduced in each vermireactor. Moisture was maintained at 70 ± 10% with water sprinkling. Experiment was performed in triplicates for a period of 90 days and homogenized samples (on dry weight basis) were drawn after the completion of process to analyze physico-chemical attributes such as pH, EC, TOC, OM, TKN, TAP and TK as per methods described in chapter 3. Earthworms' biological performance was also studied during the two seasons. Statistical analysis was performed using SPSS 21 to find significance (at $p < 0.05$) between different vermireactors for physico-chemical and biological characteristics during summer and winter season.

c) Results and Discussion

i Effect of Seasonal Variation on Vermicomposts' Physico-chemical Characteristics

Figure 4.20 and Figure 4.21 show temperature variation during the time periods of experiment. During winter season, average temperature varied between 6.4°C and 36.7°C while summer temperatures varied from 25.3°C to 47.7°C. Table 4.23 represents the physico-chemical parameters of end products during winter and summer seasons.

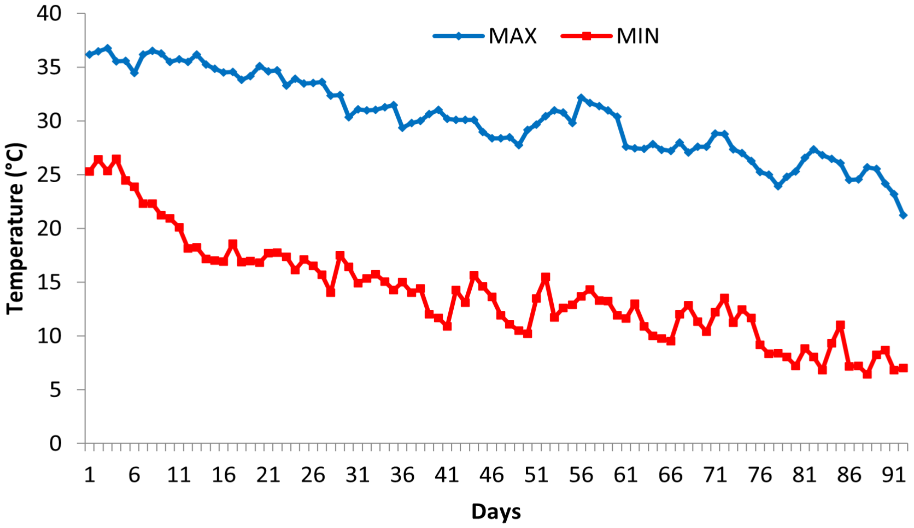


Figure 4.20: Temperature variations in Faridabad city from 1^{st} October to 31^{st} December 2016

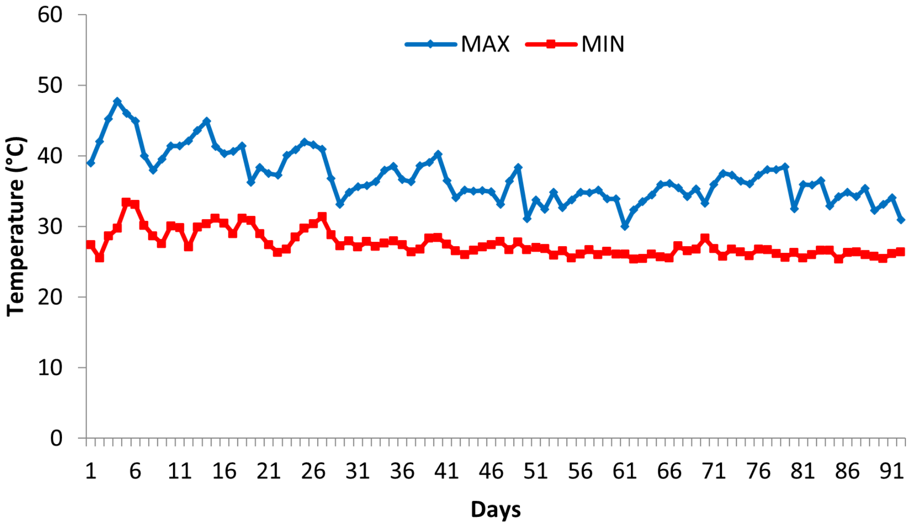


Figure 4.21: Temperature variations in Faridabad city from 1^{st} June to 31^{st} August 2017

pH reduction was observed in all the vermireactors at varying extent and decrease was found to be more marked in winter (8.3 - 10.8%) than summer season (6.9 - 9.7%) at the completion of experiment. Electrical conductivity of vermicomposts produced from different combinations of household waste and cow dung tend to increase in both seasons. This is due to conversion of non-available nutrients into their available forms and production of salts, ammonium and inorganic ions [152]. In winter, EC increase was in range of 2.3 - 3.3 dS/m and was 60.9 - 80.8 % more than initial feed material while in summers it varied from 2.2 - 3.1 dS/m with 57.5 - 71% increase over initial values.

Table 4.23: Physico-chemical characteristics of Vermicomposts during different seasons (Mean ± SEM, n=3)

Vermi reactors	**pH**		**EC (dS/m)**		**TOC (g/kg)**		**Organic matter (%)**	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
V1	7.5±0.02a	7.56±0.01a	2.34±0.06a	2.29±0.04a	234±1.52a	275±3.4a	40.3±0.8a	47.4±0.98a
V2	7.35±0.01a	7.39±0.03a	2.63±0.08c	2.55±0.04d	257±2.20b	287±4.1a	44.3±1.0b	49.5±1.2b
V3	7.04±0.01a	7.20±0.04a	2.93±0.04c	2.89±0.03b	275±2.45c	290±4.7b	47.4±1.2c	50.0±2.3c
V4	7.03±0.03a	7.15±0.05a	3.23±0.01b	3.10±0.02c	303±2.87d	317±5.6c	52.2±2.5d	54.6±1.4d
V5	7.03±0.04a	7.09±0.04a	3.30±0.03a	3.18±0.04a	328±2.98e	340±6.4d	56.5±2.7e	58.7±2.6e

Mean values followed by different letters in same column are statistically different (ANOVA; Tukeys's test, $P \leq 0.05$)

This shows that production of salts and ions was more in winter as compared to summer and more increment was observed in winter season.

Reduction in TOC content was recorded in all the vermireactors in both seasons, but winter season vermireactors had shown more TOC decline (1.47 - 1.78 fold) than summer reactors which showed 1.45 - 1.65 fold decrease. TOC varied significantly in all the vermireactors in winter and summer seasons ($p<0.05$). TOC decline at completion of process might be attributed to synergistic activity of earthworms and microorganisms in degradation of organic matter.

Organic matter also showed trend of decline from their initial values in all the vermireactors in summer and winter season. Organic matter reduction ranged from 31.2 - 39.9% in summers and was found to be slightly lower than winter season (32 - 41.8%). Maximum descend in organic matter was seen in 100% cow dung in summer (39.9%) and winter season (44%) followed by 40% HSW (39.5%) in summers and 41.8% in winters. The results showed that winter temperature favoured more organic matter reduction which might have been occurred due to better activity of earthworms along with microorganisms in conversion of raw waste. Table 4.23 compared seasonal variation in organic matter reduction. Significant variation was observed in all the five vermireactors in both the seasonal temperatures ($p<0.05$) while V2 and V3 showed no statistical difference.

Nutrient enhancement (NPK) after the accomplishment of vermicomposting was achieved in all the vermireactors in summer and winter temperatures due to organic matter mineralization. TKN levels were higher during winter (1.54 - 2.25 times) than summers and showed 1.06 - 1.61 fold increase over initial levels (Figure 4.22). Although increase in TKN relies on initial concentration in feed materials, it might be owed to addition of mucus and excretorty substances by earthworms [109] and loss of carbon along with increase in nitrogen. TKN levels were significantly different in different vermireactors in winters and summers ($p<0.05$).

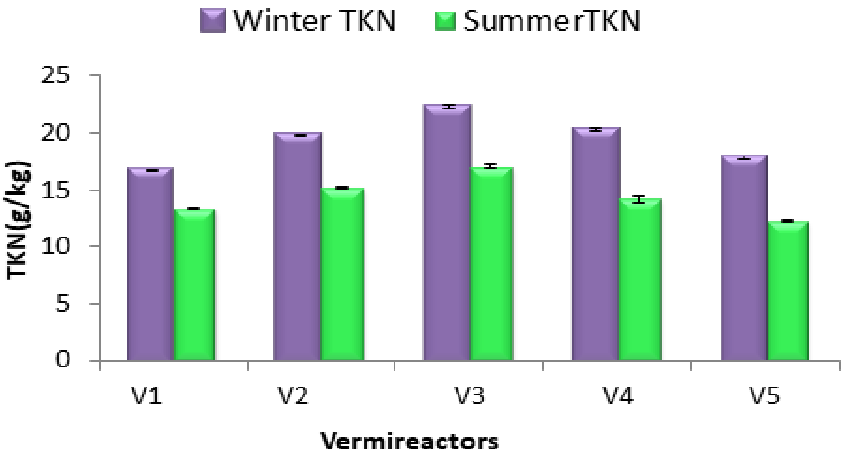


Figure 4.22: Total Kjeldahl Nitrogen after 90 days in different seasons

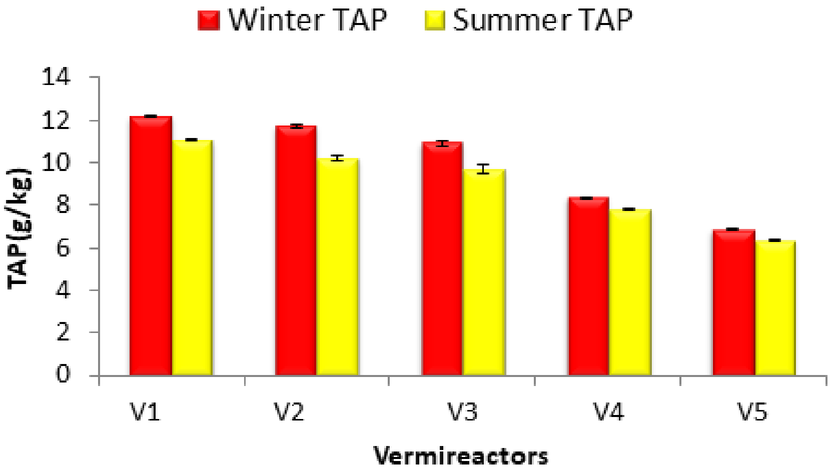


Figure 4.23: Total Available Phosphorus after 90 days in different seasons

Vermicomposts had more phosphorus concentration as compared to the feed materials in both seasons but incremental change was more in winters when compared to summers (Figure 4.23). Winters showed 1.34 - 1.7 fold ascend in TAP with highest increase in V3 while TAP was 1.12 - 1.49 times more than the initial feed materials. Maximum increment was observed in V3.

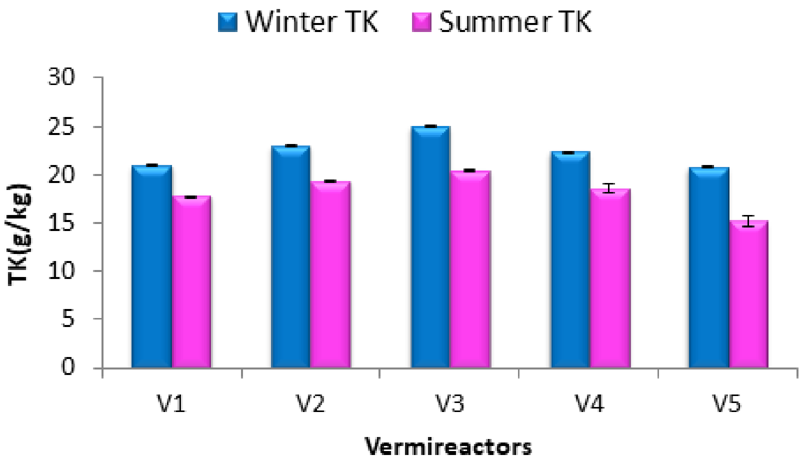


Figure 4.24: Total Potassium after 90 days in different seasons

TK levels in winter vermicomposts were remarkably higher than those obtained in summers (Figure 4.24). In winter, 1.61-2.36 fold rise over initial contents was recorded whereas summer vermicomposts had slightly lower potassium values (1.16 - 1.86 times). Thus, it can be marked that winter vermicomposts was found to possess higher nutrient profile than those obtained in summers.

Vermicomposts produced in both winter and summer temperatures had shown significant drop in C:N and C:P values in vermireactors. C:N value was found to be decreased from their initial values of 42 ± 1.56 - 49.1 ± 1.15 to 12.3 ± 0.78 - 18.4 ± 0.67 in winters and fall in range of 16.9 ± 0.78 to 27.6 ± 0.67 from previous values of 43.0 ± 1.56 - 52.0 ± 1.14 in summers. Descend in C:N was more marked in winters (56.1 - 74.3%) than summers with 35.8 - 62.2 % decrease. C:P ratio is yet another vermicompost stability parameter and had also shown a trend of deceleration in both seasons with higher deduction in winter season (from 56.4 ± 1.14 - 94.7 ± 2.42 to 19.1 ± 1.02 - 47.8 ± 1.18) while summer vermicomposts had final C:P values in range of 24.7 ± 1.02 to 53.1 ± 1.18.

ii **Effect of Seasonal Variation on Biological Characteristics of *Eisenia fetida***

Earthworm population increased in all the vermireactors after 90 days of vermicomposting, in fact, winter vermireactors had shown slightly increased earthworm population (43 ± 2.6 to 80 ± 3.0) as compared to summer vermireactors

(41 ± 1.6 to 78 ± 2.7). There was 2.1 - 4.0 times increase in earthworm number at the offset of winter experiment while in summers, 2.0 - 3.9 fold increment was noted in the vermireactors. Table 4.24 - 4.25 represent biological parameters in winter and summer seasons.

It was indicated from findings that earthworms achieved biomass gain in all the feed materials up to variable extents. Figure 4.25 compares mean net biomass gain in winter and summer season. Winter reactors recorded biomass gain of 645 ± 4.78 to 864 ± 5.1 whereas it was 598 ± 5.1 to 824 ± 6.3 in summer vermireactors. It might be due to better earthworm activities owing to presence of more organic matter and nutrients in winter season. Decent amount of organic matter in vermireactors makes the environment favourable for earthworms [153]. Greater biomass gain was noticed in 100% cow dung followed by 20% HSW and 40% HSW in both winters and summers although earthworms performed significantly well in winter season. This can also be explained by higher organic carbon and organic matter reduction in corresponding season.

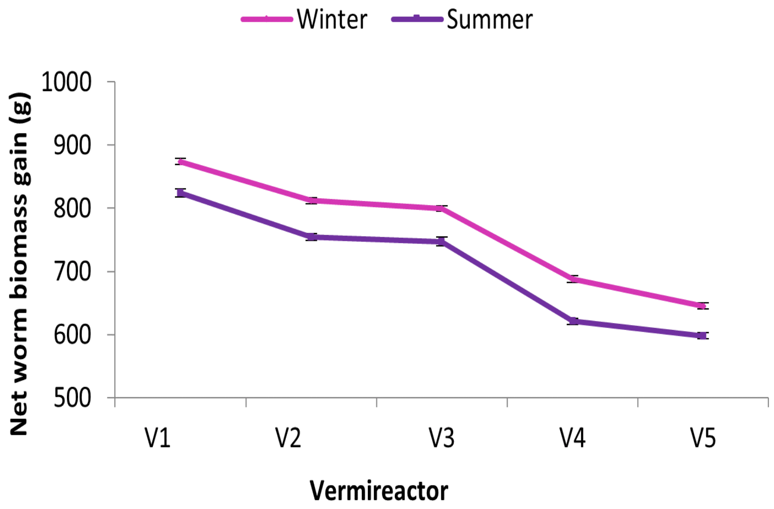


Figure 4.25: Net worm biomass gain after 90 days in different seasons

Table 4.24: Biological characteristics of raw waste and vermicompost produced in different vermireactors during summer season (Mean ± SEM, n=3)

Vermireactor	**Earthworm population**		**Live earthworm biomass(mg)**		**Biomass gain (mg)**	**No. of cocoons**	**Biomass achieved (days)**	**Fecundity (cocoon /worm)**	**Growth rate /worm/day (mg)**
	Feedstock	VC	Feedstock	VC					
V1	20	78±2.7d	162±2.6a	986±2.2e	824±6.3d	280± 4.8e	75	3.58	10.09±0.09c
V2	20	74±2.3d	196±3.1c	950±3.4d	754±5.6c	236±3.6d	75	3.18	10.05±0.06b
V3	20	67±2.3c	188±2.2b	935±2.5c	747± 6.8c	207±4.2c	75	3.08	9.96±0.09b
V4	20	56±2.1b	191±3.4c	812±2.1b	621± 4.8b	123±3.2b	90	2.19	6.90±0.06a
V5	20	41±1.6a	167±2.8a	765±2.2a	598±5.1a	67±2.5 a	90	1.63	6.64±0.05a

Mean values followed by different letters in same column are statistically different (ANOVA; Tukeys's test, $p \leq 0.05$)

Table 4.25: Biological characteristics of raw waste and vermicompost produced in different Vermireactors during Winter season (Mean ± SEM, n=3)

Vermireactor	**Earthworm population**		**Live earthworm biomass (mg)**		**Biomass gain (mg)**	**No. of cocoons**	**Biomass achieved (days)**	**Fecundity (cocoon /worm)**	**Growth rate /worm/day (mg)**
	Feedstock	VC	Feedstock	VC					
V1	20	80±3.0e	154±1.7a	1028±4.2e	874±5.1e	289±4.8e	60	3.61	14.56±0.08d
V2	20	76±2.8d	176±2.8	975±3.4d	812±4.8d	246±3.6d	60	3.23	13.53±0.05c
V3	20	69±3.8c	160± 1.9c	949±4.8c	799±4.2c	227±4.2c	60	3.28	13.31±0.06c
V4	20	59±2.2b	166±2.3cd	854±4.4b	688±5.34b	151±3.2b	75	2.55	9.17±0.06b
V5	20	43±2.6a	155±2.45b	800±3.5a	645±4.78a	73±2.5a	90	1.70	7.16±0.05a

Mean values followed by different letters in same column are statistically different (ANOVA; Tukeys's test, $p \leq 0.05$)

Growth rate, cocoon number and fecundity were affected by amount of amendment (cow dung) and get decreased with greater household waste amount. Number of cocoons were found to be more in cow dung due to luxuriant growth of earthworms in both seasons, however, number was slightly less than winters. Fecundity and growth rate/worm/day was better achieved in winters when compared to summers. Fecundity of 1.63 - 3.58 was recorded in vermireactors established in summers whilst winter vermireactors possessed fecundity of 1.70 - 3.61 after 90 days of vermicomposting experiment. On same pattern, growth rate/worm/day was remarkable in winters (7.16 ± 0.05 - 14.56 ± 0.08mg /worm /day) in comparison to summer growth rates of 6.6 ± 0.05 - 10.09 ± 0.09mg/worm /day) as indicated in Figure 4.26.

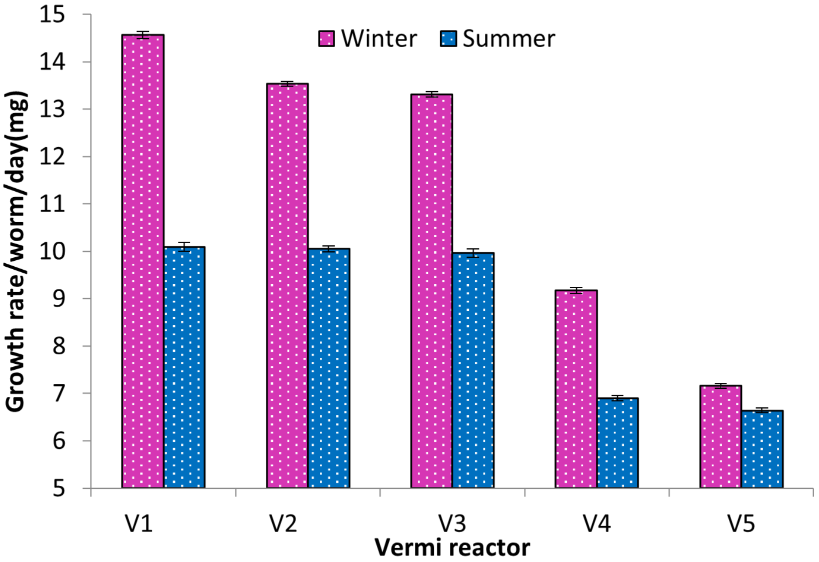


Figure 4.26: Growth rate/worm/day(mg) after 90 days in different seasons

Ambient temperature also had an impact on biological characteristics of earthworms. After 90 days, growth started declining in both seasons due to temperature extremities faced by earthworms, however, it was more in summers.

c) Conclusions

Waste conversion by earthworms in vermicomposting system is affected by environmental conditions. *Eisenia fetida* is tolerant to a wide range of temperature but extreme temperatures can affect earthworm activity. Organic matter reduction was more favorable during winter than summer temperatures. Decrease in C:N ratio in different feed substrates was noticed in both winter and summer season. The C:N value decline was higher in winter (56.1 - 74.3%) than in summer (35.8 - 62.2 %).

NPK profile of winter vermicomposts was also enriched than those obtained from summer experiments. Net earthworm biomass achieved was higher in winter as compared to summer. Earthworms performed quite well in winter temperatures than summer ones during the experimental time. It was inferred from the results that ambient temperature besides feed nature and quantity also affects growth and fecundity of earthworms.

4.4 DEVELOPMENT OF AN ON-THE-SITE PROTOTYPE VEMICOMPOSTER FOR MANAGEMENT OF ORGANIC COMPONENT OF HOUSEHOLD SOLID WASTE

4.4.1 Introduction

The present research aimed at developing a novel vermicomposter for on-the-site vermicomposting of organic wastes and the physico-chemical quality of the end product, i.e., vermicompost was also evaluated. Keeping this in view, a novel vermicomposter was designed and developed made up of wooden structure for an on-site household application. The organic waste from a household of 4 - members family was fed to the vermicomposter on daily basis. This system is a small-scale continuous flow vermicomposter which fill the organic waste up to approximately 20 kg in every bin. The composter has four bins for constantly switching from one bin to another for filling the waste. The advantage of the developed prototype vermicomposter is that it can be used as an on-the-site small scale system in a household to manage and decompose the organic waste generated. Further, it utilized small spaces for setting up in spite of the required large spaces by the traditional process. On one hand, the vermicomposter will not only manage the household organic waste by decentralizing the overall solid waste management, but also, resource utilization is there by converting waste into manure for further use.

4.4.2 Materials and Methods

a) Construction of Prototype Vermicomposter for Organic Waste Management

A four - bin vermicomposter was developed for managing household organic waste (fruit & vegetable peels, garden waste) in household of 4 - 5 members family. The vermicomposter made out of wooden structure has four horizontal compartments (1^{st} to

4th bin), each having dimensions of 30cm × 60cm × 60cm with wheels at the bottom for its easy movement. Each bin was constructed of an appropriate size and volume to accommodate the organic waste of at least one month generated in the selected household size. Four bin system maintain the system's continuity as once first bin is full of organic waste generated, filling of waste can be started in next bin and so on. Small holes (air spaces) were kept in all the four bins for proper aeration in all the compartments throughout the process. Also wood, being porous, allows to retain moisture and maintain aeration. Figure 4.27 depicts the schematic representation of four - bin vermicomposter designed in the study. The bin was fed with waste at a single time in a day. The performance of the vermicomposter was investigated for conversion of waste and manurial quality of vermicompost.

Figure 4.28 shows the schematic representation of a single vermireactor bin. A bedding (≈10 cm) of garden soil and leaf litter was prepared for earthworms. Bin has leachate collecting tray at the bottom. About 20 number of earthworms per one kg waste were added to carry out vermicomposting. Each bin could handle ≈ 20 kg of wet waste easily and as one bin fills, second compartment can be used to collect waste and so on. When fourth bin was filled with waste, the vermicompost in the first bin can be harvested. Waste materials can be turned and mixed in one compartment, allowed to pre-compost followed by vermicomposting.

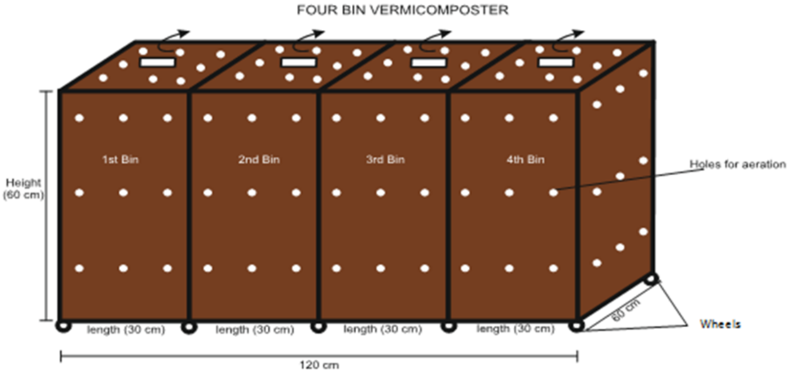


Figure 4.27: Schematic presentation of Four-bin Vermicomposter

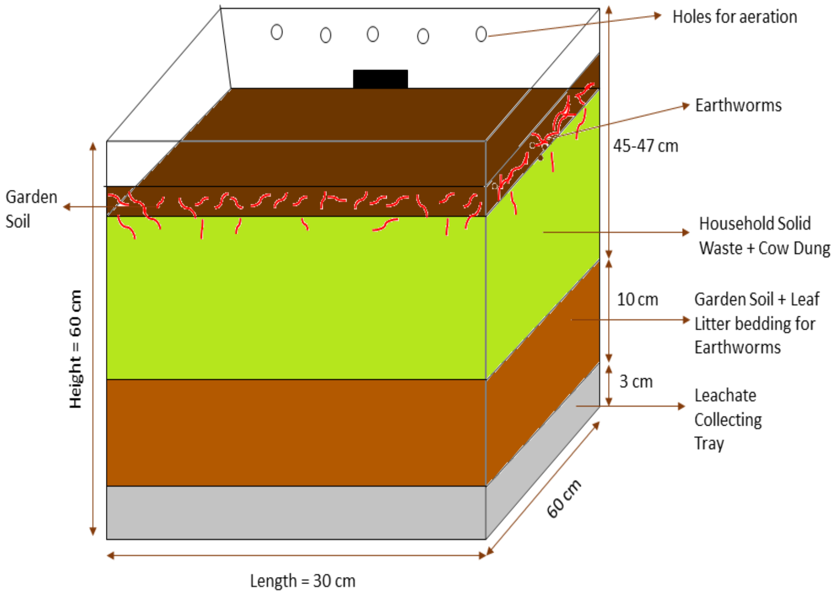


Figure 4.28: Schematic Representation of Vermireactor Bin

b) Organic Waste Collection, Earthworms, Leaf Litter, Garden Soil

Cow dung (CD) was obtained from a livestock farm situated at NIT Faridabad, India. The organic waste mainly consisting of kitchen waste and garden waste, leaf litter and garden soil was collected from a residential household located at Faridabad city, India. The earthworms were taken from the stock culture developed at the Departmental laboratory.

c) Experimental Set up

To start with the vermicomposting process, different layers were used in the vermicomposter unit. First layer is the bedding layer that consisted of (bottom most layer) garden soil and leaf litter. This layer provided the habitat for the earthworms in the unit as well as absorbed leachate formed from above layers. Second layer was the substrate layer wherein mixture of household solid waste was spread on daily basis and cow dung was added on weekly basis. HSW and cow dung was maintained in the ratio of 4:2. About 10 - 12 days old cow dung was used in this layer, this cow dung was then mixed with small amount of water and slurry was made of it so that the cow dung loose its heat. Cow dung worked as bulking agent. After one month of adding HSW and subsequent pre-composting, a third layer, i.e., clitellated *Eisenia fetida* earthworms (20 earthworms per kg of waste) were added. These earthworms were evenly spread above the second layer. After these initial layers, fourth layer of garden soil was added in the unit so as to cover it. No more addition of HSW was done in this bin.

First bin was filled in this manner for about 30 days. Once it was full, earthworms were added and covered with garden soil. The bin was watered at regular intervals to maintain moisture at 60 - 70%. Now the filling of second bin with HSW was started and it followed the same procedure as was with first bin. Third and fourth bin were filled in similar manner. As the fourth month approached, the vermicompost in the first bin was ready to harvest. It was manually taken out from the bin. The earthworms were separated by light treatment and vermicompost was kept for few days before its use in horticulture. Now the first bin is ready to accommodate new HSW waste. The on-site prototype vermicomposter was kept indoor with decent ventilation conditions at room temperature between 25-30ºC. The samples of feed mixtures were collected at 0, 21, 42 and 63 days from the vermicomposter. The physico-chemical characteristics were estimated for each feed mixture in triplicates using the standard protocols as mentioned in chapter 3. The photographs of vermicomposter developed in the study have been given at the end of this chapter.

4.4.3 Results and Discussion

Table 4.26 represents the change in physico-chemical parameters during vermicomposting process. Final vermicompost is homogenized, grounded, porous, odor-free and earthy brown in colour with increased NPK levels from the raw waste. The pH values determine the fate of degradation of initial waste material and it was reduced from 8.21 ± 0.02 to 7.45 ± 0.01 after 63 days of vermicomposting (Figure 4.29).

The pH shift can be attributed to formation of nitrites and nitrates, organic acid production and carbon dioxide evolution due to joint working of earthworms and microorganisms [41],[154]. According to previous research studies, near neutral (pH 7-8) are considered ideal for determining mineralization and stabilization of waste materials [117]. An initial increase in the feed substrate pH was observed during the process. It can be owed to formation of basic hydroxides due to availability of adequate moisture levels in the system, which in turn, enhances systems' pH in initial stage of microbial decomposition upto 21 days.

Table 4.26: Change in physico-chemical parameters in vermicomposter during vermicomposting process (Mean ± SEM).

Parameters	**Time (Days)**			
	0	21	42	63
pH	8.21±0.02	8.34±0.03	7.8±0.02	7.45±0.01
EC (dS/m)	1.42±0.03	1.88±0.08	2.56±0.06	2.89±0.05
Organic matter (%)	80.9±2.1	71.6±2.56	68.5±2.02	49.3±1.88
Ash content (g/kg)	191±2.92	284±4.98	315±4.62	507±3.8
TOC (g/kg)	469.2±4.76	415.3±4.54	397.3±3.28	294.3±2.87
TKN (g/kg)	9.28±0.34	14.2±0.78	19.0±1.01	22.5±1.98
TAP (g/kg)	7.2±0.05	8.6±0.07	10.4±0.03	12.8±0.05
TK (g/kg)	9.6±0.03	12.9±0.12	17.2±0.06	22.7±0.10
C/N	50.5±2.34	29.2±2.11	20.8±1.76	13.0±1.52
C/P	65.1±3.28	48.2±2.25	38.1±2.03	22.9±1.96

Note: 0 Day refers to the day of introducing earthworms after 21 days of pre-composting.

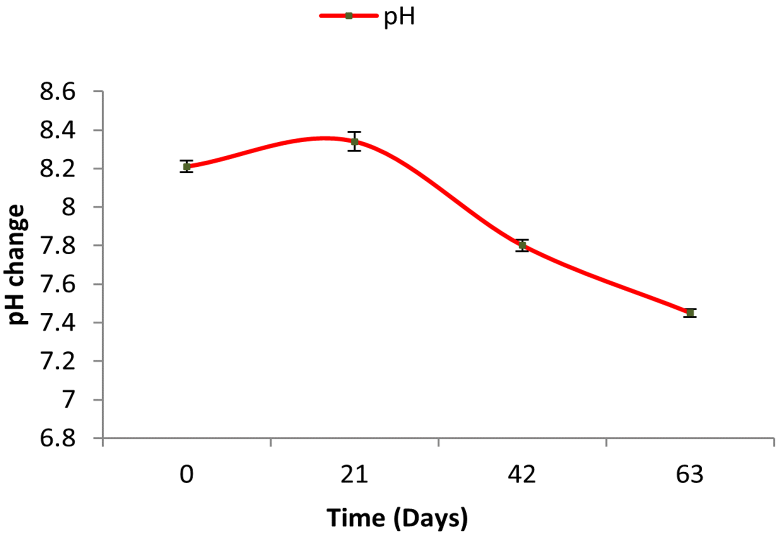


Figure 4.29: Changes in pH with time in vermicomposter

Thenafter, degradation of complex organic composites into simpler forms during the process and microbial activities produce weaker acids, which dominates the concentration of basic hydroxides. The net result is decrease in feed substrate pH to near neutral level till the feed is stabilized.

EC values assess the presence of salts and inorganic ions for establishing vermicompost suitability in agronomic applications. Initally, EC of waste material waste was 1.42 ± 0.03 dS/m, while it increased to 2.89 ± 0.05 dS/m in final vermicompost after 63 days (Figure 4.30). Increase in EC may be owed to formation of salts, ammonium and inorganic ions as well as release of non-available nutrients into accessible forms due to organic matter degradation [89]. The EC values of < 4dS/m are considered suitable for use of vermicompost as an organic fertilizer and the present study fulfills this condition.

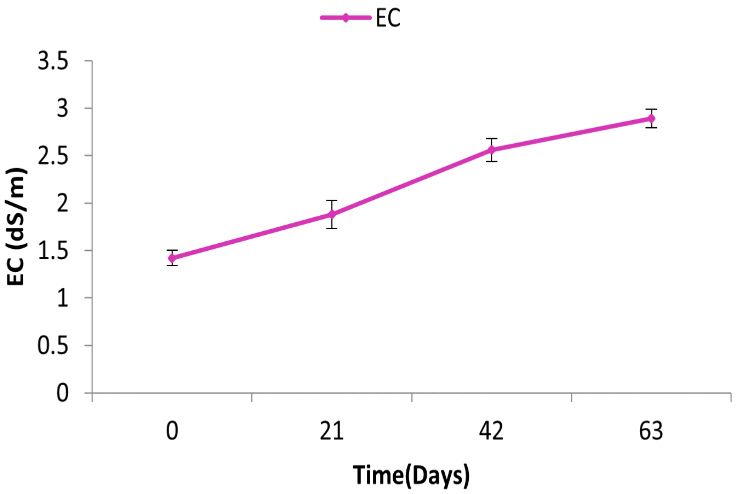


Figure 4.30: Changes in EC with time in vermicomposter

Organic matter content reduced from 80.9 - 40.9% (809 - 409 g/kg) as vermicomposting proceeded in forward direction due to degradation of waste material by earthworms and microbes (Table 4.26). In due course of time, ash content escalated to higher levels owing to efficient waste decomposition and mineralization of organic matter by combined activity of earthworms and microbes. The ash content was found to be increased till the end of experiment and significant enhancement from initial level of 191 ± 2.92 g/kg to final value of 507 ± 3.8 g/kg after 63 days of vermicomposting was observed, whereas, TOC dropped from 469.2 ± 4.76 g/kg to 294.3 ± 2.87 in final vermicompost owing to utilization of carbon pool as energy source by earthworms and microbes [110] and as part of respiratory processes [28] that resulted in carbon reduction. Significant difference was found for ash content increase and TOC decrease with vermicomposting time. Increase in ash content and decrease in TOC is depicted in Figure 4.31. During the initial stage of decomposition; microbes, fungi, actinomycetes present in the waste start softening of the feed materials. This action increases the palatability of feed for earthworms. The latter breaks feed substrate into finer segments in the intestine as well as gut as a result of churning and grinding action. In this way, the complex composites such as carbohydrates, fats, proteins, minerals, etc. are transformed into simple forms such as sugars, fatty acids, amino acids, magnesium, nitrogen, etc. The simple form of nutrients and compounds further increase microbe-earthworm activities. The consumed substrate is excreted by earthworms as vermicastings having very fine particles due to which volume of substrate ultimately decreases and have a higher surface to volume ratio [155]. Enhanced levels of ash content exhibited high rate of volatilization which indicate remarkable organic waste degradation.

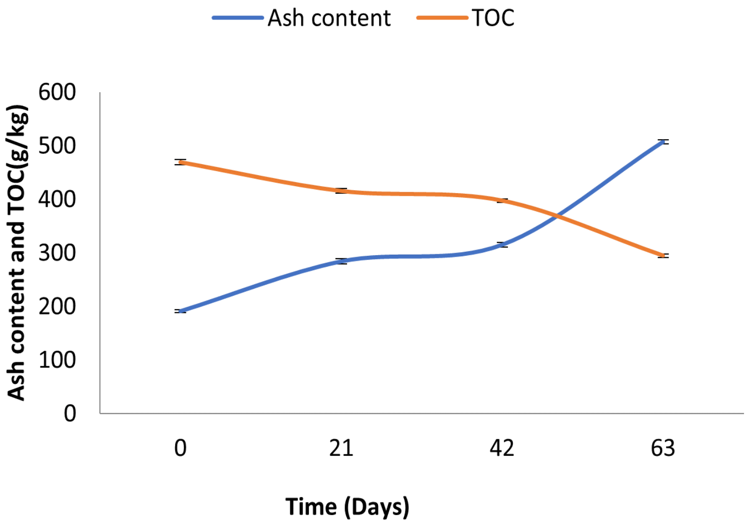


Figure 4.31: Changes in Ash content and TOC with time in vermicomposter

Vermi conversion of household solid waste resulted in decomposition of organic matter along with depletion of carbon source; thereby instigated nutrient levels (NPK) in final vermicomposts (Figure 4.32). About 2.42 fold increment over the initial nitrogen content was recorded in final vermicompost after 63 days of vermicomposting. Increased nitrogen content can be attributed to efficient nitrogen mineralization along with organic carbon degradation. Besides the release of excretory materials and mucus; reduction in waste mass[33] and initial nitrogen concentration [48] also decides final nitrogen content in vermicompost obtained. Phosphorus was found to be 1.77 times more in final vermicompost with respect to initial content that can be owed to joint action of earthworms & microbes in mineralization of phosphorus and also depends upon the initial phosphorus content of waste material. Phosphatase enzyme and phosphate-solubilizing bacteria in earthworm's gut release phosphorus in soluble forms [114] thereby increasing TAP in final vermicompost. TK also showed a remarkable rise of 2.36 fold over initial content after 63 days of vermicomposting. Efficient decomposition of household waste as well as release of exogenic/endogenic enzymes because of increased microbial activity in presence of earthworms had resulted in TAP increase [90].

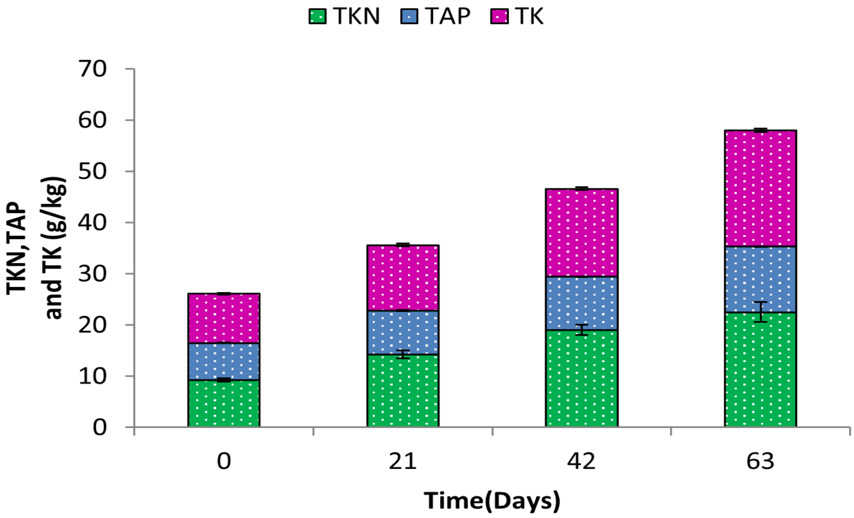


Figure 4.32: Changes in TKN, TAP and TK(g/kg) with time in vermicomposter

C:N and C:P ratios are assertive parameters to reflect the stability of vermicompost and its agronomic application. Change in C:N and C:P ratios are presented in Figure 4.33. C:N ratio denotes the rate of organic matter decomposition. C:N value $<$ 20 marks vermicompost stability [117] and $<$ 15 can also reflects its value as an organic manure [90]. C:N descended from its previous value of 50.5 to 13.0 after 63 vermicomposting days and were statistically different. C:P levels also showed a decline from 65.1 to 22.9 at the completion of vermicomposting process. C:P ratio deceleration suggests waste material degradation and hence vermicompost stability.

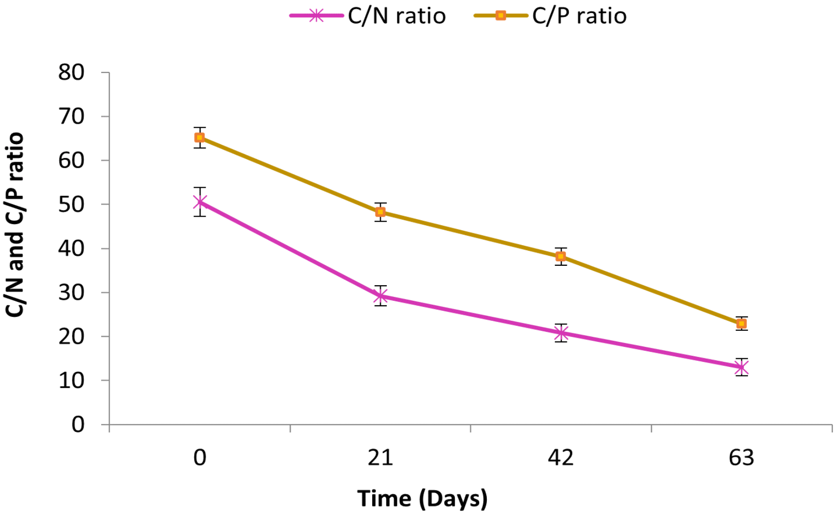


Figure 4.33: Changes in C: N and C: P with time in vermicomposter

Four bin vermicomposting system allows continuous processing of large amount of organic materials than single / two / three bin systems. Four Bin vermicomposter can be a good option for decentralized and home-vermicomposting of Household solid waste where there was 3.02 fold reduction in waste mass after vermicomposting. It starts from the most fundamental approach of waste segregation at the immediate source of generation, acts as a separate bin for collection of biodegradable components and a reactor for vermicomposting process in a clean manner. Vermicompost produced can be used for pots and garden in homes thereby minimizing the use of inorganic fertilizers / need to buy from market. If the organic portion is managed, approximately half of the waste management issue can be resolved at the source level hence can go a long way in sustainable waste management and help to reduce an individual familys' waste generation footprint.

The photographs of prototype vermicomposter developed in the study are as below:

Figure 4.34: Prototype Four bin vermicomposter

Figure 4.35: Vermicomposter bin with bedding material and Household solid waste+cow dung

Chapter 5

SUSTAINABLE TREATMENT AND NUTRIENT RECOVERY FROM FOOD PROCESSING INDUSTRY WASTE THROUGH VERMICOMPOSTING

5.1 INTRODUCTION

Cruciferous crops (also called as *Brassicas* or crucifers, family *Brassicaceae*) are one among the largest groups of temperate vegetables in the world. They are significant contributors to the global foodscape from a nutritional and culinary perspective, being viewed for high carotenoids, vitamins, calcium, iron, potassium, dietary fibers and phytochemicals with possible anticancer effects [156]. Among these, Cabbage (*Brassica oleraceae* var. *capitata*) and Cauliflower (*Brassica oleraceae* var. *botrytis*) are the dominant crops with an annual global production of 71.8 and 25.3 million tons, respectively (Food and Agriculture Organization, 2018). According to statistics, India is the second largest cabbage producer, with a production of about 8.8 million tons, after China with 33.9 million tons; both contribute together 59% of world cabbage production. Other significant cabbage producers are Russian Federation, South Korea, Ukraine, Indonesia, Japan and Poland. Similarly, India is the second largest producer of cauliflower also with 8.2 million tons production, while China with the largest production (10.3 million tons), both amounting to 70% of total cauliflower production worldwide. The other major cauliflower producer countries are Spain, Italy, France, followed by Poland and Turkey.

It is estimated that cabbage and cauliflower generate on an average upto 30 - 50% of waste material, in the form of stem, stalk and leaves, which are not further used [157]. During different phases of vegetable supply chain, including harvesting, transport, marketing, storage and processing, huge quantities of waste and by-products are produced by these two cruciferous vegetables throughout the world. Utilization of these wastes is neither efficient nor structured in most of the localities; these contain high water content and biodegradable organic compounds which readily decompose and create negative impact on environment in absence of proper waste collection facilities [158]. Non-edible portion of cauliflower such as stalk and surrounding thick green leaves are discarded as waste from food processing industries where cauliflower is a part of packaged frozen veggies. Similarly, outer leaves of cabbage are discarded from houses, markets and food processing units. This waste biomass is dumped in along with other solid waste streams, leading to the formation of leachate and greenhouse gases emission in landfills and/or incinerators and reducing efficiency of the waste management systems [159]. It has been reported that poorly managed landfilling or dumping of crop residue biomass results in emission of approximately 2.8 metric tons of methane per year [160]. Moreover, presence of high contents of sulfur and nitrogen in cabbage and cauliflower residual mass can contaminate soils and impact the surface water and groundwater quality if remain unutilized [161].

Both cabbage and cauliflower grow in same season and close proximity and hence generates huge amount of waste as leaves and stalk. Presence of high sulfur content in residue of cabbage and cauliflower smells badly during degradation, therefore, not preferred as animal feed [162]. Effective collection and cost-efficient methods to manage these biodegradable wastes are needed urgently. Various researchers have reported the application of vegetable wastes to develop value-added materials and energy through anaerobic digestion, ethanol production, composting, vermicomposting, etc. [163]. Abbasi and Abbasi [164] have suggested that the vermicomposting process is more efficient in handling phytomass as compared to the composting and anaerobic digestion, latter being the cumbersome and expensive processes.

Vermicomposting is a cost - effective and sustainable technology to decompose non-toxic waste biomass originating from household, agricultural and industrial activities [56]. It is a bioprocess of converting innocuous phytomass with combined action of earthworms and microorganisms along with other degradable community into stabilized manure known as vermicompost [56]. The beneficial effects of vermicompost in soil conditioning via physical, chemical and biological enhancements and presence of useful secondary metabolites in plants due to application of vermicompost have been reported [165]. The efficacy of vermicomposting technology has been established by various researchers for fruit and vegetable residues, to name a few: food and vegetable processing waste [56], grape marc [62], mushroom residues [166], apple pomace [60]. The fertilizer value and amount of vermicompost produced are dependent on the quality of raw waste / substrate as well as earthworm species in the study [28]. As per available reports and researches, the vermicomposting potential of cabbage and cauliflower waste biomass have been rarely investigated by previous researchers. Thus, an understanding is required to explore the utilization of cabbage and cauliflower waste sustainably in degradation process to give new perspectives in waste conversion technologies.

Considering the aforementioned points, present research aimed at exploring the potential of cabbage and cauliflower residual mass as feedstock for earthworms and efficacy of the vermicompost in terms of nutrient availability and stability. Both cruciferous vegetables are soft and delectable to be used as feeding substrate in the process of vermicomposting after spiking with cow dung. *Eisenia fetida* has been employed for the process as it has high fecundity rate, wide range of environmental tolerance and great acceptability for many substrate mixtures [90]. The efficacy of process was estimated by monitoring the changes in the earthworm population and biomass, physico-chemical parameters, nutrient profile along with parameters of stability as ash level, C/N/P ratio, Germination index and FT-IR analysis of vermicompost through a comparative assessment of degradation of cabbage and cauliflower residual biomass by earthworms in due course of time.

5.2 MATERIALS AND METHODS

5.2.1 *Eisenia fetida*, Cow Dung, Cabbage Leaves and Cauliflower Residue

Stock cultures of *Eisenia fetida* were maintained under the laboratory conditions for use in the investigation. Cruciferous vegetable (cabbage & cauliflower) residues were collected from vegetable market and agricultural fields situated in peri-urban area of Faridabad city, Haryana (India). It was found that the residues of leaves, stalks and roots of both the vegetables are not utilized anywhere and usually dumped. Fresh urine free cattle dung for the experiment was collected from a local dairy farm at the city. Cow dung, Cabbage leaf waste and Cauliflower waste were analyzed for various parameters (Table 5.1).

5.2.2 Experimental Setup

Several previous studies reported that addition of cattle dung with organic waste increases the rate of earthworm survival and activates the microbial population [24]. Hence, cow dung was employed as blending feedstock in the experiments to enhance the rate of vermicomposting process. Different ratios of cow dung (CD), cabbage (CAB) and cauliflower (CAU) residual biomass on dry weight basis were taken as follows: V_{CD} (100% CD), V_{CAB} (60% CD + 40% CAB) and V_{CAU} (60% CD + 40% CAU). Vegetable wastes were diced into about 2-5 cm pieces in order to increase surface area to facilitate degradation process. Two kilogram of waste mixture (on dry weight basis) was placed in triplicates in rectangular plastics bins of 10 litre capacity in each set-up and kept for pre-decomposition for 15-20 days to remove offensive odors to increase palatability for earthworms. After pre-decomposition, 40 mature worms (clitellated, weighing approx. 550 - 600 mg each) were picked from stock culture and introduced in experimental vermibins. Vermibins were kept at 20-25ºC ambient temperature and turned on frequent intervals for providing an aerobic environment to the earthworms. About 70-80% moisture was sustained throughout the experiment. The bins were covered with moistened jute bags to avoid surface drying, flies, insects and odors. The experiment in triplicate set-ups were performed for 90 days and about 30g of sample was drawn from each bin at intervals of 15, 30, 45, 60, 75 and 90 days. The samples (free of earthworms and cocoons) were air-dried, grinded and kept in air-tight packs for parametric evaluation. The earthworms were hand sorted into adult and hatchlings. Earthworm biomass gain was measured after every 15 days up to 90 days and number of cocoons were also recorded. The physico-chemical analysis of waste mixtures was done on dry weight basis whereas worm biomass was estimated as fresh weight.

Table 5.1: Characteristics of initial cow dung, cabbage leaves and cauliflower wastes (Mean ± SEM of three replicates)

Parameters	Cow Dung (CD)	Cabbage leaf waste	Cauliflower Waste
pH	8.2±0.20	6.2±0.25	5.7±0.21
EC (mS/cm)	1.62±0.02	3.45±0.05	2.03±0.03
Ash Content (g/kg)	228±1.52	111±2.01	90±1.58
OM (g/kg)	772±1.56	889±2.02	910±1.44
TOC (g/kg)	448±1.42	515±4.4	527±1.50
TKN (g/kg)	8.3±0.01	17.1±0.02	15.2±0.01
TAP (g/kg)	7.20±0.01	2.30±0.04	4.71±0.02
TK (g/kg)	7.90±0.01	1.74±0.05	3.26±0.03
C/N	53.9±0.15	27.6±0.01	34.6±0.01
C/P	62.2±0.02	42.9±0.03	112.1±0.02
Moisture content (%)	84±0.15	81.6±0.25	84.1±0.008
Total Cu (mg/kg)	82.2±0.01	54.21±0.02	59.4±0.04
Total Fe (mg/kg)	1638±1.5	1087±2.5	1098±2.08
Total Zn (mg/kg)	187±0.88	162.6±0.20	171.0±1.5
Total Mn (mg/kg)	124.8±0.01	82±0.69	89.4±0.15
Total Cd (mg/kg)	2.32±0.04	2.18±0.05	2.38±0.06

5.2.3 Physico - chemical Estimation and Maturity Profile of Materials

Samples from VCD, VCAB and VCAU vermibins were estimated for pH, Electrical Conductivity (EC), Ash content, Organic matter content (OM), Total Organic Carbon levels (TOC), Total Kjeldhal Nitrogen (TKN) content, Total Available Phosphorus content (TAP), Total Potassium content (TK) and micronutrients viz. Total Cu, Fe, Mn, Zn and Cd. To assess the maturity of vermicompost produced, C/N and C/P ratio, FT-IR analysis and seed germination index of feed mixtures and vermicomposts were compared. The parameters were analyzed in the study using standard methodology (Chapter 3).

Seed germination Index was calculated by the method given by Zucconi et al [98]. 5g final vermicompost sample was taken from each vermibin and mixed with 50 ml distilled water, allowed to agitate (at 150 rpm) for 1 hr and filtered. Twenty seeds of *Vigna radiata* (green gram) were placed on the petri plates lined with filter paper followed by addition of 10 ml of vermicompost extract. The petri plates were placed under dark environment at 25ºC for 5 days. Experimental trial was conducted in triplicates with sterile distilled water as control. The count of germinated seeds and root length were analyzed for all test petri dishes as well as for control. Percent Germination Index (GI) was calculated from the formula [167],[84]

$$GI(\%) = \frac{RSG}{RRG} \times 100 \qquad (5.1)$$

Where, RSG = Relative Seed Germination; RRG = Relative Root Germination

5.2.4 Earthworm Dynamics

Biological analysis was performed to estimate the rate of growth of earthworms, biomass gain and fecundity (cocoon/worm) rates. Wet samples were drawn out of bins on a plastic mat at every 15^{th} day till 90^{th} day. Every time, small piles of wet sample were made. Eventually earthworms move to the central part of pile on facing light and totaled by taking out the upper layer of piles. Manual sorting was done for adult earthworms, hatchlings and cocoon for each vermibin. Earthworms, hatchlings and cocoons were counted, worms washed with water, weighed on digital weighing balance and returned back to their respective bins.

5.2.5 Statistical Analysis

Data for physico-chemical characteristics, nutrient profile and earthworm dynamics were analyzed with the help of ANOVA to find the difference between the three vermibins. The findings were represented as mean of triplicates (mean ± SEM). Post-hoc tool for comparative analysis of means at statistically significant levels ($p<0.05$), i.e., Tukey's HSD analysis was used. Germination index was also statistically evaluated in order to determine the significance level of three feedstock variations. The IBM-SPSS Statistics 21 tool was used for analysis.

5.3 RESULTS

5.3.1 Changes in pH, EC and TOC

pH is a key factor in determining the fate of waste decomposition process. pH levels of $7-8$ (near neutral) are considered ideal for mineralization process and stabilization of waste materials during vermicomposting [117]. In present study, increase in pH was observed at initial stage of decomposition process, at day 15, it increased up to 8.6 in V_{CD}, 8.01 in V_{CAB} and 8.5 in V_{CAU}, followed by a gradual reduction in all the vermibins towards the completion of experiment (7.4 in V_{CD}, 7.2 in V_{CAB} and 7.1 in V_{CAU}) (Figure 5.1A). The current results were in line with the former studies available in literature database [65],[140],[84]. Gusain and Suthar [84] reported an increase in pH at initial stage of vermicomposting (at day 10), afterward, showed a continuous decline till the process completes. The pH reduction from initial values was observed in the order of $V_{CD} > V_{CAU} > V_{CAB}$. Shift in pH levels throughout the process is variable and influenced by original feedstocks utilized in vermiconversion. In the present research, cauliflower waste biomass showed more decrement in pH as compared to cabbage leaf residue during vermicomposting. However, the variations in pH values among the final vermicompost samples was not statistically different from each other ($p<0.05$) (Table 5.2). Initial enhancement in pH levels may be due to formation of ammonical compounds $NH_4^+ - N$ and NH_3 during initial stage of waste degradation and subsequent decrease may be due to nitrification of these ammonical compounds into nitrates (NO_3^-) and nitrites (NO_2^-) along with production of carbon dioxide and organic acids due to cumulative activities of earthworms and microbial community [41].

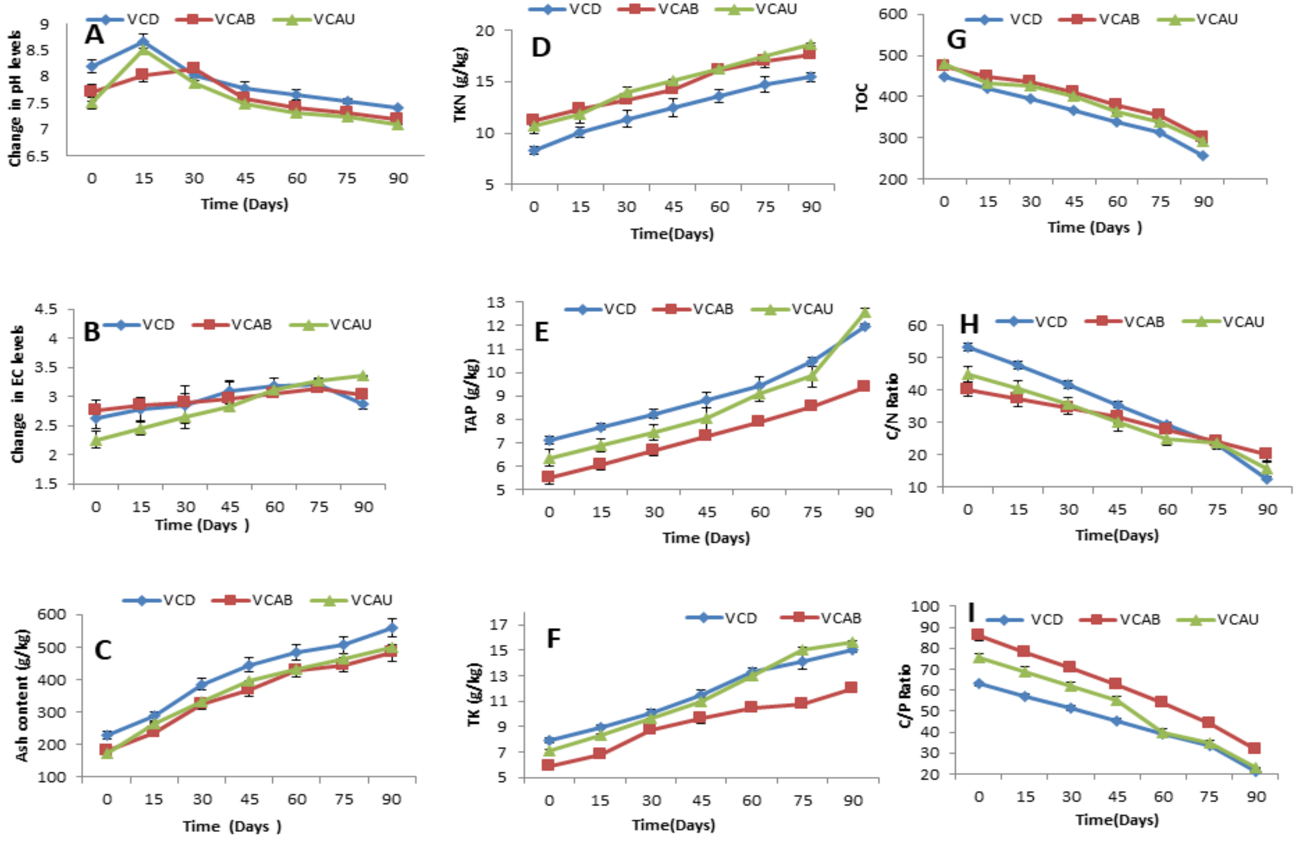


Figure 5.1: Changes in parameters with time in different vermibins: A (changes in pH), B (changes in EC), C (changes in Ash content), D (changes in TKN), E (changes in TAP), F (changes in TK), G (changes in TOC), H (changes in C/N) and I (changes in C/P)

EC levels ranged from 2.26 to 2.75 mS/cm in vermibins at the onset of experiment, while it varied from 2.87 - 3.35 mS/cm in final vermicomposts (Table 5.2). EC content increased in V_{CAB} (33.03%). Cauliflower waste biomass has reflected the maximum increment in EC values as compared to cabbage leaf and CD alone. This shows the presence of more cations and anions in cauliflower residue vermicompost. Values for EC in all vermibins (Figure 5.1B) were significantly different in final vermicomposts ($p<0.05$).

Increase in EC during vermicomposting has also been reported by earlier researchers [168]. Increase in EC was due to release of locked nutrients into more available form and production of salts, ammonium and inorganic ions. EC is a critical factor for determining the suitability of vermicompost in agronomic applications. The vermicomposts produced in the present research were found to be within the limits for EC values that are not toxic to plants (< 4mS/cm) and can be applied as an organic manure.

Earthworms and microbes in conjugation consume organic carbon as a part of respiration forming carbon dioxide thus resulting in decline in TOC content [169],[93]. Present study has shown TOC decline in range of 36.7 - 42.8% in final vermicomposts (Figure 5.1G). A steady decline in TOC was observed with time during the process and a higher reduction was witnessed in V_{CAU} (42.8%) than V_{CAB} (39.2%) .It may be attributed to more efficient decomposition of cauliflower biomass than cabbage biomass with time, also marked by more EC values in V_{CAU}. TOC variation was significantly different in the three vermibins ($p<0.05$). Reduction in TOC due to decomposition of organic material has also been suggested by earlier researchers [140]. Hussain et al. [78] reported TOC decrement at the end of vermicomposting of vegetable market waste amended with rice straw as organic matter undergoes mineralization. Yadav and Garg [170] have also reported about 19.4 - 28.2% reduction in TOC in the end products. Humification, decomposition of carbon and mass decrement in the feedstocks during the process induced TOC decline in the end product [109]. Boruah et al. [90] have suggested that mixing cow excrement with feed material is one of the factor for enhancing earthworm and microbial activities resulting in better reduction of organic carbon.

5.3.2 Nutrient (NPK) Profile

TKN ranged from 8.32-11.2 g/kg in initial substrate which increased to 15.42-18.64 g/kg in vermicomposts after the completion of experiment (Table 5.2). TKN values showed a continuous enhancement in all the vermibins during the study period (Figure 5.1D). The final vermicompost from cauliflower waste biomass had more nitrogen levels (18.64 g/kg), followed by cabbage leaf residue (17.67 g/kg) and control (15.42g/kg). However, highest percentage increment was found in V_{CD} (85.3 %) preceded by V_{CAU} (75.18%) and V_{CAB} (49.74%). This trend of increase may be attributed due to initial N levels in the feed materials. The difference among different vermibins significantly varied for overall increase in TKN values ($p < 0.05$). Various factors are responsible for increased TKN values during vermicomposting as suggested by literature studies. The action of N-fixing bacteria, mucus nitrogenous excretory substances, decomposed tissues and coelomic fluid of earthworms may be responsible for the augmented nitrogen levels [171],[63],[126]. Loss of biomass through CO_2 respiration by the waste degrading community during vermicomposting also concentrates TKN in vermibins [172]. Our findings are closely associated with the earlier studies that found a substantially increased TKN of green waste vermicompost [90],[140].

An incremental change in TAP values with time was recorded in all the feed mixtures up to variable extents (Figure 5.1E). Initial TAP levels varied between 5.52-7.12 g/kg and increased to the levels from 9.38 – 12.56 g/kg in the vermibins as the process completes (Table 5.2). The pattern of percent increase was as: V_{CAU} (98.1%) $> V_{CAB}$ (69.9%) $> V_{CD}$ (68.2%) .The TAP values in vermicomposts were significantly different from each other ($p<0.05$). In general, joint action of earthworms and microbes including phosphate solubilizing bacteria and phosphatase enzyme enhances the solubility of organic phosphorus into soluble form thus amplifying TAP content in vermicomposts. Some researchers have reported that the release of phosphorus in the feed mixtures is due to the microbial use of humic acids throughout the degradation process [84]. Previous studies also established intensification in TAP up to 75% [169] and 97.9 % increment in available phosphorus in vegetable waste vermicompost [66].

Table 5.2: Initial and Final Physico-chemical characteristics of feed materials and final vermicompost in vermibins (Mean ± SEM of three replicates)

Vermibin	**pH**	**EC (mS/cm)**	**Ash content (g/kg)**	**TOC (g/kg)**	**TKN (g/kg)**	**TAP (g/kg)**	**TK (g/kg)**	**C/N ratio**	**C/P ratio**
Initial feed characteristics									
V_{CD}	8.2±0.17b	2.62±0.01b	228±1.5c	448±1.5a	8.32±0.21a	7.12±0.30c	7.84±0.26c	53.4±1.15c	62.9±1.02a
V_{CAB}	7.7±0.15ab	2.75±0.02c	182±2.08b	474±1.20b	11.8±1.15c	5.52±0.4a	5.85±1.45a	40.2±2.23a	86±2.52c
V_{CAU}	7.5±0.03a	2.26±0.15a	173±1.5a	479±0.07c	10.64±0.93b	6.34±0.18b	7.08±1.88b	45±2.35b	75.5±2.1b
Final vermicompost characteristics									
V_{CD}	7.4±0.08a	2.87±0.02a	558±0.01c	256±1.12a	15.42±0.02a	11.98±0.03b	15.04±0.23b	12.6±0.11b	21.36.±0.02a
V_{CAB}	7.2±0.01a	3.02±0.35b	482±1.7a	300±1.06b	17.67±1.12b	9.38±0.33a	11.97±1.16a	20.3±2.02a	31.98±0.15b
V_{CAU}	7.1±0.02a	3.35±0.05c	498±0.12b	291±0.05c	18.64±0.08c	12.56±0.21c	15.6±2.04c	15.61±2.15c	23.1±0.11a

Different alphabets in each parameter shows statistically significant difference (ANOVA, Tukey's HSD test $p \leq 0.05$)

Significant enhancement in TK content with time was noted in all the three vermi - bins during vermicomposting process (Figure 5.1F). TK levels in vermicomposted cow dung, cauliflower and cabbage waste biomass were higher (11.97 – 15.6 mg/kg) after completion of vermicomposting as compared with the initial levels of feed mixtures (5.85 – 7.84 g/kg). Percent increase of 91.83% to 120.34% in TK values was found in final vermicomposts. TK values in vermicompost produced was in the order: $V_{CAU} > V_{CAB} > V_{CD}$ (Table 5.2). Further, TK values were statistically different in vermicomposts of all vermibins ($p < 0.05$). The findings are consistent with earlier reports on green waste vermicompost [93],[140]. Decomposition of waste mixture and endogenic and/or exogenic enzymes release due to cumulative activities of earthworms along with microbes lead to increased TK in the final vermicompost relative to raw feed material. Reduction in organic matter due to respiration of CO_2 as well as resultant TK release is attributed to increased potassium during vermicomposting process [90].

5.3.3 Change in Heavy Metal Content

Micro-nutrients are important for plant growth at low concentrations, but as the concentration crosses the permissible limit, these can hamper soil fertility and plant growth due to bio-accumulation property followed by entry into the human food chain. Thus it is necessary to establish the heavy metal contents in vermicompost prior to its use as manure in agricultural fields. Heavy metal content can increase or decrease due to decrease in mass/volume in final vermicomposted product [56],[173] and/or due to release of free metals from bound state [166]. Binding of metals to humic acids limits the reduction of metals through leaching and bio-concentration [168] whereas, decreased concentration may result from accumulation of heavy metals by earthworm's body [174]. Li et al. [175] also found heavy metal reduction in final vermicompost. Initial waste mixtures as well as final vermicomposts were analyzed for Cu, Fe, Zn, Mn and Cd. Heavy metals were found to be varied in all the feed treatments irrespective of composition and initial values (Table 5.3). In the present study, Cu, Fe, Zn, Mn, and Cd increased from 133 - 135%, 20 - 22%, 41 - 48%, 84 - 105% and 65 - 68%, respectively.

Cu concentration in vermicompost ranged from 182.4 to 201.2 mg/kg, whereas it was 77.6 - 86.2 mg/kg in starting feed mixes. The highest Cu content was reported in V_{CAU}, followed by V_{CD} and V_{CAB} (Table 5.3). The results of increased Cu content after vermicomposting of different waste biomass was reported by other researchers.

[H]

Table 5.3: Heavy metal concentration in initial feed materials and vermicomposts in vermibins (Mean ± SEM of three replicates)

Vermibin	**Total Cu (mg/kg)**	**Total Fe (mg/kg)**	**Total Zn (mg/kg)**	**Total Mn (mg/kg)**	**Total Cd (mg/kg)**
Initial heavy metal content					
V_{CD}	82.2±1.65b	1638±2.45b	187±1.54b	124.8±0.15b	2.32±0.01a
V_{CAB}	77.6±1.48a	1547±3.6a	183.8±0.15ab	116.6±2.38a	2.30±0.02a
V_{CAU}	86.2±1.95c	1548±3.2a	184.2±0.18ab	118.9±3.45a	2.34±0.03a
Heavy metal content in final vermicompost					
V_{CD}	192.6±0.28b	1981±1.62c	277.6±1.12c	229.7±0.02b	3.82±0.01a
V_{CAB}	182.4±2.20a	1856±2.83a	263.2±0.14b	239.6±0.18c	3.85±0.13a
V_{CAU}	201.2±1.28c	1897±3.52b	259.2±0.08a	224.4±0.20a	3.94±0.64b

Different alphabets in each parameter shows statistically significant difference (ANOVA, Tukey's HSD test $p \leq 0.05$)

Sharma and Garg [93] have reported an increase of 255 - 479 % in rice straw and paper waste and Mago et al. [140] reported 178 - 344% increase of Cu in banana leaf waste. Fe content was 1547 - 1638 mg/kg in initial vermibins, further, increased in the range of 1856 - 1981 mg/kg in final vermicomposts and was of order: V_{CD} (1981mg/kg) > V_{CAU} (1897mg/kg) > V_{CAB} (1856 mg/kg). Statistically significant difference was recorded for total Cu and Fe in all vermibins ($p < 0.05$). After vermicomposting, Zn content increased from 187 to 277.6 mg/kg in V_{CD}; 183.8 to 263.2 mg/kg in V_{CAB}; 184.2 to 259.2 mg/kg in V_{CAU}. Similarly, 1.6 fold increase in Zn concentrations in citronella bagasse vermicompost was recorded by Boruah et al. [90]. Difference between all the vermibins was significantly different from one another ($p<0.05$). Total Mn concentrations escalated from 116.6 mg/ kg to 239.6 mg/kg in V_{CAB} followed by 124.8 to 229.7 mg/kg in V_{CD} and 118.9 to 224.4 mg/kg in V_{CAU} in mature vermicompost. Significant difference between the vermibins for total Mn was recorded ($p<0.05$).

Initial and final values of Cd in various feed mixtures were in range of 2.30 ± 0.02 to 2.34 ± 0.03 and slightly increased invariably in range of 3.82 ± 0.01to 3.94 ± 0.64 .No statistical significant difference was observed in three vermibins. ($p > 0.05$). V_{CAU} was significantly different from other treatments whereas, V_{CD} has no significant difference with V_{CAB} for Cd concentration. Enhancement in heavy metal concentration depends on the bioconversion of organic wastes with metal production in free form in the vermicompost [176]. Despite the incremental change in the heavy metals at the completion of the vermicomposting process, final concentrations were under the threshold limits and can be applied as potting media or in agricultural crops as an organic fertilizer [177].

5.3.4 Vermicompost Maturity Indices

a) Ash Content

Enhancement in ash level indicates good degradation and mineralization of feed materials and is also an indicative of vermicompost maturity [90]. Ash content was found to be incremented with time in all the three vermibins in comparison to the initial feed mixtures at the end of experiment. Ash content was noted to be highest in V_{CD} (558 g/kg) preceded by V_{CAU} (498 g/kg) and V_{CAB} (482 g/kg) (Table 5.2). Percent increment in vermibins was in order of 187.8% (V_{CAU}) >164.8% (V_{CAB}) > 144.7% (V_{CD}). Incremental change in ash content can be due to degradation of organic materials present in the feed material. Cauliflower residual biomass amended with cow dung was found to have more ash content as compared to cabbage leaf residue at the end of experimental trial indicating good decomposition of feed material and stability of vermicompost. Earthworm's palatability for the feed materials spiked with cow dung and addition of more nutrients resulted in efficient decomposition and increased ash content. The three vermibins were significantly different from one another ($p<0.05$).

b) C/N and C/P Ratios

C/N ratio is considered as prime indicator of stability and maturity of biomass. Most preferable range of C/N for mature compost is less than 15 [90] and value below 20 highlights the stability of vermicompost [117]. C/N levels were found to be dropped from their initial values in all the three vermibins with time (Figure 5.1H). Percent decline varied from 49.5% - 76.4% with highest decrement in V_{CAU} and lowest decrease in V_{CAB}. C/N drop in cauliflower residual biomass was more than cabbage leaf waste. Initially, C/N ratio was 53.4 in V_{CD}, 40.2 in V_{CAB} and 45.0 in V_{CAU}. C/N values get reduced to 12.6, 20.3 and 15.60 in V_{CD}, V_{CAB} and V_{CAU}, respectively at the offset of process (Table 5.2). C/N reduction can be corresponded to enhancement of nitrogen content due to production of mucus and excretory products by earthworms and degradation of organic matter [178]. The significance of C/N ratio is due to the fact that a reduction in the ratio indicates an increased humification of feed materials [170]. Alidadi et al. [120] has also suggested that carbon is lost during the microbial respiration and might result in low C/N ratio. Loss of carbon was attributed to joint activity of earthworms-microbes in decomposition and digestion of carbohydrates and polysaccharides in waste materials. Ananthavalli et al.[91] reported a decrease in C/N values by 38.64% in final vermicompost prepared from seaweeds spiked with cow dung (1/1). Vermicomposts of cow dung and cauliflower waste had an appropriate C/N ratio well near to the prescribed range for mature compost, i.e., 15.6. Plants can absorb nitrogen well at this ratio [179]. Low C/N ratio values was also marked in vermicompost prepared from fruit and vegetable waste using excess activated sludge [67]. Although the vermicompost obtained from vermibin V_{CAB} has slightly higher C/N ratio (20.3) than the other two vermibins; experimental findings suggest that cabbage and cauliflower residues can be employed for vermicomposting when blended with adequate proportion of cow dung as an additive material. Initial nitrogen and organic carbon can affect the change in carbon to nitrogen ratio of end products. C/N values varied statistically in the three vermibins ($p<0.05$).

A decreasing trend was also observed for C/P values in all the vermibins (Figure

5.1I). Initially, C/P values were of order of 62.9 - 86.3 in different feed units and as the process proceeded towards completion, levels of C/P varied between 21.36 - 31.98 (Table 5.2). Gupta and Garg [179] earlier recorded decrease in C/P ratio in vegetable waste in range of 21.8 to 37.3 in final vermicomposts. Sharma and Garg [83] also recorded carbon to phosphorus levels varying from 20.1 - 40.1 in food and vegetable processing wastes. Cauliflower residual biomass had shown C/P value of 23.1 as compared to cabbage leaf residue that had carbon to phosphorus ratio of 31.98. A significant difference ($p < 0.05$) for C/P level was found in vermicomposts which reflect the good rate of feed material degradation by earthworms.

c) Germination Index

Germination index (GI) is an important parameter to determine the vermicompost maturation. GI values $>80\%$ are indicative of non-toxic nature of manure for plant applications [98]. In present study, Germination Index was calculated from relative seed germination and relative root germination in different treatments for the plant *Vigna radiata* . Relative Seed Germination (RSG) for V_{CD}, V_{CAB} and V_{CAU} were 94.4 %, 72.2% and 88.8% respectively and Relative Root Germination (RRG) were 74.9% for V_{CD}, 73.6% for V_{CAB} and 64.3% for V_{CAU} .GI of initial feed mixtures was 28 - 56% which shows the unsuitable nature of feed wastes in this form for plant application. GI for different vermicomposts produced was in the range of 98 - 138% and followed the trend: 138% (V_{CAU}) $>$ 126% (V_{CD}) $>$ 98% (V_{CAB}) reflecting the maturity upto different extents (Figure 5.2). The results are in line with the requisite germination index $> 80\%$ as suggested by Zucconi et al. [98]. Significant variation was observed among the three treatments for germination index ($p < 0.05$).

The vermicompost produced from cauliflower residual biomass showed high GI as compared to cabbage leaf waste and cow dung vermicompost establishing its use as plant applicator. Various researches have recorded GI for a variety of seeds with different vermicomposts viz. 72 - 162% for *Brassica rapa* L.[167], 51 - 128 % for *Raphanus sativus*, 98 - 162% for *Lycopesicon esculentum*, 48 - 81% for *Daucus carota* [54], 279 - 360% for maize, 86.9 - 98.25% [123] 124.3 - 384.3% for *Triticum aestivum* [79], 89.5 - 115.32% [84]; 95 - 150% [84] for *Brassica campestris*. Different GI values indicate different maturity level of vermicomposts due to varying degree of mineralization and organic acid degradation during vermicomposting. Several metabolic products formed by organic matter decomposition transform into more accessible forms making them well suited for plant growth [167].

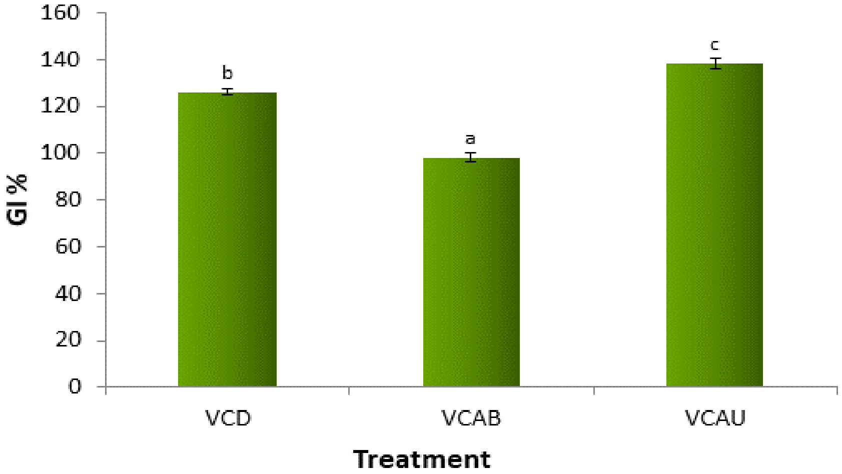


Figure 5.2: % Germination Index (GI) in different treatments

d) FT-IR Analysis

FT-IR spectroscopy is an instrumental technique that depicts the presence or absence of various functional groups in the degrading feed materials during vermicomposting. It is an important tool used to determine the maturity and stability of compost /vermicompost produced [180]. Different band spectra analysis helps in predicting the shift in functional groups and reflects the chemical composition of feed substrate and vermicomposts formed. FT-IR analysis of cow dung, cabbage leaf waste and cauliflower waste along with their vermicomposts are presented in Figure 5.3 - Figure 5.8.

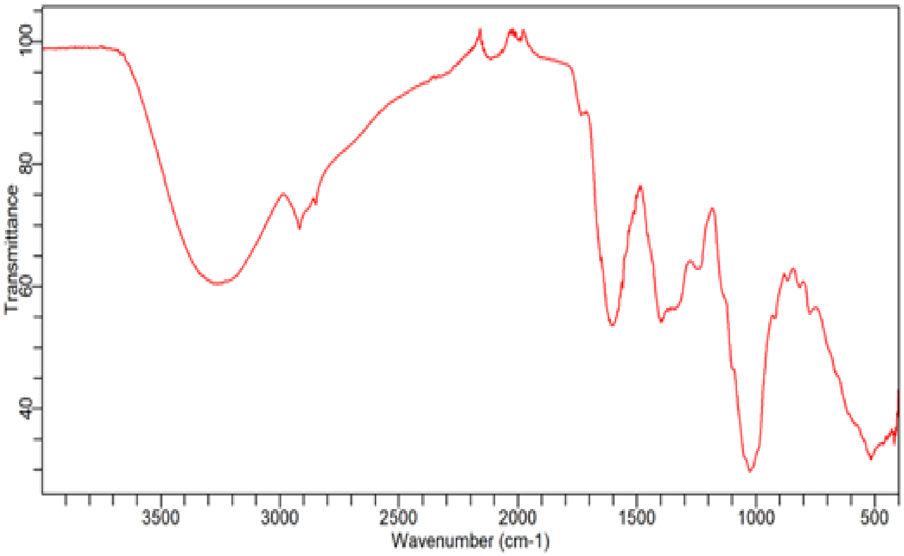


Figure 5.3: FT-IR spectra of initial feed material CD

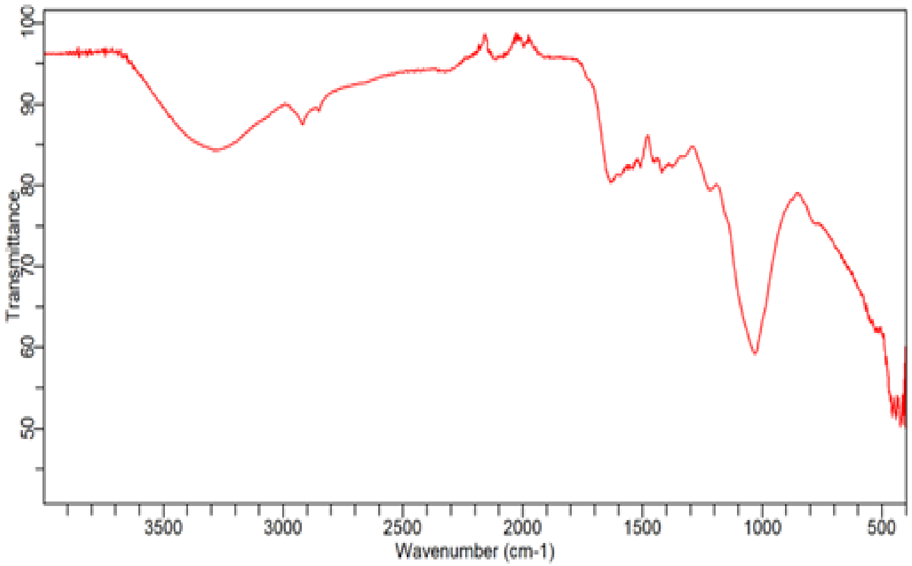


Figure 5.4: FT-IR spectra of CD vermicompost

Band spectra in CD reveal various peaks at 3000 - 3500 cm^{-1} (-OH bond stretch of phenols, alcohols), 2800 and 2900 cm^{-1} (-CH stretching of fatty acids, lipids) [181], small peak between 2000 and 2200 cm^{-1} (CN stretching and absorption band of alkynes), 1800 - 1900 cm^{-1}, 1600 - 1700 cm^{-1}(-COOH stretch of carboxylic acids), strong peak at 1500 cm^{-1} (due to aromatic rings), peaks at 1100 - 1400 (CO stretch of polysaccharides and CN groups, C−H stretch of polysaccharides [182](Figure 5.3). Analysis of CD vermicompost FT-IR spectra confirms the decomposition as there was reduction in band heights at 3000 - 3500 cm^{-1}, 2800 - 2900 cm^{-1}, 1600 - 1700 cm^{-1}, 1500cm^{-1} and 1000 - 1400 cm^{-1} which reflects the degradation of alcohols, phenols, fatty acids aromatic rings, carboxylic acids, polysaccharides and reduction in CN, CH_2 groups (Figure 5.4).

Spectra of cabbage waste and vermicompost produced has shown the reduced band heights in 3000-3500 cm^{-1}, reduced peak intensities in 2800 - 2900 cm^{-1}, 2000 - 2200 cm^{-1}, 1500 cm^{-1}, 1200 - 1400 cm^{-1} confirming the decomposition of complex compounds as alcohols, fatty acids, polysaccharides, aliphatic compounds in final vermicompost when compared to initial feed material (Figure 5.5 - 5.6). Reduced peaks in 800 - 900 cm^{-1} (cellulose stretching) explains the degradation of cellulosic material.

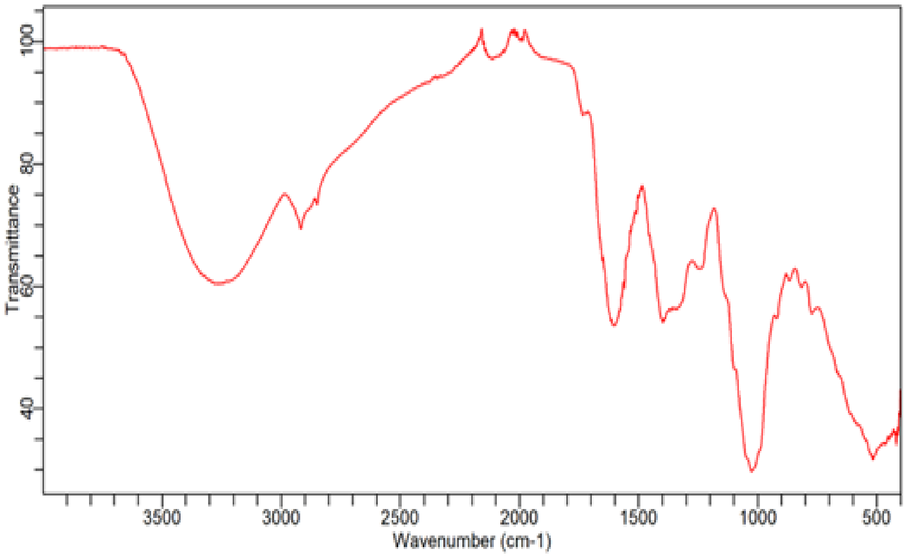


Figure 5.5: FT-IR spectra of Cabbage leaf feed material

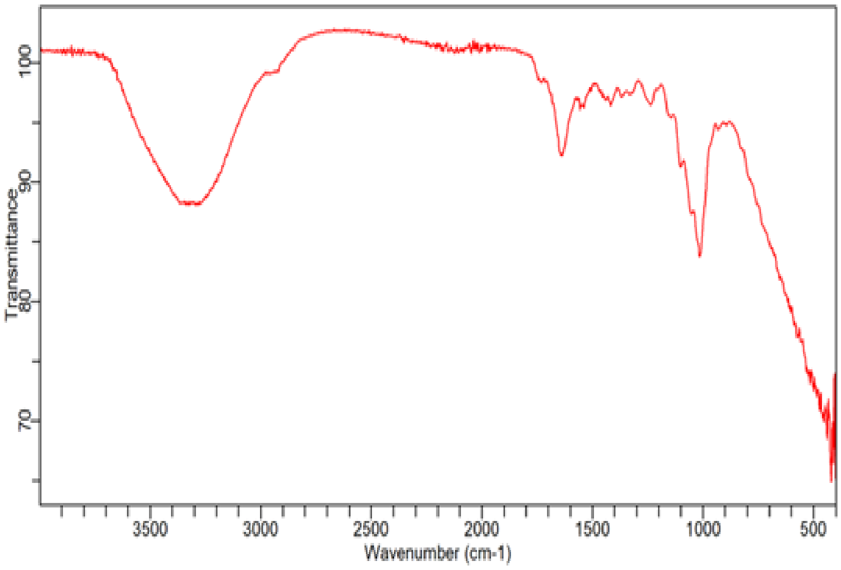


Figure 5.6: FT-IR spectra of Cabbage leaf vermicompost

During the degradation of cauliflower blended with cow dung by earthworms, weak peak intensities and decreased band height had revealed the decrement in aliphatic /aromatic compounds and decomposition of organic matter present in cauliflower waste more efficiently as compared to cabbage (Figure 5.7 - 5.8). Presence of peaks around 1600 cm^{-1}, 1400 - 1450 cm^{-1} and 750 - 800 cm^{-1} confirms the carbonyl and nitryl stretch indicating escalated amounts of nitrogenous substances in cauliflower waste vermicompost [28]. Hence cauliflower waste vermicompost was found to be stabilized and mature end product that can be effectively used as fertilizer for agronomic purposes.

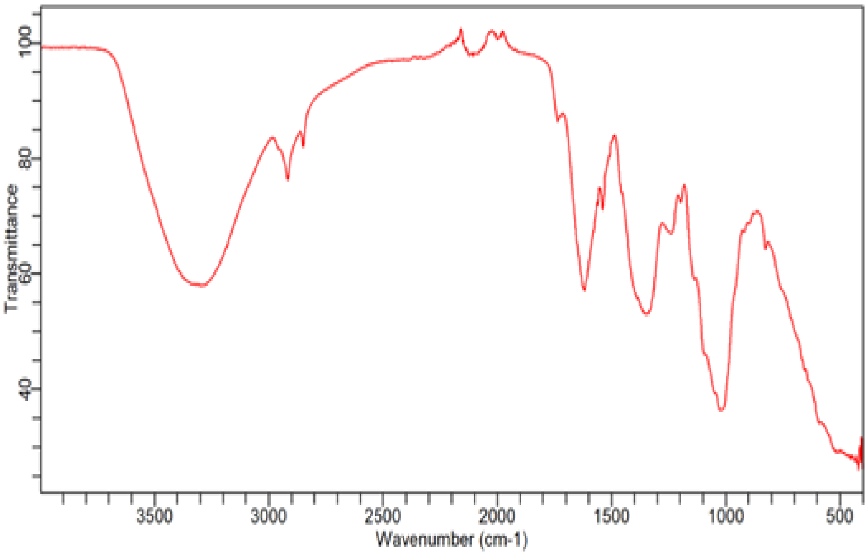


Figure 5.7: FT-IR spectra of Cauliflower waste feed material

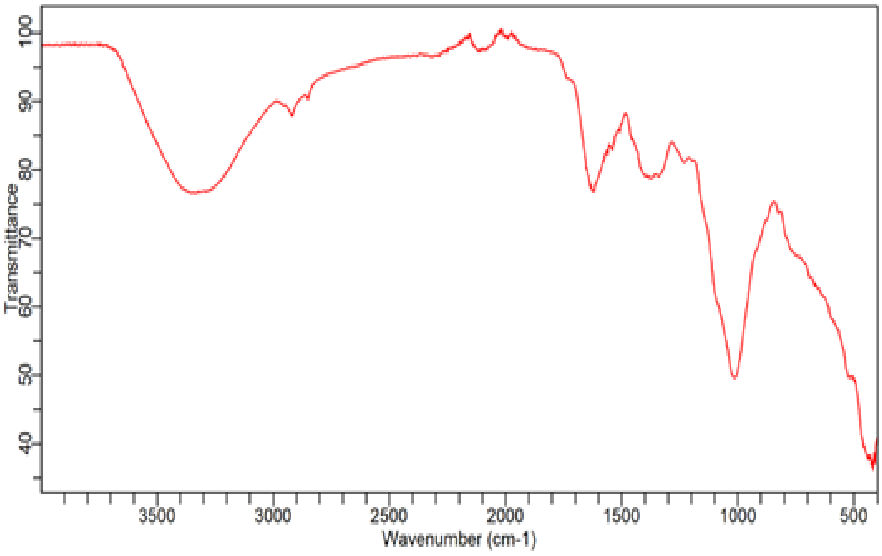


Figure 5.8: FT-IR spectra of Cauliflower waste vermicompost

5.3.5 Change in Earthworm Biomass and Fecundity

Initially, earthworm biomass varied from 557 ± 1.2 mg to 572 ± 1.93 mg and reached to maximum of 1381 mg (V_{CAU}) in 60 days preceded by 1290 mg (V_{CD}) in 45 days and 1214 mg (V_{CAB}) in 75 days after inoculation into the feed mixtures (Table 5.9). In initial days, earthworms gained weight slowly in three vermibins as they adapt to the respective feed mixtures. Increase was fast in V_{CD} as cow dung provided conducive environment to the earthworms. Trend in growth was better in cauliflower waste as compared to cabbage leaf waste and after reaching to maximum, earthworm biomass started descending as most of the organic matter appeared to be assimilated by earthworms. Initial and maximum biomass attained in three vermibins were significantly different from one another ($p < 0.05$). Incremental change in biomass was recorded in order: V_{CAU}(809 mg) > V_{CD}(733mg) > V_{CAB} (646 mg). Compared to initial worm biomass, the biomass gain increased over 131.6%, 113.7% and 141.4 % in V_{CD}, V_{CAB} and V_{CAU}respectively. Maximum biomass was achieved on 45^{th}, 60^{th} and 75^{th} day in vermibins V_{CD}, V_{CAB} and V_{CAU}, respectively and the enhanced value followed by a decrease in consequent days of vermicomposting (Figure 5.9). Biomass gain was also reported to be high in the feed substrate than cow dung by earlier researchers [63]. Spiking of cow dung to cabbage and cauliflower made them palatable to earthworms and a significant increase in biomass was noted in the vermibins but up to different extents.

Our findings also reflected progressive enhancement in earthworm biomass, maximum in V$_{CAU}$ which could be attributed to high organic matter in cauliflower as compared to cabbage leaf residue that provided suitable feed culture to *Eisenia fetida*. It has been earlier established that high amount of organic matter creates a favorable environment for earthworms [183]. It can be due to production of acetic acid by microorganisms that might slightly affect the growth but overall earthworms in conjugation with microbes help in good decomposition in both cauliflower and cabbage leaf waste without foul odors. Difference between the vermibins were significantly varied for worm biomass increase ($p < 0.05$). Increase in biomass can be explained by survival, growth rate and fecundity of earthworms [83] which in turn is dependent upon the nature of feed substrate used.

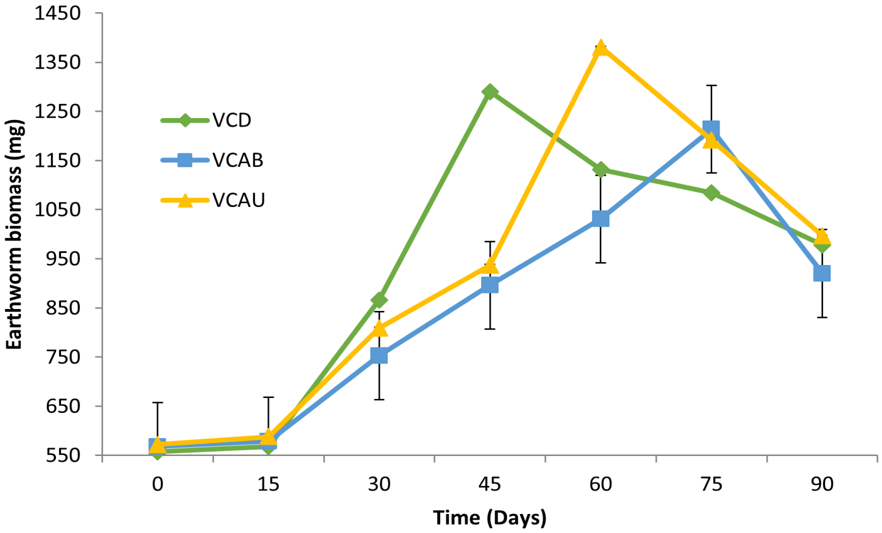


Figure 5.9: Change in earthworm biomass (mg) with time in different vermibins

Maximum growth rate per worm per day was recorded in V_{CD} (100% CD) and it was in order $V_{CD} > V_{CAU} > V_{CAB}$ (Table 5.4). Biomass gained per unit feed waste ranged from 12.92 – 16.18 mg/g in various vermibins with maximum biomass gain in V_{CAU}, followed by V_{CD} and V_{CAB}. Growth rate and biomass gain in vermibins statistically varied from one another ($p < 0.05$). Rate of cocoon formation were recorded in the study and followed the order: V_{CAU} (108 ± 1.8) > V_{CD} (102 ± 1.4) > V_{CAB} (84 ± 2.28). Mean statistical difference between V_{CAU} and other two vermibins (V_{CAB} and V_{CD}) were significant whereas V_{CAB} and V_{CD} were statistically indifferent from each other. Fecundity rate (cocoon/worm) was more in cauliflower residue (2.7 ± 0.2) than cow dung (2.5 ± 0.20) and cabbage leaf residue (2.1 ± 0.15) (Table 5.4).

V_{CAU} was significantly different from both V_{CD} and V_{CAB} for fecundity rate. Fecundity rate for cow dung and cabbage leaf waste were insignificantly different from each other. Findings suggest that feed material with cow dung as amendment show good fecundity rate. Henceforth, earthworm growth trend has suggested that cauliflower and cabbage leaf residues can be resourcefully used as feed materials for vermicompost production when mixed in appropriate proportions rather cauliflower residue comes out to be better than cabbage leaf residue when compared.

Table 5.4: Growth and fecundity of *Eisenia fetida* in different vermibins (Mean ± SEM of three replicates)

Vermibin	**Earthworm mass (initial) (mg)**	**Earthworm mass (attained) (mg)**	**Biomass gain (g)**	**Biomass gain (%)**	**Maximum growth achieved (on day)**	**Growth rate/worm/day (mg/worm/day)**	**Biomass gained per unit feed waste (mg/g)**	**Total no of cocoons**	**Fecundity (cocoon /worm)**
V_{CD}	557±1.2a	1290±2.06b	733±1.73b	131.6±2.35b	45	16.28±0.02c	14.66±0.02b	102±1.4b	2.5±0.20b
V_{CAB}	568±1.8b	1214±2.18a	646±1.58a	113.7±3.67a	75	8.61±0.0a	12.92±0.05a	84±2.28a	2.1±0.15a
V_{CAU}	572±1.93c	1381±1.21c	809±2.11c	141.4±2.56c	60	13.48±0.01b	16.18±0.11c	108±1.84b	2.7±0.20b

Different alphabets in each parameter shows statistically significant difference (ANOVA, Tukey's HSD test $p \leq 0.05$)

5.4 CONCLUSIONS

The results of study acclaimed that 40% cauliflower and cabbage leaf residues mixed with cow dung could be efficiently used in vermicomposting using *Eisenia fetida*. Vermicomposts produced had high NPK values with less TOC, C/N and C/P ratio as compared to initial values. The results of the study conveyed higher organic matter decomposition in cauliflower + cow dung mixture (V_{CAU}) rather than the cabbage leaf + cow dung mixture (V_{CAB}). Biomass gain results showed highest percent increment in cauliflower residue followed by cow dung and cabbage leaf residual mass. Good germination index also suggests the utilization of cruciferous vegetable residue as potting media. Cruciferous vegetable residual biomass- cabbage leaves and cauliflower waste can be managed in a more eco-efficient manner through the process of vermicomposting. Cabbage and cauliflower waste vermicomposting can provide an efficient eco-tool to mitigate the harmful effects of inefficient disposal of these residual biomass and cow dung available in vast amounts in a country like India and pave the way towards sustainable management of cruciferous vegetable waste.

Chapter 6

VERMICOMPOSTING OF BAKERY INDUSTRY SLUDGE AMENDED WITH DIFFERENT ORGANIC WASTES

6.1 INTRODUCTION

Bakery industry, one of the largest segments of food processing industries worldwide, produces waste of varied proportions and raw sewage of high strength in absence of suitable wastewater treatment [184]. According to Food and Agriculture organization, almost 1.6 billion tons of wastage of food is estimated every year in the whole food supply system including bakery, fresh fruits & vegetables, meat and dairy foods [185]. Approximately 1.2 million tons of bakery waste are generated on annual basis contributing to food waste globally [186]. Improper and poor management of this bakery waste create pressure on economy and population health as well as affect our environment and sustainable development. In addition to this, huge amount of bakery wastewater is generated from cleanup operations in the production of biscuits, cakes, pie, cookies, bread, bun, doughnuts, roll baking, etc. This high strength wastewater contains high levels of organic compounds & suspended solids, which in turn, produces large amount of raw sewage and/or sludges and must be treated before its discharge in municipal drains. There is always a risk of environmental effects due to improper disposal of bakery sludge in the form of soil pollution, groundwater pollution, offensive odors and leachate formation [137]. In addition, biodegradation of bakery sludge leads to methane and carbon dioxide production, thus, contributing to greenhouse gas emissions. Therefore, efficient and sustainable methods to manage bakery industrial sludge are required that are economically feasible and acceptable to community as well. Generally, bakery sludge is non-toxic, biodegradable and has considerable amount of nutrients, organic matter, biological oxygen demand, organic carbon, sugary and protein rich substances that can be used for recycling and recovery purposes. Similarly, fruit and vegetable waste, another organic waste from food supply system, are generated in huge quantity during the entire process of production-processing-consumption from varied sources, viz., households, markets, processing industries, restaurants, hotels, etc. Generally, it is characterized by high water content and biodegradable organic compounds, if improperly disposed off, may lead to negative environmental impacts.

In yester years, the biological processes, viz., composting and vermicomposting are gaining researcher's attention to treat non-toxic organic waste to convert/recycle them into energy and organic fertilizers in a decentralized manner. Earlier research studies have shown that vermicomposting technology can be efficiently utilized for biotransformation of organic wastes into value added products through combined action of earthworms and micro-organisms as compared to composting [187]. It is a low cost and environment-friendly technology in which earthworms-microbes action transforms biodegradable organic materials into a product, vermicompost, which is rich in plant nutrients, stable and aesthetically sound. The latter is a humus like material with excellent nutrient availability, porous structure, good aeration and enhanced moisture holding capacity favourable for plant growth [188],[115]. Many researchers have investigated the potential of vermicomposting process in treating various industrial sludges, viz., textile industry sludge [189]; distillery sludge [190]; dairy industry sludge [94], paper industry sludge [108]; sugar industry waste [191], etc. and converted into vermicompost. Bioconversion of bakery sludge into valuable resource can be achieved by process of vermicomposting and make its use in agricultural applications. Microbes in sludge contribute to degradation and conversion of organic matter jointly with earthworms [70]. It has been investigated by the researchers that to improve the efficacy of industrial sludge in vermicomposting, addition of organic amendments (as animal manure, green waste, household waste, crop residue, etc.) is must for reducing the undesirable effects of sludge and to enhance nutrient quality [109],[140]. Very less literature is available for combined treatment of industrial sludge and fruit-vegetable waste, therefore in present study, influence of fruit-vegetable waste biomass on bakery sludge vermicomposting has been demonstrated. Both bakery sludge and fruit-vegetable waste are locally generated wastes and can be managed simultaneously via vermicomposting technology. Bakery sludge contains residual mass and microorganisms that actively participate in vermicomposting. Fruit and vegetable waste has more organic matter and nutrient content as compared to bakery sludge which is non-toxic to earthworms. Thus, the addition of fruit-vegetable waste along with cow dung in appropriate ratio and impacts on the vermi-stabilization of bakery sludge have been investigated in the study. Changes in various physico-chemical, biological and maturity parameters were assessed along with micro- and macro-nutrients evaluation.

6.2 METHODS AND MATERIALS

6.2.1 Bakery Sludge, Fruit and Vegetable Waste, Cow Dung and *Eisenia fetida*

Bakery sludge (BS) was taken from a the waste water treatment facility of a local bakery industry, Faridabad city, India. Fruit-Vegetable Waste (FV) was obtained from a local vegetable market in Faridabad city, fragmented into small pieces and cow dung (CD) was collected from a nearby cattle farm. The waste mixtures were allowed to pre-decompose for fifteen days by drying in sun in order to expel excessive moisture and odor. Pre-decomposition of waste material increases their digestibility for earthworms and passes over the thermophilic phase that liberates heat. Cow dung is predominantly employed as boosting material in vermi-processing owing to greater number of microorganisms and good nutrient content. *Eisenia fetida* earthworm was used in the experimentation due to its extensive tolerance for various types of feed mixtures. It was collected from The Energy Research Institute, Gurugram (India) and raised in cow dung. Earthworm culture was established in the laboratory and a required number of earthworms were added in different waste combinations as and when required. Initial physico-chemical parameters of waste materials viz. BS, FV and CD are presented in Table 6.1.

Table 6.1: Initial Physico-chemical characteristics of Cow Dung (CD), Fruit and. Vegetable waste (FV) and Bakery Sludge (BS) (Mean ± SEM of three replicates)

Parameters	**Cow Dung (CD)**	**Fruit and Vegetable waste (FV)**	**Bakery Sludge (BS)**
pH	8.4±0.5	7.48 ±0.3	6.6±0.8
EC (dS/m)	1.6±0.1	2.4±0.01	1.9±0.02
Ash content(g/kg)	228±2.1	113±1.8	346±0.6
TOC (g/kg)	448±2.5	514 ±3.3	379±1.5
OM (g/kg)	772±3.15	887±4.01	654±2.02
TKN (g/kg)	8.3±0.5	12.1±0.3	10.1±0.2
TAP (g/kg)	7.0±0.12	4.62±0.05	4.38±0.02
TK (g/kg)	7.7±0.20	5.42±0.32	2.82±0.02
C:N ratio	53.9±2.4	42.4±1.88	37.5±0.84
C:P ratio	64.0±1.5	109.8±2.15	86.5±1.65
Moisture content (%)	84±1.5	89±1.8	92±1.9

6.2.2 Experiments and Analytical Methods

The batch vermicomposting units (VU) were established with two kg (dry weight basis) of different waste combinations each in the following composition:
VU1 (CD_{100}) – 100% CD;
VU2 ($CD_{75}BS_{25}$) –75% CD + 25% BS;
VU3 ($CD_{50}BS_{25}FV_{25}$)-50% CD + 25% BS+25% FV;
VU4 ($CD_{25}BS_{25}FV_{50}$)– 25% CD + 25% BS + 50% FV and
VU5 ($CD_{25}BS_{50}FV_{25}$) –25% CD+ 50% BS + 25% FV

The waste combinations were set in rectangular plastic containers (5 l capacity) in triplicate for each unit for time duration of 90 days and sprinkled with water to maintain upto 60-70% moisture throughout the experiment. Turning of waste mixtures and sprinkling of water was done on a frequent basis to keep the mixture well aerated and moist. In a pre-experiment conducted with higher proportions of Bakery sludge (>50%) in waste mixtures, the earthworms couldn't survive in the condition and died in a short period.

To start the vermicomposting experiment, 50 numbers of *Eisenia fetida* (initially weighing 192 - 236 mg/worm) from stock culture were introduced in all the vermi-units. The vermi-units were covered by moistened gunny cover to retain desirable moisture levels and to provide a dark, habitable ambience to the earthworms. Cover also reduces the chance of attracting flies, mosquitoes and moths. Homogeneous samples (about 20g) were drawn after every 15 days interval up to 90 days, dried, grinded and stored in airtight plastic pouches for further parametric evaluation. The changes in physico-chemical parameters were analyzed on dry weight basis whereas earthworm weight, fecundity rate and other biological analysis was performed on fresh weight basis during the experimental period. The samples extracted from VU1- VU5 were evaluated for physico-chemical parameters using standard methodology (Chapter 3). After completion of the experiment, dynamics of earthworm population, biomass, cocoons and growth rate were determined as mentioned in chapter 3. Earthworms + cocoons were sorted manually, counted and placed back in vermi-units.

6.2.3 Seed Germination Assay and Respiration Rate Estimation

Seed germination test serves as an important index to establish vermicompost maturity and phytotoxicity. In present work, phytotoxicity experiments were performed on *Cicer arietinum* (chick pea) seeds to assess the quality of vermicompost prepared from BS, FV and CD waste mixtures. Germination index (GI) assess the utility of vermicompost for plant growth. Vermicompost extract from each vermi-unit was prepared in sterile distilled water (1w:10v) at 150 rpm for 1 hr. Fifteen chick pea seeds were placed in filter paper lined petri dishes and incubated for 5 days at 25 °C in dark. Triplicates were established. De-ionized water was taken as control in experiment. Germinated seed count and root lengths were recorded for each triplicate and control at day 5. Germination index was calculated using Relative Shoot Germination (RSG) and Relative Root Germination (RRG) as GI =RSG/RRG for 0, 15, 30, 45,60, 75 and 90 days sample according to methodology given by previous researchers [167].

The measurement of soil respiration rate reflects the microbial decomposition and vermicompost maturation [84]. Ten gm vermicompost sample was added to a closed gas jar containing 10 ml NaOH and incubated for 48 hrs. Back titration of NaOH was performed with $BaCl_2.2H_2O$ with phenolphthalein as an indicator to determine the amount of CO_2 dissolved ($mgCO_2kg^{-1}VC48hr^{-1}$).

6.2.4 Statistical Interpretation of Data

Statistical investigation was carried out using IBM-SPSS Statistics 21 tool to find the comparison of vermicomposts and waste mixtures as per the methods and tools given in Chapter 3. F- value was calculated as variation between the sample means within the samples. It is calculated as mean squares treatment/ mean squares error.

6.3 RESULTS AND DISCUSSION

6.3.1 Changes in Physico-chemical Parameters

a) Effect on pH, EC, TOC and Ash Content

pH is an important variable affecting microbial activities and mineralization process during vermicomposting and values between 7.0 and 8.0 are considered ideal [84]. At the onset of the experiment, pH ranged from 7.4 - 8.3 in initial waste mixtures. Earthworm mediated organic matter decomposition for 90 days reduced the pH levels from 6.9 - 7.6 in all vermi-units, i.e., near neutral range (Table 6.2). pH deduction was estimated in the order: VU1 (CD_{100})> VU3 ($CD_{50}BS_{25}FV_{25}$) $>$ VU4 ($CD_{25}BS_{25}FV_{50}$) $>$ VU2 ($CD_{75}BS_{25}$) $>$ VU5 ($CD_{25}BS_{50}FV_{25}$) (Figure 6.1). However, no significant difference was seen in different vermi-units with respect to change in pH levels (F= 26.55, p=0.09). Earlier researchers have also reported decline in pH levels either due to phosphorus/ nitrogen mineralization or volatilization of ammonia in vermicomposting system [141]. Formation of humic and fulvic acids in vermicomposting process assists in reduction of pH to slightly acidic or neutral [189].

EC is an indicator of presence of salts and marks the suitability of vermicompost for plant production. As shown in Table 6.2, EC values of all vermi-units was higher than initial waste mixtures at the end of experiment. Initially, EC ranged from 1.62 - 2.11 dS/m in vermi-units (VU1-VU5) and the values enhanced ranging from 1.99 - 2.69 dS/m after 90 days of vermicomposting. Highest increment was registered in VU3 ($CD_{50}BS_{25}FV_{25}$) - 40.1% preceded by VU1 (CD_{100}) - 22.8%, VU4 ($CD_{25}BS_{25}FV_{50}$) - 22.7%, VU2 ($CD_{75}BS_{25}$) - 21.7% and VU5 ($CD_{25}BS_{50}FV_{25}$) - 19.43% (Figure 6.1). Different vermi-units were significantly different from each other for increment in EC values (F=109.39, p=0.00). The vermicompost in VU3 (50% CD + 25% BS + 25% FV) showed significant higher percentage of increase among all other vermi-units including control VU1 (100% CD).

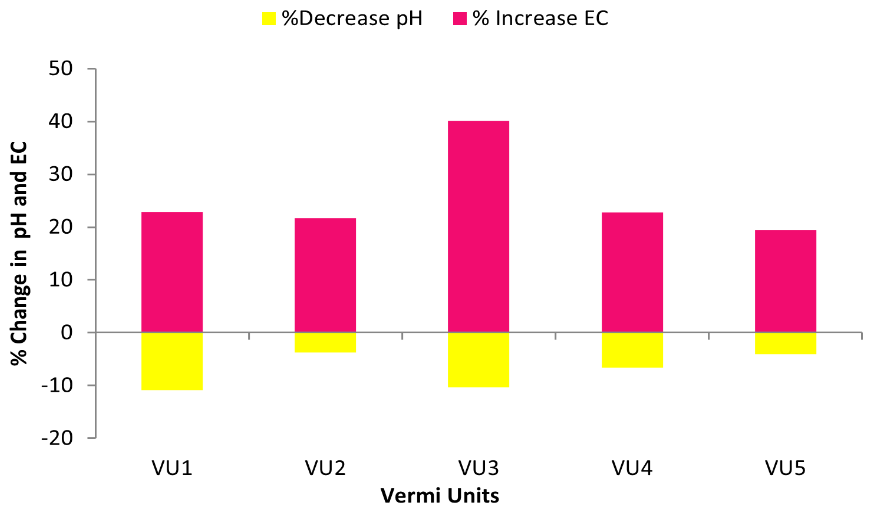


Figure 6.1: Percentage pH and EC change in various vermicomposting units

These observations indicated that addition of fruit-vegetable waste in an appropriate amount alongwith cow dung as bulking agent, i.e., 25% addition to BS + CD waste mixtures, promoted EC values in vermicomposts, but more addition of FVW didn't support significant EC enhancement. In the present study, differential increase in EC values in vermi-units was observed as a result of different rate of organic matter degradation due to addition of bulking agents in different proportions. Conversion of organically bound nutrient elements to accessible forms, production of soluble salts, ammonium and other inorganic ions enhanced the values of EC in final vermicomposts [109]. However, EC value vermicomposts in all vermi-units is within the recommended limits as organic fertilizers (<4.0 dS/m) for plant growth [192].

TOC is a pivotal parameter in establishing the rate of mineralization and earthworm activity in vermicomposting system. In present study, all the vermi-units showed declining trends of TOC in comparison to raw waste mixtures after 90 days of vermicomposting. TOC content ranged from 448 - 482 g/kg in initial blends to 312 - 378 g/kg in end products (Table 6.2). TOC reduction followed the order: 33.1% (VU3) ($CD_{50}BS_{25}FV_{25}$) $>$ 29.6% (VU 4) ($CD_{25}BS_{25}FV_{50}$) $>$ 25% (VU1) (CD_{100}) >23.2% (VU2) ($CD_{75}BS_{25}$) $>$ 21.5% (VU 5) ($CD_{25}BS_{50}FV_{25}$) towards the end of experiment. The vermi-units for TOC decline were statistically different from each other (F= 214.46, p = 0.001). Moreover, amount of sludge affected the percent carbon loss, as depicted from the observation that higher the amount of sludge in waste mixtures, less decrease in carbon content was registered in those experiments. It was also observed that the addition of FV waste as bulking agent in bakery sludge + cow dung increased the efficiency of earthworms and microbes in terms of carbon loss as compared to control and bakery sludge + cow dung alone as obvious from enhanced TOC values in VU3 ($CD_{50}BS_{25}FV_{25}$) and VU 4 ($CD_{25}BS_{25}FV_{50}$) feed mixtures. Decline in TOC values are in line with the previous research reports by Sharma and Garg [93] (39.9 - 48.2%); Yadav and Garg [65] (26.1 - 42.8%); and Gusain and Suthar [84] (24.3 - 38.2%). According to earlier research reports, the consumption of carbon pool by earthworms in conjugation with microbes as an energy source during metabolic activities, release of carbon dioxide due to respiration and other activities cumulatively reduce TOC content during the process of vermicomposting [115].

Ash content indicates efficient degradation and mineralization of organic waste material in feed mixtures, therefore, is usually taken as an index of vermicompost maturity. The earthworms churn the waste mixtures like a grinding machine and convert into fine slurry by adding mucus inside their guts. By this, they support endo/exogenous enzymatic as well as microbial activity by enhancing workable surface area and enhance carbon mineralization in vermicomposting system [193]. In the present experiment, there was an increment of 86.4 – 137.4 % in ash contents in the final vermicomposts in comparison to the starting materials (Table 6.2). The ash content levels were in the range of 169 ± 1.12 - 228 ± 2.5 g/kg at the onset which was boosted to levels of 399 ± 2.3 - 463 ± 1.8 g/kg. Maximum increment was noted in VU3 ($CD_{50}BS_{25}FV_{25}$) (137.4%), i.e., greater than control VU1 (CD_{100}) and VU2 ($CD_{75}BS_{25}$), which showed effective mineralization and decomposition of bakery sludge + cow dung blended with 25% fruit-vegetable waste that favored the organic matter utilization in a better manner by the duo of earthworms and microbes. Earlier studies too have reported higher ash contents at the end of process [108]. Significant statistical variation was observed in VU3 ($CD_{50}BS_{25}FV_{25}$) compared with other vermi-units with respect to enhanced ash content in vermicomposts produced from different waste combinations (F = 242.6, p = 0.001); however, difference between VU1 (CD_{100}) & VU4 ($CD_{25}BS_{25}FV_{50}$) and VU2 ($CD_{75}BS_{25}$) & VU 5 ($CD_{25}BS_{50}FV_{25}$) was not significantly different from one another (p = 0.99 and 0.90, respectively).

Table 6.2: Physico-chemical characteristics of initial waste mix and finished vermicompost produced in different vermicomposting units (Mean ± SEM, n=3)

Vermi Unit (VU)	**pH**	**EC (dS/m)**	**TOC (g/kg)**	**Ash Content (g/kg)**	**TKN (g/kg)**	**TAP (g/kg)**	**Tk (g/kg)**	**C/N**	**C/P**
Initial waste mix 0^{th}(day)									
VU1	8.3±0.05b	1.62±0.12a	448±1.5a	228±2.5e	8.2±0.06a	7.4±0.14a	7.9±0.21c	54.6±1.20d	60.5±1.82e
VU2	7.9±0.03ab	1.84±0.11b	455±2.5a	216±1.8d	9.5±0.12b	8.6±0.23b	7.6±0.15bc	47.8±0.18c	52.9±2.02d
VU3	7.7±0.02ab	1.92±0.10bc	467±1.5b	195±2.77c	11.1±0.18c	8.4±0.03b	7.8±0.22bc	42.0±2.16b	55.5±1.5c
VU4	7.6±0.04ab	1.98±0.18c	475±0.88b	181±3.32b	12.9±0.08e	8.3±0.02b	7.2±0.2ab	36.8±1.31a	57.2±1.08b
VU5	7.4±0.03a	2.11±0.08d	482 ± 1.30c	169±1.12a	12.1±0.13d	8.1±0.12b	6.8±0.3a	39.8±1.42ab	59.5±1.2a
Finished Vermicompost 90^{th}(day)									
VU1	7.4±0.12a	1.99±0.14a	336±1.52b	421±2.08b	18.2±0.15a	15.2±0.52a	16.8±0.20c	17.8±0.52b	24.5±1.32b
VU2	7.6±0.15a	2.24±0.15b	349±3.88c	399±2.32a	18.3±0.06a	15.1±0.12a	14.2±0.27b	18.4±1.75b	28.9±1.42d
VU3	6.9±0.07a	2.69±0.05c	312±2.02a	463±1.82c	24.8±0.22c	17.1±0.09b	19.9±0.10e	12.8±0.35a	18.2±0.79a
VU4	7.1±0.08a	2.43±0.25cd	334±1.58b	422±1.52b	26.4±0.05d	17.9±0.30c	17.8±0.06d	13.2±0.62a	25.6±0.04c
VU5	7.1±0.05a	2.52±0.15d	378±3.32d	401±1.80a	20.8±0.02b	14.9±0.18a	11.8.±0.70a	18.1±1.17b	30.8±1.45e

Various alphabets in each parameter represent significant variance (ANOVA, Tukey's HSD test $p \leq 0.05$)

b) Effect on TKN, TAP and TK Content

Nutrients are essential for plant growth and metabolism and their enhanced concentration in vermicomposts promotes plant growth [176]. The organic matter mineralization along with consumption of carbon content by earthworms-microbes enhanced nutrient concentrations (N, P, K) in waste mixtures during vermicomposting process. In the present study, TKN levels increased remarkably from the range 8.2 ± 0.06 - 12.9 ± 0.08 g/kg in initial waste mixtures to 18.2 ± 0.15 - 26.4 ± 0.05 g/kg in the vermicomposts (Table 6.2). There was 1.84 - 2.38 fold increment in all the combinations; order of TKN increase was: VU3 ($CD_{50}BS_{25}FV_{25}$) > VU4 ($CD_{25}BS_{25}FV_{50}$) > VU1 (CD_{100}) > VU5 ($CD_{25}BS_{50}FV_{25}$) >VU2 ($CD_{75}BS_{25}$). Significant variation was found for nitrogen content in vermi-units (F=515.1, p=0.003) except for VU1 (CD_{100}) and VU2 ($CD_{75}BS_{25}$) which were not statistically different (p = 0.992). Maximum TKN was found in VU3 ($CD_{50}BS_{25}FV_{25}$) which was significantly higher than other vermicomposts produced in the study. Lowest TKN value was observed in VU 2 ($CD_{75}BS_{25}$), i.e., without any FVW addition. The results showed that increase in the TKN values was dependent on the combination of waste mixtures. Earlier research studies have attributed the increase in TKN contents to efficient mineralization of organic matter, degradation of organic carbon, production of nitrogenous excretory materials and mucus along with decrement in overall mass and volume in waste materials and bulking agents at the end [173],[82]. The findings of the present research study indicated that addition of fruit and vegetable waste along with CD for vermicomposting of BS resulted in TKN-rich vermicomposts.

The vermicomposts of all vermi-units in the present study exhibited enhanced values of TAP as compared to control (100% CD). Initial TAP in various blends was in between 7.4 ± 0.14 – 8.6 ± 0.23 g/kg and escalated to 14.9 ± 0.18 - 17.94 ± 0.30 g/kg in end products (Table 6.2). There was 1.75 - 2.62 times increase in TAP levels with highest values in VU3 containing CD, BS and FV in 2:1:1 ratio and lowest increase in VU2 having CD and BS in ratio of 3:1. Phosphorus increment can be owed to organic matter decomposition by earthworms and microbes during vermicomposting whereby soluble phosphorus is released by the enzymes like phosphatase associated with microbial activities in earthworm's gut [194]. In the present study, incorporation of fruit and vegetable waste in BS + CD vermi-units had allowed better degradation of organic matter by earthworms as indicated in VU3 ($CD_{50}BS_{25}FV_{25}$) with highest value of TAP increase. In the present study, mean difference in VU1, VU2 and VU5 for increased TAP is statistically insignificant (F = 66.58, p = 0.068) but statistical difference was recorded for TAP in VU2 and VU3 (p = 0.003). Insignificant difference was found between vermi- units VU1 and VU2 (p = 0.98); VU1 and VU5 (p = 0.64); VU2 and VU5 (p = 0.88). In an earlier research study, Yadav and Garg [169] documented 29.5 - 75% increase in phosphorus content in final vermicomposts. Increase of 137 - 187% for TAP in end products was reported by Gusain and Suthar [84]. Phosphorus gets converted into plant available forms and contributes to enhanced plant growth and metabolism [195]. Further, the loss of organic matter and TOC enhanced the TKN and TAP levels during the process of vermicomposting [110],[196].

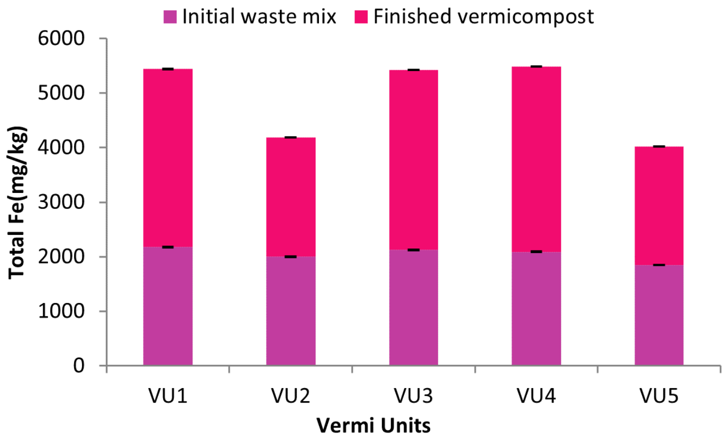
After vermicomposting for 90 days, TK concentration was remarkably greater than initial materials in all the five experimental units. There was 1.73 times - 2.53 times increment in potassium levels at the end of experiment. At the onset, TK content was at levels of 6.84 ± 0.3 - 7.9 ± 0.21 g/kg and increased to 11.84 ± 0.70 - 19.9 ± 0.10 g/kg after vermicomposting (Table 6.2). TK content among all the vermi-units showed significant variation (F = 276.0, p = 0.000). Trends of enhancement were: 2.53 fold in VU3 ($CD_{50}BS_{25}FV_{25}$), 2.47 fold in VU4 ($CD_{25}BS_{25}FV_{50}$), 2.12 fold in VU1 (CD_{100}), 1.86 and 1.73 fold in VU2 ($CD_{75}BS_{25}$) and VU5 ($CD_{25}BS_{50}FV_{25}$), respectively. About 1.1 - 2.6 fold increment in potassium levels in paper mill sludge vermicomposting was documented by Sharma and Garg[93]. Degradation of organic material through CO_2 respiration and TK release in vermicompost enhanced potassium levels in final vermicompost. In addition, the production of exogenic/endogenic enzymes associated with enteric microorganisms of earthworms enhance the mineralization rate which in turn increases the level of soluble potassium [90]. The findings of present study exhibited that addition of fruit and vegetable waste in combination with cow dung had improved potassium levels in finished end products. Higher F - value in ANOVA shows higher variation between sample means. Higher the F - value, lower is corresponding p - value.

c) Effect on Micronutrient Levels (Fe, Cu, Mn, Zn, Ni)

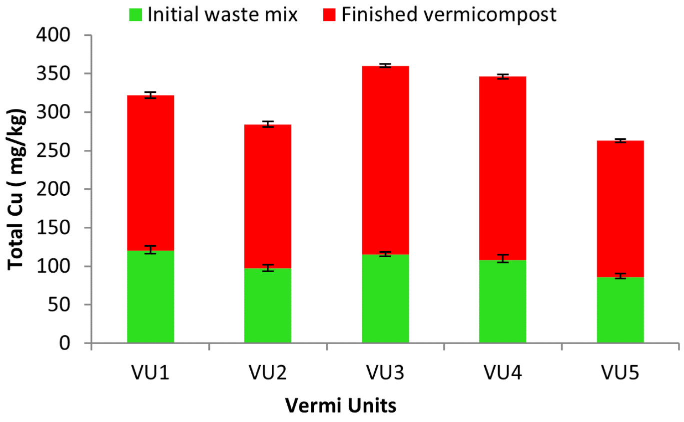
Micronutrients, viz., Fe, Cu, Mn, Zn, and Ni are important for plant development in trace amounts, whereas, high levels of these elements may be toxic to plants. Therefore, it necessitates to know their level of increase or decrease after vermicomposting of waste materials. The present study shows a substantial manifold change in micronutrient's concentration of all five vermi-units, but to variable extents (Figure 6.2). Fe is a vital micro-element that aids in biological processes of plants and crucial for chlorophyll biosynthesis. Enzymes produced in the worm's gut increase the concentration of

Fe in final vermicompost during organic matter degradation. Fe concentration significantly increased 1.09 - 1.62-folds in final vermicomposts and a significant statistical difference was observed among all vermi-units (F = 142.66, p = 0.000). On zeroth day, Fe content ranged from 1844 - 2177 mg/kg and increased to 2178 - 3298 mg/kg on the 90^{th} day experiment. Cu helps in synthesizing enzymes essential for photosynthetic processes. Cu instigated from 70 – 92 mg/kg to 154 - 210 mg/kg in vermireactors. Mean statistical difference among various vermicomposts produced in all units for increased copper content was significant (F = 189.0, p = 0.001). Cu containing oxidizing enzymes might have increased Cu concentrations at the end of vermicomposting process. Mn acts as a catalyst for enzymatic action and aids in the production of chlorophyll. In comparison to initial levels (86 - 120 mg/kg), Mn increased in the range of 177 - 245 mg/kg in all the blends irrespective of different combinations.

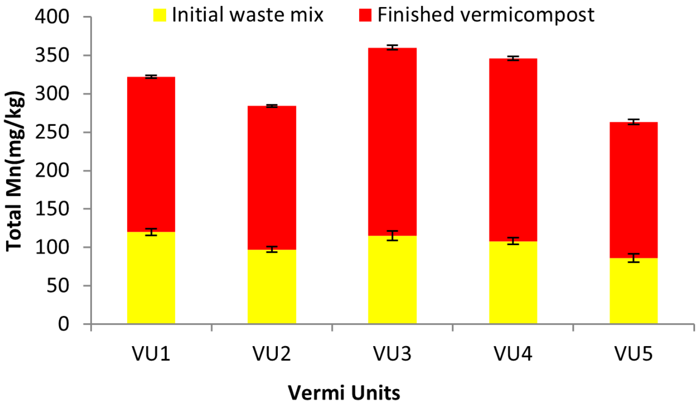
Statistical difference was found among the waste mixtures (F = 142.66, p = 0.003) except for VU3 ($CD_{50}BS_{25}FV_{25}$) & VU4 ($CD_{25}BS_{25}FV_{50}$) which were not significantly different (p = 0.09). Zn is required by plants for maintaining the hormone balance and is involved in cell division. Incremental change of 1.45 - 1.83 times was observed for Zn levels in all the waste blends and ascending trend was: 179 to 328 mg/kg (VU3) ($CD_{50}BS_{25}FV_{25}$) $>$ 188 to 332 mg/kg (VU1) (CD_{100})$>$ 181 to 299 mg/kg (VU4) ($CD_{25}BS_{25}FV_{50}$) $>$ 123 to 198 mg/kg (VU5) ($CD_{25}BS_{50}FV_{25}$) $>$ 167 to 243 mg/kg (VU2) ($CD_{75}BS_{25}$). Significant variations in various vermi-units were found for Zn levels (F = 180.7, p = 0.001). Ni is a micro-component of enzyme urease and is essential in metabolism of nitrogen in plants. Ni levels also followed a trend of increase in waste blends and registered 1.45 – 1.86 fold increment with final levels 2.68 - 3.28 mg/kg among vermi-units. There was a significant variation in all units for change in Ni levels (F = 115.07, p = 0.000). The earthworms mineralize the organic waste materials and release the organically bound metals into free forms [166]. Further, loss of mass through respiratory activities of earthworms and microorganisms in vermi-units concentrate the metal in end product. Other possible reasons may be physico-chemical properties of initial substrate, chelating with humic acids which reduces the possibility of loss of a metal through leaching or bioaccumulation [75] and reduction in final weight of vermicompost. In the present study, vermicomposting enhanced the micronutrients in finalized vermicompost produced from all the vermi-units but micronutrient levels were well within the allowed limits to be used as an organic fertilizer in agricultural and horticultural applications [129].



(a) Total Fe level

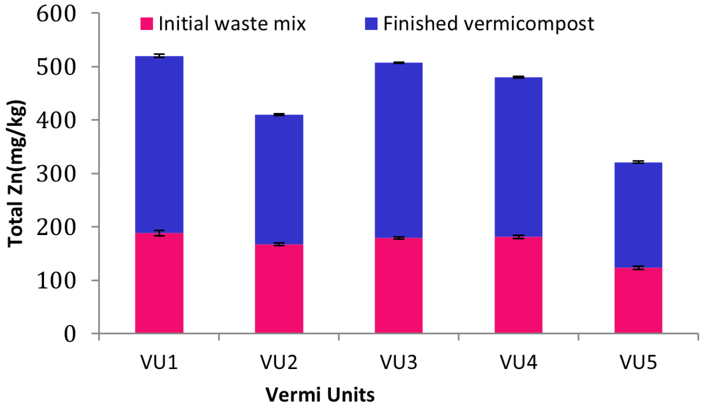


(b) Total Cu level

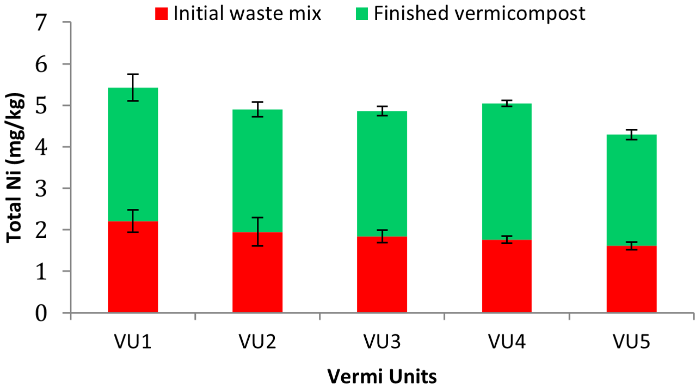


(c) Total Mn level

Figure 6.2: Micronutrient levels (mg/kg) change in initial waste mix and finished vermicompost a) Total Fe level b) Total Cu level c) Total Mn level d) Total Zn level e) Total Ni level



(d) Total Zn level



(e) Total Ni level

Figure 6.2: Micronutrient levels (mg/kg) change in initial waste mix and finished vermicompost a) Total Fe level b) Total Cu level c) Total Mn level d) Total Zn level e) Total Ni level

6.3.2 Stability and Maturity Indices

a) C /N and C/P Ratio

The C/N and C/P ratio indicate compost maturity and stable conditions. In the experiment, C/N ratio exhibited a declining trend in vermi-units as the process proceeded towards completion. C/N decrease was significant following the order: VU3 (69%) ($CD_{50}BS_{25}FV_{25}$) > VU1 (67%) (CD_{100}) >VU4 ($CD_{25}BS_{25}FV_{50}$) (64%) > VU2 (61%) ($CD_{75}BS_{25}$) > VU5 ($CD_{25}BS_{50}FV_{25}$) (54%) (Table 6.2). The initial values of C/N ratio were in between 36.8 - 54.6 and changed to 12.8 - 18.4 in final vermicomposts. The earlier research reports have also reported reduction in C/N ratio of the vermicomposted waste mixtures owing to organic matter mineralization, respiratory loss of carbon dioxide and enhancement of nitrogen levels during the process [120],[197]. High amount of bakery sludge with less addition of cow dung and FV showed least decline in carbon to nitrogen ratio. While, VU3 showed maximum reduction in C/N ratio indicating the suitability of right proportions of feed mixtures for vermicomposting. VU3 and VU4 differed significantly from VU1, VU2 and VU5 (F = 287.85, p = 0.000) but statistically indifferent from each other (p = 0.15; p = 0.70; p = 0.70 for VU1 - VU2, VU1 - VU5, VU2 - VU5, respectively) for reduction in C/N levels. A C/N ratio below 20:1 is regarded ideal for compost maturation and thus stabilization of finalized products [118] and C/N $>$15 is suggestive of agronomic applicability [90].

The C/P ratio also represents vermicompost maturity and suggests organic matter mineralization, carbon loss and increased availability of phosphorus in the vermicompost formed after the completion of the process. In the present study, drop in C/P ratio significantly varied among all the five vermi-units (F = 528.7, p = 0.001) (Table 6.2). Initially, C/P levels were between 52.9 - 61.5 and following the descending trend, reached to the levels in the range of 18.2 - 30.8 in vermicomposts after 90 days. Highest reduction (60.7%) was marked in VU3 ($CD_{50}BS_{25}FV_{25}$) and lowest reduction (44.8%) was seen in VU5 ($CD_{25}BS_{50}FV_{25}$) with less percentage of cow dung and fruit-vegetable waste and more amount of bakery sludge. The C:P ratio of the order of 15:1 is considered important for better plant absorption [12]. Decrease in carbon to phosphorus was also documented in earlier research studies [198],[82].

b) Germination Index

The mature vermicompost with Germination Index (GI) values $\leq$ 80 is considered as non-toxic for plant applications [98]. Immature vermicompost favors accumulation of plant toxic substances such as ammonia, phenol, ethylene and organic acids and inhibits plant growth. Thus, vermicompost prepared from organic waste materials should be assessed for maturity levels before applying for agricultural and horticultural purposes. Seed germination experiment was performed for evaluation of maturity and non-toxicity of vermicompost produced for plant growth. On the 0^{th} day, GI of *Cicer arietinum* (Chick pea) was in the range of 20 $\pm$ 0.04 - 59 $\pm$ 0.05% which may have unfavorable effects owing to presence of ammonium compounds and organic acids, if used as potting media. Figure 6.3 shows GI drop in initial days of vermicomposting. Research studies have attributed this to presence of high salinity, volatile acids and compounds of ammonia responsible for increasing toxicity levels [118]. GI increased as the process of vermicomposting proceeds. At 90^{th} day, GI reached to the value of 71 $\pm$ 0.06 - 138 $\pm$ 0.05% due to organic matter degradation and mineralization into simpler forms easy to be assimilated by plants. Difference in final germination index were statistically significant in vermi-units (F = 302.0, p = 0.002) except for VU1 and

VU4 (p = 0.277). Seed germination assay of *Cicer arietinum* in different vermicomposts followed the trend: 138% (VU3) > 129% (VU4) > 124% (VU1) > 89% (VU2) > 71% (VU5). VU3 has shown highest germination index representing its use as soil applicator. It also suggests utility of vermicompost prepared from feed mixtures VU2 (CD: BS: FV) in ratio 2:1:1 followed by VU4 (CD:BS: FV) in ratio 1:1:2. GI of VU5 (71%) was not found to be suited for plant growth. GI levels in the present research complies with previous studies viz. 72 -162% for *Brassica rapa L.* by Zhang and Sun [167], 89.5 - 115.32% for *Brassica campestrius* by Gusain and Suthar [84]; 51 - 128 % for *Raphanus sativus* by Unuofin and Mnkeni [54]. As per a recent research study, phytotoxicity of organic wastes is reduced significantly due to exhaustion of phenolic compounds accelerated by earthworms during the process of vermicomposting [199].

c) Respiration Rate Assessment ($mgCO_2kg^{-1}VC48h^{-1}$)

Soil respiration is an indicative of microbes' action and reflects vermicompost maturity. The rate of respiration as ($mgCO_2kg^{-1}VC48h^{-1}$) determines maturation phase of vermicompost, its readiness to harvest and marks the termination of process as well. In the experiment, earthworms mediated microbial activity instigated respiration rate initially in all the five vermi-units, but with different extents, as sufficient organic matter was available for microorganisms to act upon in each unit.

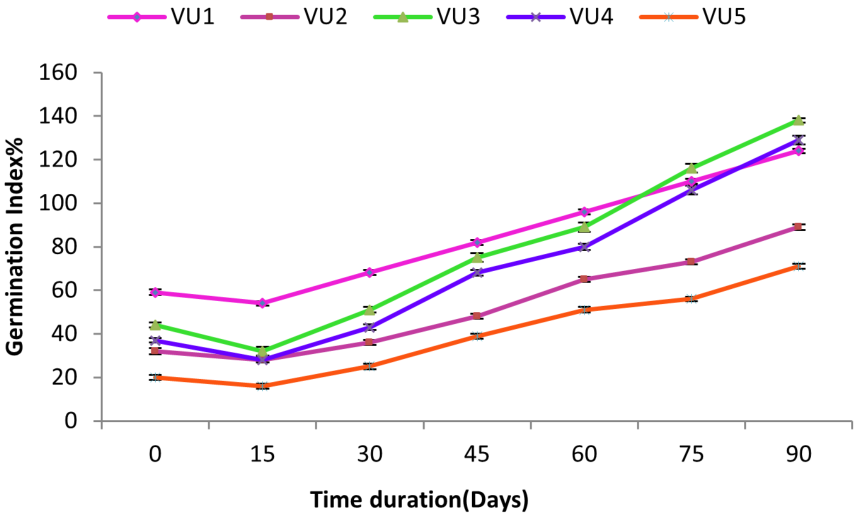


Figure 6.3: Change in Germination Index (%) in different vermicomposting units with time

On 45th day, rate of respiration attained maximum values ($mgCO_2kg^{-1}VC48h^{-1}$) with order: VU3 ($CD_{50}BS_{25}FV_{25}$) > VU1 (CD_{100}) > VU4 ($CD_{25}BS_{25}FV_{50}$) > VU2 ($CD_{75}BS_{25}$)

> VU5 ($CD_{25}BS_{50}FV_{25}$) and depleted towards completion of vermicomposting process as shown in Figure 6.4. Finally, respiration rates of 69-115 ($mgCO_2kg^{-1}VC48h^{-1}$) were achieved in end products that signified their stability and maturity. The values were in the allowable limits of 120 ($mgCO_2kg^{-1}VC48h^{-1}$) [121]. At the onset of process, good source of carbon was present in waste mixtures that increased microbial respiration thereby accelerating the respiration rate. Further, decrease in respiration rate can be attributed to exhaustibility of waste materials by the microbes thus declining the carbon pool. Vermi-units showed statistically significant difference for drop in respiration rate (F = 81.99, p = 0.000).

6.3.3 Effect on Biological Parameters (Biomass Gain, Earthworm Population, Earthworm Growth and Fecundity

Biological characteristics are studied to assess the potential of waste materials to be used as feed substrate for earthworms in process. Earthworms have a lead role in taking the vermicomposting process forward and producing organic manure. Biomass gain, growth status, fecundity and cocoon production are crucial determinants of feed acceptance by earthworms and hence production of good vermicompost.

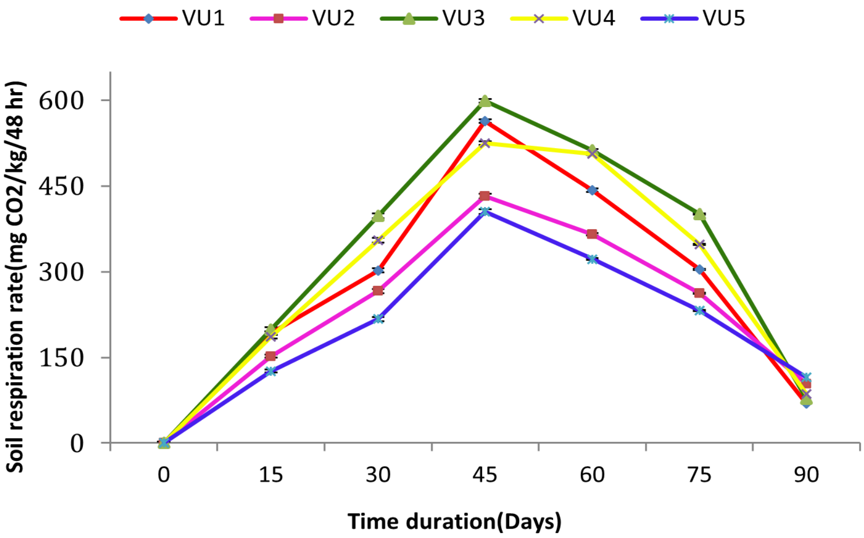


Figure 6.4: Soil respiration rate ($mgCO_2kg^{-1}VC48h^{-1}$) change with time in various vermicomposting units

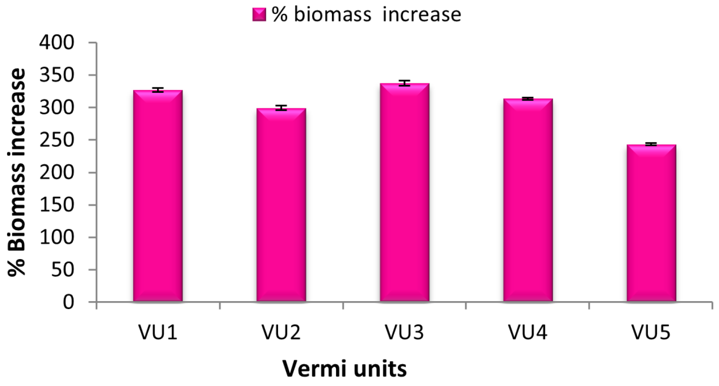
a) Effect on Earthworm Biomass

Initially, live earthworm biomass was in range of 192.4 ± 2.08 to 236 ± 1.16 mg/worm and increased maximally to 735 ± 1.37 to 998 ± 2.08 mg/worm with highest biomass of 998 ± 2.08 mg/worm after 90 days of vermicomposting. Different vermi-units showed statistically significant variation for maximum live biomass (F = 317.3, p = 0.000). CD exhibited regular growth of earthworm biomass till the process lasted. Increase in biomass was slow during the first week and gradually increased after 2^{nd} week, maximum gain achieved in 6^{th} week (VU1 and VU3); 7^{th} week (VU4); 8^{th} week (VU2) and 9^{th} week (VU5). Initially worms get acclimatized to the new habitat and sooner palatability increases thereby accelerating the weight of earthworms. Earthworm biomass slowly declines at the end of the process due to exhaustion of food source and conversion into stabilized product [200].

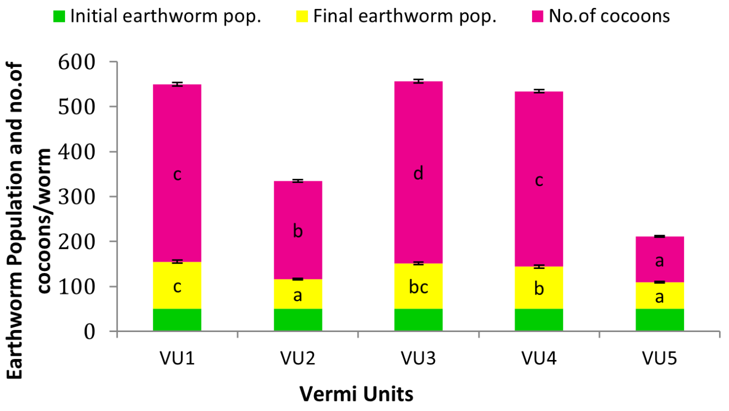
CD: BS: FV in ratio of 2:1:1 had shown more growth of earthworms due to increased palatability of bakery sludge blended with FV and CD in a proper ratio. This may be due to the reason that FV favored more growth owing to microbial communities, palatability and more organic matter. The results of maximum biomass obtained in the present study was higher than 735 mg/worm in BS vermi-transformation with CD [65]; 892.21 mg/worm in paper industry sludge [108]; 900.3 mg/worm in sludge of paper mill [201]. Percentage biomass gain was significantly different in all vermi-units (F = 265.1, p = 0.001). Order of increase was: 337.7 % (VU3) $>$ 327.0% (VU1) $>$313.5% (VU 4) $>$ 299.0 % (VU 2) $>$ 243.4% (VU5). Percentage biomass change in different vermi-units can be seen in Figure 6.5a. Minimum % gain in biomass was recorded in VU5 containing higher proportion of BS and less amount of amending materials (FV and particularly CD) indicating that nature of amendment plays an important role in better biomass gain.

b) Dynamics of Earthworm Population

In the present study, initially 50 earthworm individuals *(E. fetida)* were inoculated for vermi-conversion of different blends of BS + FV+ CD. Bakery sludge alone has less organic content and when FV was used as bulking material in addition to CD, chemical environment was more conducive for earthworms. The trend of *E. fetida* population was: VU 1 $>$ VU3 $>$ VU4 $>$ VU2 $>$ VU5 (Figure 6.5b). Least population increase at the termination of experiment was found in VU5 due to least amount of cow dung and more proportion of bakery sludge. Results indicated 2.02 fold increase in earthworm population in VU3 and 1.32 times rise in VU2. Population increase was more marked in VU3 which can be attributed to better acceptability of waste materials (CD: BS: FV)



(a) Biomass increase (%)



(b) Changes in earthworm population and number of cocoons / worm in different vermicomposting units

Figure 6.5: a). Biomass increase (%) b) Change in earthworm population and number of cocoons / worm in different vermicomposting units

in ratio of 2:1:1. Difference between the vermi-units VU2 and VU5 was statistically insignificant for the final earthworm population (F = 141.54, p = 0.10) however statistical difference from VU1, VU 3 and VU 4 was noted. Earlier researches also suggest rise in earthworm population as the vermicomposting process ends [89].

c) Effect on Cocoon Production

Mean difference for cocoon production was significant for all vermi-units (F = 675.6, p = 0.000) except in VU1 and VU4 which were insignificantly different (p = 0.46). Highest cocoon number was detected for VU3 followed by VU1 , VU4 , VU2 and VU5 . Nutrient content in VU3 due to addition of FV with CD was in favor of earthworm fecundity and cocoon production. It was inferred from the study that fecundity rate, viability of cocoons produced and survival of earthworms is dependent on the nature of waste blends and easily metabolizable organic content. Earthworm population and number of cocoons per worm are shown in Figure 6.5b. Bakery sludge is non-toxic and when mixed with FV and CD in appropriate proportions can favor earthworm growth and fecundity. Fruit and vegetable waste amendment reduced the amount of cow dung to be used where bakery sludge is to be treated through vermicomposting.

d) Effect on Earthworm Growth Rate (mg/worm/day)

Growth rate of earthworms depend on the chemical nature of raw material as well as amending agents like cow dung during the process of vermicomposting. In the present study, VU3 had the highest growth rate (mg weight/worm/day) in which addition of 25% FV + 50% CD in 25% BS supported earthworms with better nutrient content and organic matter. This can also be justified by decrease of total carbon and organic matter in VU3. Growth rate was also better in 1:1:2 ratio of CD: BS: FV rather than 3:1 ratio of CD: BS. Vermi-unit 5 showed least growth rate that might be due to less amount of bulking materials. Growth rate trend in different vermi-units was in order: VU3 (18.33mg/worm/day) >VU4 (15.10 mg/worm/day) > VU1(14.95 mg/worm/day) > VU2 (11.07 mg/worm/day) > VU5 (8.26 mg/worm/day). Statistical significant variation was found in respective vermi-units for growth rate comparison (F = 242.0, p = 0.000)

6.4 CONCLUSIONS

In present study, addition of fruit - vegetable waste into bakery sludge spiked with cow dung produced nutrient enriched, more stable and mature vermicompost in terms of C/N, C/P ratio, phytotoxicity test, respiration rate assessment, in addition to increased earthworm growth and fecundity. Based on results, fruit-vegetable waste and cow dung amendment at 25% and 50% respectively are suggested appropriate to produce enriched vermicompost from bakery sludge using *E. fetida*. The study signifies that amendment of fruit−vegetable waste can be a promising approach to convert bakery sludge into more enriched and agronomically useful vermicompost as compared to bakery sludge and cow dung alone.

Chapter 7

NUTRIENT RECOVERY AND MANAGEMENT OF BANANA CROP WASTE BIOMASS BY VERMI-TECHNOLOGY

7.1 INTRODUCTION

Banana *(Musa paradisiaca)*, family *(Musaceae)* is one of the leading crops in world agriculture widely cultivated in tropical and subtropical regions for its valuable applications in the food industries. According to Food and Agriculture Organization (FAO, 2020), increasing population and growing consumer demand in recent decades has led to rapid increase in banana crop production globally. The estimates show that globally banana production was 69 M tons in 2000 - 02, which increased upto 116 M tons in 2017-19. India, the largest producer of banana in the world with annual gross production of 29 million tons on an average, contributes to 25.7% of overall global banana production, while other major producers are China, Brazil and Philippines. It has been reported that about 85% of total banana produced globally is consumed locally, mostly in top producing countries such as India, China, and Brazil, and in some African countries where bananas contribute largely to people's diet (FAO, 2020). Whole banana plant including leaves, fruit, stem and florescence is widely used in food, pharmaceutical, packaging and many other industries for making various products [202]. The banana leaves alone have variety of uses from feed to packaging and processing material, used as disposable plates, and cups for serving food, especially in banana growing areas of Asian countries, where eating food on banana leaves is considered quite healthy and auspicious. According to estimates, banana leaf, whether remain unutilized in agricultural fields or used for making by-products generate tonnes of waste plant biomass throughout the whole supply chain, i.e., from production to consumption [203]. These huge volumes of waste biomass are either left in the agricultural field for decomposition, burnt on-site or disposed off in dumping ground or as a part of traditional municipal solid waste management systems (usually landfilled and incinerated), contributing to environmental impacts like discharge of leachates in groundwater and greenhouse gas emissions [159]. Burning of plant waste produces CO_2 and CO gases and cause various health problems / pollution. Further, sanitary landfills are overburdened due to disposal of large biodegradable solid wastes and are considered as inherently unsuitable for plant biomass disposal. These waste dumping sites are among the significant emitters of global anthropogenic methane [204] and unmanaged dumping / landfilling of post-harvest biomass is responsible for emission of 2.8 metric tons CH_4 / year or approximately 60 metric tons CO_2 equivalent per year [160]. These practices also result in loss of valuable nutrients locked in plant biomass [205].

Normally, the banana leaves are characterized by high concentration of lignocellulosic phytomass, rich in plant nutrients which can be recovered with traditional bio-treatment methods like composting, vermicomposting, anaerobic digestion, etc. Among these methods, vermicomposting has been so far appreciated in literature as a promising method to convert the nutrient rich phytomass into soil-friendly and plant-friendly organic fertilizers [56],[206],[207]. Abbasi and Abbasi [164], based on their significant and vast experimentation with plant biomass, have also mentioned that the bio-treatment methods like composting and anaerobic digestion are not only cumbersome and expensive processes but incapable of handling phytomass with efficiency in comparison to vermicomposting. During vermicomposting, the plant nutrients present in the phytomass are converted, by the joint action of earthworms and their intestinal microflora, in much soluble and available form to plants than the forms present in parent residues [137],[208]. The earthworms consume organic matter with the help of enzymes, viz., amylase, cellulase, protease, lipase, etc. produced by gut microflora [209]. Moreover, vermicomposting process involves much lesser energy or material requirements and inherited with its ability to return to the soil the carbon content and all the nutrients that were contained in the parent phytomass [210]. A literature survey has shown that controlled use of earthworms to process phytomass has been largely confined to food-based waste, namely, fruit and vegetable waste [211]; mushroom residues [166]; vegetable waste [172]; biogas slurry, [63], garden and kitchen waste [212]; mix of rice husk, banana, honeydew and papaya [64]; food waste [213], mix of fruit, vegetables waste and pruning waste [68], etc. When it comes to leaf-based waste, weeds and grasses, the researchers have investigated the vermicomposting potential to treat mango and guava leaves [214], water hyacinth along with animal dung [215], leaf litter of *Acacia*, *Eucalyptus*, Neem, *Sababul Albezia lebbeck* and *Terminalia arjuan* [216], mango leaf litter [217], Parthenium [169], mix of grasses, aquatic weeds and municipal solid waste [218], etc. These studies assess vermicomposting of different types of phytomass blended with sludge, plant substrate or animal manure, under the action of different species of earthworms like *Eisenia fetida*, *Eudrilus eugeniae*, *Perionyx excavates*, *Eisenia andrei*, *Lumbricus rubellus*, *Lampito mauritti*, *Drawida willsi*, *Allolobophora parva*, *Pheretima sp.*, etc. Further, the researchers have also demonstrated that microbial degradation of leaf based waste takes more time due to its complex structure containing lignin, cellulose, and hemicellulose; while vermicomposting facilitates its fast degradation by various lignocellulolytic microflora present in the earthworm intestine [219].

However not much literature is available on the assessment of vermicomposting of banana leaf biomass and its conversion into value added products. Thus, the objective of the present study is to vermicompost banana leaf waste biomass which is not gainfully utilized presently, co-treated with cattle dung in different proportions, using earthworm *Eisenia fetida* and recycled a vast nutrient pool embedded in this plant biomass for supplementing the soil with organic fertilizer in the form of vermicompost. The overall goal of this paper was to present the results obtained from a 105 days activity of *Eisenia fetida* during vermicomposting of pre-composted banana leaf waste biomass mixed with cow dung.

7.2 METHODS AND MATERIALS

7.2.1 Earthworms and Organic Waste Collection

The experiment was conducted with earthworm species *Eisenia fetida* which is tolerant to a wide range of temperature and has high growth rate, high rate of reproduction and capable of converting weakly decomposed phytomass into stable products, as investigated in other studies [220],[179],[221]. Earthworms were taken from the commercial market and grown in laboratory for use in experiments. Only clitellated adult earthworms were selected for the study.

Banana leaf waste biomass (BL) was collected from a vegetable wholesale god - own located at NIT 2, Faridabad (India). The banana leaves were used to pack raw and ripen banana and transported to vegetable markets. After use, the huge amount of leaves were thrown along the roadsides openly and either burnt on-site or dumped with municipal solid waste. To carry out the experiment, used banana leaves were collected from the containers and cut into small pieces of 2 - 3 cm for easy decomposition. Urine free cow dung (CD) was obtained from a local dairy farm situated locally in Faridabad. The basic physico-chemical properties of BL & CD are presented in Table 7.1.

7.2.2 Experimental Setup

To evaluate the suitability of banana leaf waste in vermicomposting process, six vermireactors ($VR_1 - VR_6$) were prepared (Table 7.2). Rectangular plastic containers with a capacity of 10 litres (28cm × 20cm × 14cm) containing different waste compositions of Banana leaf waste and cow dung were set up. Each treatment consisted of 1.0 kg feedstock substrate (dry weight basis) and was established in triplicates. A three weeks pre-decomposition of feedstock mixtures was performed to provide better aeration, moisture control and to remove volatile toxic gases to have better action of earthworms and microorganisms later in the process [179],[221],[61]. After three weeks, 20 healthy clitellated *E. fetida* earthworms (individual weighing $\approx$ 330 – 400 mg) were randomly picked from earthworm culture, weighed and added into each vermireactor. The moisture levels were maintained at 60 - 80% by sprinkling of water, together with covering each vermireactor with jute bag to minimize moisture loss and avoid the insects. Waste mixtures were turned manually and on a weekly basis in order to maintain aerobic conditions essential for earthworms. The experiment continued up to 105 days

Table 7.1: Initial physico-chemical characteristics of Cow dung and Banana leaf Biomass used in different vermireactors (Mean ± SEM, n=3) .

Parameters	**Cow dung (CD)**	**Banana leaf Biomass (BL)**
pH	8.21±0.08	6.4±0.15
EC (dS/m)	1.62±0.01	1.98±0.02
Ash content (g/kg)	228±2.08	295±1.52
TOC (g/kg)	448±1.45	408±1.5
OM (g/kg)	772±1.2	705±1.5
TKN (g/kg)	8.3±0.11	7.1±0.12
TAP (g/kg)	7.2±0.12	5.9±0.15
TK (g/kg)	7.9±0.15	6.22±0.1
C:N ratio	53.9±0.1	57.46±0.15
C:P ratio	62.2±0.12	69.15±0.14
Moisture content (%)	84±1.5	74±1.5

and growth in terms of biomass gain by earthworms was investigated lastly. The earthworms were separated as adult and hatchlings [215; 222]. After 105 days, about 20g homogenized wet samples (free of earthworms and cocoons) were drawn from each vermireactor. Each collected sample was air-dried, sieved and kept in air-tight plastic bag for physico-chemical analysis.

Table 7.2: Cow dung (CD) and Banana Leaf Waste Biomass (BL) ratio in feed stock. used for vermicomposting (on dry weight basis)

Vermireactor no.	**Feed stock ratio (CD:BL)**	**Feed stock composition (CD+BL)**	**Total Feed stock**
VR_1	CD:BL (100:0)	1000 g + 0 g	1.0 kg
VR_2	CD:BL (80:20)	800 g + 200 g	1.0 kg
VR_3	CD:BL (60:40)	600 g + 400 g	1.0 kg
VR_4	CD:BL (40:60)	400 g + 600 g	1.0 kg
VR_5	CD:BL (20:80)	200 g + 800 g	1.0 kg
VR_6	CD:BL (0:100)	0 g + 1000 g	1.0 kg

7.2.3 Physico-chemical Analysis

The wastes (CD and BL) and waste mixtures were analyzed for pH, EC, Total Organic Carbon (TOC), Total Kjeldhal Nitrogen (TKN), Total Available Phosphorus (TAP), Total Potassium (TK) and heavy metal contents (Cu, Fe, Mn, Zn, Cd, Pb and Cr). The physico-chemical analysis was done as reported in Chapter 3. Initial physico-chemical parameters of waste mixtures at the onset (after pre-composting) of the experiment are given in Table 7.3. Benefit Ratio for heavy metals was calculated as reported by [55]:

$$Benefit \quad Ratio \quad (BR) = \frac{\text{Average conc. (105 Days) – Average conc. (0 Day)}}{\text{Average conc. (0 Day)}} \tag{7.1}$$

(Conc.= Concentration)

7.2.4 Statistical Analysis

In the present study, data is presented as mean ± SEM (n = 3). One-way ANOVA was applied to the data to find out the statistical significance in the physico-chemical and worm growth parameters. Statistical analysis was carried out with SPSS 16.0 with $p<0.05$.

7.3 RESULTS

7.3.1 Alteration in Physico-chemical Properties of Waste Mixtures

During the vermicomposting process, earthworms induced decomposition of the waste mixtures and remarkable change altered the physico-chemical properties of the waste mixture (Table 7.3) The vermicomposts so produced were fine, earthy, homogeneous, odourless and nutrient-rich. Out of six vermireactors, VR_6 containing 100% banana leaves (without cow dung) was not able to support earthworms. Therefore, this vermireactor was terminated during the experiment. Initial pH of all waste mixtures was alkaline. After 105 days of vermicomposting, pH of all the waste mixtures was reduced. Initial pH of feed mixtures ranged in between 8.0 - 8.3 which changed to 7.1 - 7.3 after vermicomposting (Table 7.3). Maximum pH reduction was in vermireactor $VR_2(80\%CD+20\%BL)$ (Figure 7.1). Singh et al. [223] have reported that decrease in pH may be due to the transformation of complex organic compounds into simpler ones and release of humic acids during the process. pH shift can be due to nitrogen and phosphorus mineralization into nitrates and orthophosphates during vermicomposting [224].

The addition of H^+ by microbes, during the conversion of $NH_4^+ - N$ into $NO_3 - N$ in waste mixtures may also contribute to pH reduction in waste mixtures [225]. The pH values in the vermireactors were not statistically variable from one another ($p > 0.05$).

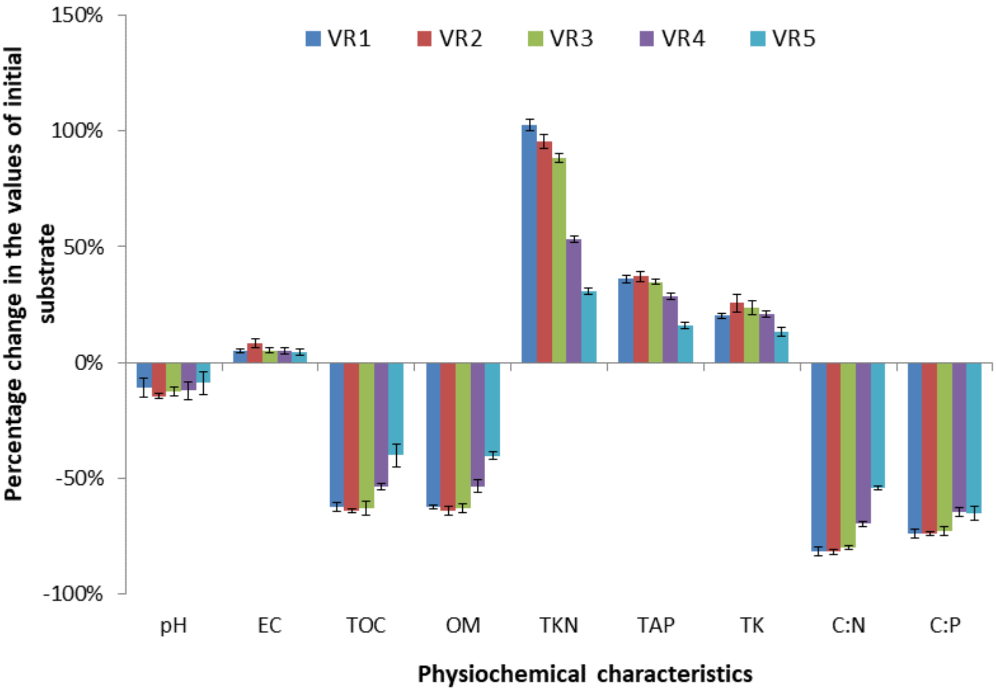


Figure 7.1: Percentage change in physio-chemical characteristics in different vermireactors

Salt concentration of vermicompost determines its use for growth of plants [43]. Release of soluble salts is essential for growth of plants and is an important parameter in determining its suitability as manure. In this study, salt content of the waste mixtures and vermicomposts has been determined as EC. The EC of vermi-manures was more than the feed mixtures in all vermireactors. EC was in the range of 1.7 – 1.88 dS/m in vermicompost (Table 7.3). Highest increase in EC was recorded in the vermireactor VR_2 (8.37%) followed by VR_3 (5.23%), VR_4 (5.05%) , VR_1 (4.93%) and VR_5 (4.45%) at the end of the experiment (Figure 7.1). The addition of soluble salts such as calcium, phosphorus and potassium (exchangeable minerals) during the degradation of organic matter may lead to increase in EC [154]. Increase in EC can also be attributed to organic matter loss and production of mineral salts of phosphate, ammonium and Potassium [200],[226].

Organic matter (OM) was initially high in all the waste mixtures (715 - 794 g/kg). OM content decreased significantly during the vermicomposting. Vermicomposting has led to 40.09 - 64.06 % reduction in TOC with maximum reduction in VR_2 (64.06%) and least reduction in VR_5 (40.09%) (Figure 7.1). Organic matter reduction was in the following order: $VR_2 > VR_1 > VR_3 > VR_4 > VR_5$. Decrease in TOC may be due to loss of carbon, as microbes and earthworms utilized carbon dioxide during respiration [227]. The direct consumption of wastes by worms helped in organic matter degradation and it is enhanced in presence of microbes and earthworms [228],[197]. During vermicomposting, organic matter degrades and gets converted to stable humic forms [208]. The findings of this study revealed that mineralization was inversely proportional to the banana leaf content in the waste mixture. Sharma and Garg [93] have also concluded 17% to 58% reduction in TOC in rice straw, paper waste and cow dung mixtures after vermicomposting. According to Aira et al [193], earthworms modify the substrate to promote loss of carbon in the form of carbon dioxide as microbes respire. TOC reduction indicates that waste undergo degradation process and gets converted into a stable end product [229]. The differences between VR_1, VR_2 and VR_3 were not significant for TOC reduction (p>0.05).

Total Kjeldahl Nitrogen (TKN) content of the vermicomposts was greater than the raw waste substrates. It ranged between 7.80 - 9.53 g/kg in initial waste substrates. Maximum nitrogen content (18.6 ± 0.20 g/kg) was in the vermicompost produced in VR_2 (80%CD + 20%BL) treatment. The change in TKN content after vermicomposting was in order: VR_1 (102.41%) > VR_2 (95.17%) > VR_3 (88.29%) > VR_4 (53.3%) > VR_5 (30.76%). TKN content of vermicomposts varied significantly from each other in all vermireactors ($p < 0.05$). An increase in nitrogen content depends upon the initial concentration of N in the feedstock and earthworm activity during the vermicomposting. Pigatin et al.[230] reported a 19.5% - 152% higher nitrogen concentration in the vermicomposts produced from different agricultural residues. Various reasons reported for increase in nitrogen content during vermicomposting include reduction in TOC, nitrogenous secretions by earthworms during the process including growth hormones and enzymes, mucus, and other excretory products [208],[89],[83].

Total Available Phosphorus (TAP) content was more in the vermicomposts than the waste mixtures. TAP content at the beginning and the end of the vermicomposting process was between 6.23 - 7.2 g/kg and 7.23 – 9.8 g/kg, respectively. The maximum TAP increment was in VR_2 (37.14%) followed by VR_1 (36.1%), VR_3 (34.78%),

VR_4 (28.46%) and VR_5 (16.05%). TAP insignificantly varied for VR_1, VR_2 and VR_3 ($p>0.05$) but significantly vary for VR_4 and VR_5 ($p < 0.05$). Earlier studies have also reported the increase of phosphorus content at the end of vermicomposting process. Increase in alkaline phosphatase can be ascribed to the mineralization of phosphate due to activity of earthworms [231]. Suthar et al.[113] also reported that final vermicast contains 64.1 - 112.8% more available phosphorus than initial waste substrates. Ramnarain et al.[232] attributed the increase in phosphorus content to the activity of phosphate solubilizing enzymes present in earthworm's gut. Earthworms enhance the activity of phosphorus solubilizing microorganisms and help in converting insoluble phosphorus into more soluble form. So, the presence of phosphatase enzyme in the gut of earthworm may be predominantly responsible for the increased phosphorus content in different vermireactors.

Total Potassium (TK) content in waste mixtures ranged between 6.3 - 7.9 g/kg (Table 7.3). As the process progressed, potassium content incremented between the levels 7.13 - 9.8 g/kg in vermicomposts. TK increase was in the range of 13.1 – 25.85% in vermicomposts. The minimum TK content was in VR5, which may be due to the low initial TK content in the waste mixture. Hussain et al. [78] also reported the increase in potassium content during vermi-stabilization of vegetable market waste and rice straw waste mixtures. Due to increased action of earthworms, mineralization becomes faster and there is change in potassium distribution between exchangeable and non-exchangeable forms [233].

The Carbon-to-Nitrogen (C:N) ratio is an important parameter in vermicomposting process, as the appropriate C:N ratios of feed mixtures are essential to know for the survival of earthworms and microbes. It is also an indicator for determining the maturity of the manure. In this study, C:N ratio of all the waste mixtures reduced during the vermicomposting process (Figure 7.3). Maximum reduction in C:N was in VR_2 treatment (81.74%) followed by VR_1 (81.44%), VR_3 (79.9%), VR_4 (69.6%) and VR_5 (54.1%) treatments. The C:N ratios of waste mixtures were in between 46.8 - 53.9. It reduced to 8.8 -24.3 at the end of the experiment. Several researchers have reported the remarkable reduction in C:N ratio after the vermicomposting of different types of wastes [61],[229],[234]. Decline of C:N ratios is the result of utilization of OC and addition of nitrogen during vermicomposting process. C:N ratio less than 20 indicates that waste is stabilized [74],[235]. Sharma and Garg [1] have reported that C: N ratio reduction is more during the initial days of vermicomposting which may be due to consumption of organic matter, cellulose and hemicellulose by earthworms.

The C:P ratios in different waste mixtures ranged from 64 - 66.7, whereas it was in the range of 17.2 - 33.1 after vermicomposting of the waste mixtures (Figure 7.2). Maximum C: P reduction was in VR_2 (73.8%) treatment and the minimum reduction was in VR_5 (65.3%) treatment. The C:P ratio reduction of the waste mixtures in different vermireactors was in the order: VR_2(73.8%) $>$ VR_1 (73.7%) $>$ VR_3 (72.2%) $>$ VR_4 (64.7%) $>$ VR_5 (65.3%). The C:P ratio of vermicomposts statistically varied from each other ($p < 0.05$). This reduction in the C:P ratio was due to the degradation of organic matter and increase in phosphorus content due to reduction in the waste quantity.

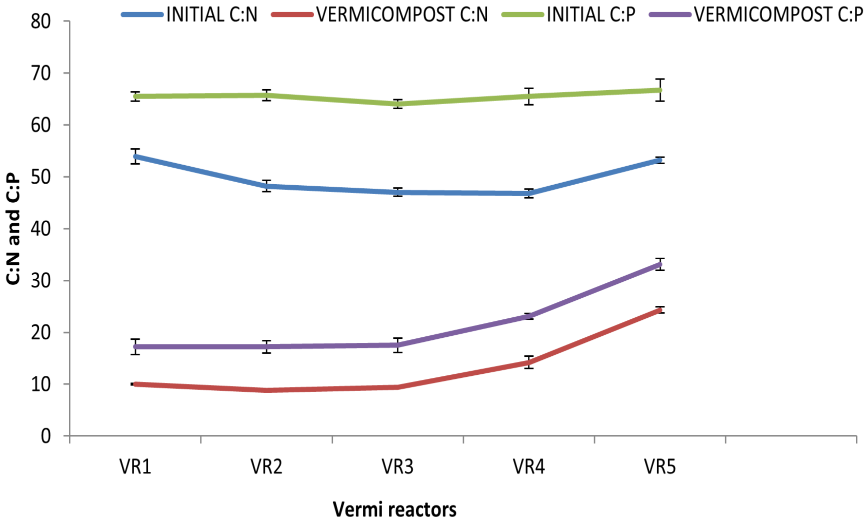


Figure 7.2: Variation in C:N and C:P ratio in different vermireactors

7.3.2 Changes in Heavy Metal Concentrations during Vermicomposting of Waste Mixtures

All composts contain heavy metals. The heavy metal concentrations of composts depend on nature and heavy metal levels of raw wastes. Now it is essential to quantify heavy metal content of composts due to various regulations. If a compost has higher heavy metal content, on application in agricultural fields, it may affect the crop growth,deteriorate quality as well as may also contaminate the soil. Heavy metal concentration of all vermicomposts was greater as compared to the respective waste mixture (Table 7.4). Cu content was 178.6 - 344.9 % more in vermicomposts as compared to waste mixtures (Figure 7.3). Fe content was 23.6 - 86.35% higher in vermicomposts than waste mixtures. Sharma and Garg [93]have also reported an increase of Cu and upto 479% and 117 % respectively in vermicompost as compared to the waste mixtures.

Zn content was from 142 to 178.8 mg/kg in initial feed mixtures, but in vermicomposts ranged 242 to 330 mg/kg. Whereas, Zn content increased in the range of 70 – 86.3% after vermicomposting. The concentration of Cu, Fe and Zn in various vermicomposts statistically varied from each other ($p < 0.05$). Cr and Cd contents increased in the range of 37.5% - 264.7% and 85.8% - 117.7%, respectively (Figure 7.3). Cr content of vermicompost obtained from VR1 statistically varied from each other ($p < 0.05$). Whereas Cd concentrations of vermicomposts obtained from different vermireactors showed significant variation from one another ($p < 0.05$). Pb concentrations in vermicomposts were in the range of 2.64 - 5.4 mg/kg. It was 57.14 – 138.3% greater in vermicomposts than raw substrates. In vermicomposts, Mn content increased upto 143.9–153.1% as compared to waste mixtures (Figure 7.3).

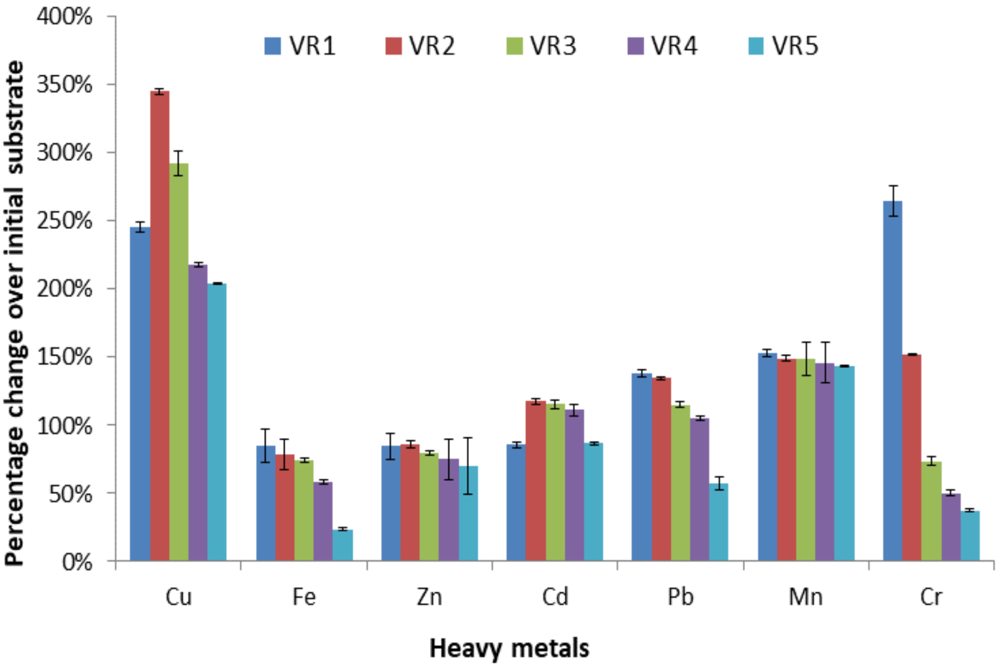


Figure 7.3: Percentage change in heavy metal content in different vermireactors

Table 7.3: Physico-chemical characteristics of CD and BL in initial waste mixture and vermicompost (Mean ± SEM, n=3)

Vermireactor	**pH**	**EC**	**OM**	**TOC**	**TKN**	**TAP**	**TK**
Initial waste mixtures							
VR_1	8.2±0.12b	1.62±0.04a	772±0.12a	448±1.20d	8.3±0.15a	7.2±0.05c	7.9±0.15c
VR_2	8.3±0.20b	1.70±0.02a	794±1.47bc	460±1.52d	9.53±0.12b	7±0.05bc	7.8±0.20bc
VR_3	8.1±0.15b	1.72±0.03a	763±0.90c	442±1.20c	9.4±0.12b	6.9±0.15ab	7.63±0.28a
VR_4	8.2±0.15b	1.78±0.04ab	726±1.23ab	421.6±0.88b	9.0±0.18b	6.43±0.17a	6.83±0.24ab
VR_5	8.0±0.12a	1.80±0.04b	715±0.66ab	415.6±0.88a	7.8±0.15a	6.23±0.12a	6.3±0.15a
Final vermicompost							
VR_1	7.3±0.15b	1.70±0.02a	292±1.48a	169±1.52b	16.8±0.31c	9.8±0.18d	9.5±0.11b
VR_2	7.1±0.12a	1.81±0.01a	285±0.85a	165.3±0.88a	18.6±0.20d	9.6±0.12d	9.8±0.14bc
VR_3	7.1±0.12a	1.81±0.02ab	284±0.84a	164.7±0.88b	17.7±0.12c	9.3±0.02c	9.45±0.12b
VR_4	7.2±0.11b	1.87±0.02b	338±1.68b	196±1.52c	13.8±0.14b	8.26±0.02b	8.26±0.20a
VR_5	7.3±0.15b	1.88±0.02bc	427±1.42c	248.6±0.88d	10.2±0.15a	7.23±0.20ba	7.13±0.12a

Values are in g/kg except EC (dS/m), pH and C:N and C:P have no units. Mean value followed by different letters is statistically different (ANOVA; Tukey's test,$p < 0.05$)

Table 7.4: Heavy metal contents (mg/kg) in initial waste mixtures and vermicompost produced from CD and BL (Mean ± SEM, n =3) .

Vermireactor	**Total Cu**	**Total Fe**	**Total Zn**	**Total Cd**	**Total Pb**	**Total Mn**	**Total Cr**
Initial wastestock							
VR_1	21.82±0.84dc	1220±3.60b	178.8±3.35c	2.26±0.02c	1.67±0.01b	88.1±0.49d	58.1±1.97a
VR_2	17.23±0.54cb	1298±7.8c	172.9±0.20b	1.80±0.20b	2.30±0.21c	85.3±1.43d	78.6±0.47b
VR_3	16.11±0.55cb	1241±5.19b	166.2±1.51b	1.35±0.01a	1.71±0.005b	76.8±0.76c	114.7±2.77c
VR_4	8.26±0.11ba	1180±17.9a	148.8±2.10ab	1.26±0.01a	1.50±0.01a	70.8±0.40b	132.1±0.84d
VR_5	6.74±0.23ba	1177.3±2.96a	142.0 ±1.15a	1.28±0.02a	1.68±1.61b	64.4±1.38a	128.0±1.16d
Vermicompost							
VR_1	75.35±0.01d	2268±4.58d	330.0±1.52e	4.2±0.02e	3.98±0.02d	223.0±1.76d	211.9±0.51b
VR_2	76.67±0.01e	2320±4.58e	322.2±0.20d	3.92±0.02d	5.40±0.03e	212.6±1.13c	198.4±1.04a
VR_3	63.25±0.014c	2162.3±4.04c	298.7±6.35c	2.91±0.02c	3.68±0.015c	191.0±1.15b	199.3±1.01a
VR_4	26.23±0.05cb	1868.6±7.6b	260.4±1.17b	2.66±0.02b	3.08±0.02b	174.2±1.44a	198.6±1.15a
VR_5	20.51±0.015a	1456±2.64a	242.2±0.52a	2.39±0.01a	2.64±0.015a	157.1±1.15a	176.0±2.18a

Mean value followed by different letters is statistically different (ANOVA; Tukey's test, $p < 0.05$)

Benefit ratio is used to evaluate the performance of waste constituents during vermicompsting. Maximum Benefit ratio was graded for Cu (3.44) in VR2 treatment (Table 7.5). Benefit ratio for Fe was in range of 0.23 – 0.85, for Zn in range of 0.70 - 0.86, for Cd in range of 0.85 - 1.17 and for Mn in range of 1.43 – 1.53. This increase in metal content of vermicomposts is due to the reduction of waste quantity during the vermicomposting process. Yadav and Garg [236] have also reported 37 - 132% increase in different heavy metal's content in vermicompost than raw materials. Song et al.[166] have reported that earthworm activity and initial metal content of the waste are interrelated to the heavy metals of vermicompost.

Table 7.5: Benefit Ratio (BR) of heavy metals in different vermireactors.

Vermireactor	**Total Cu**	**Total Fe**	**Total Zn**	**Total Cd**	**Total Pb**	**Total Mn**	**Total Cr**
VR_1	2.45	0.85	0.84	0.85	1.38	1.53	1.78
VR_2	3.44	0.78	0.86	1.17	1.34	1.49	1.52
VR_3	2.92	0.74	0.79	1.15	1.15	1.48	0.73
VR_4	2.92	0.59	0.75	1.11	1.05	1.46	0.50
VR_5	2.17	0.23	0.70	1.14	0.57	1.43	0.37

7.3.3 Growth of Earthworms in Different Waste Mixtures

Earthworm growth and reproduction are used to evaluate the suitability of waste for vermicomposting process. In present study earthworms were unable to survive in 100% BL. In 20% CD + 80% BL waste mixture, some worms died during initial days and these worms were replaced by other worms of almost equal biomass. Flegel and Schrder [237] have also stated that the surviving ability of earthworms is dependent upon food availability and production of odorous gases like ammonia, carbon dioxide during initial degradation. Mean initial biomass of earthworms in different vermireactors ranged from 332 to 391 mg/worm. Earthworm's growth and fecundity was evaluated in terms of number of worms, worm biomass, number of cocoon and hatchlings.

Among all waste mixtures, maximum mean earthworm biomass was 1096 ± 2.30 mg in VR_1 treatment. Whereas minimum mean earthworm biomass was 427 ±

2.64 mg in VR_5 treatment. Earthworm biomass values varied significantly from each other ($p < 0.05$). Maximum earthworm biomass was achieved in 6^{th} to 8^{th} week in different waste mixtures (Table 7.6). Mean net biomass gain and growth rate varied in different vermireactors and were largely dependent on the percentage of the cow dung in waste mixture. Maximum mean net biomass gain (764 ± 2.51mg) was in 100% CD. The trend of mean net biomass increase in vermireactors was: $VR_1 > VR_2 > VR_3 > VR_4 > VR_5$. The net biomass gain showed significant variations from each other ($p < 0.05$).

Yadav and Garg [43] have also reported maximum worm growth, high fecundity and maximum biomass attained in cow dung containing treatment. Biruntha et al. [152] illustrated that the growth of earthworm is dependent on the C/N ratio of the initial feed substrates and low C/N ratio is responsible for increased activity, growth and reproduction of earthworms. Belmeskine et al. [238] also reported 11.2 to 44.2% increase in worm biomass growth of earthworms (*Eisenia fetida*) after vermicomposting period. Mass gained per unit feed waste (mg/g) varied in the range of 0.90 - 15.28 in vermireactors with highest biomass gain in $VR_1(100\%CD)$ trailed by VR_2 (80%CD + 20%BL). Biomass gain per unit feed waste varied orderly as $VR_1(15.28 \pm 0.08) > VR_2$ $(12.02 \pm 0.08) > VR_3$ $(7.44 \pm 0.07) > VR_4$ $(2.44 \pm 0.12) > VR_5$ (0.90 ± 0.12) and were statistically different from one another ($p<0.05$).

Cocoon production started from 5^{th} to 7^{th} week in different vermireactors and cocoons were found in order of VR_1 $(768 \pm 1.5) > VR_2$ $(402 \pm 0.88) > VR_3$ $(328 \pm 2.08) > VR_4$ $(236 \pm 1.5) > VR_5$ (44 ± 1.52). Highest reproduction rate (cocoon/worm) was also recorded in 100% cow dung containing vermireactor (VR_1; 38.4 ± 0.15) and lowest in vermireactor VR_5 (2.2 ± 0.12). Maximum number of hatchlings were also recorded in VR_1 (230 ± 1.20) followed by VR_2 (120 ± 1.76), VR_3 (82 ± 1.20c), VR_4 (47.2 ± 0.55) and VR_5 (8.8 ± 0.15) (Table 7.6). During the study, earthworm mortality was observed in vermireactors with high percentage of banana leaf and banana leaf alone. The most promising ratios of cow dung and banana leaf waste were 80% CD + 20% BL and 60%CD + 40%BL that can be effectively converted into vermicompost. Many researchers have suggested high prolificacy of earthworms in 100% cow dung and higher concentration of cow dung containing mixtures [179],[101],[61].

Table 7.6: Earthworm growth and reproduction in various vermireactors .

Vermi-reactor	**Mean initial Biomass (mg)**	**Mean maximum biomass gained (mg)**	**Mean net biomass gained (mg)**	**Growth achieved in weeks**	**Growth rate /day/worm mg/day/worm**	**Mass gained / unit feed waste (mg/g)**	**Total no. of cocoons**	**Reproduction rate (cocoon /worm)**	**No. of hatchlings**
VR_1	332±1.52a	1096±2.30e	764±2.51e	6th	18.19±0.05e	15.28±0.08e	768±1.5e	38.4±0.15e	230±1.20e
VR_2	391±1.76d	992±1.20d	601±2.5d	6th	14.30±0.0d	12.02±0.08d	402±0.88d	20.1±0.088d	120±1.76d
VR_3	370 ±1.76b	742±1.20c	372±2.08c	7th	7.59±0.04c	7.44±0.07c	328±2.08c	16.4±0.20c	82±1.20c
VR_4	362±2.18b	484±2.08b	122±3.52b	7th	2.48±0.12b	2.44±0.12b	236±1.5b	11.8±0.15b	47.2±0.55b
VR_5	382±1.20c	427± 2.64a	45±3.71a	8th	0.91±0.13a	0.90±0.12a	44±1.52a	2.2±0.12a	8.8±0.15a

Mean value followed by different letters is statistically different (ANOVA; Tukey's test, $p < 0.05$)

7.4 CONCLUSIONS

It can be concluded from the results that banana leaf waste bioamss amended with cow dung is a good feed substrate for vermicomposting. The final vermicompost produced had an earthy odor, blackish-colour and was homogeneous in nature. 20 - 40% proportion of Banana crop waste in waste mixtures showed promising results of waste mineralization and worm growth. The vermicomposts had all the major and micro plant nutrients, like nitrogen, phosphorus, potassium, iron, zinc, copper and manganese that reveals the mineralization of feed substrates during vermicomposting. Earthworms were unable to survive in 100% banana leaves, so this affirms that amendment of a suitable bulking material is essential for the vermicomposting of banana crop waste. Finally, vermicomposting can be integrated as an important technology in overall plan of banana crop waste management.

Chapter 8

UTILIZATION OF FRUIT AND VEGETABLE WASTE FOR NUTRIENT RECOVERY AND SUSTAINABLE MANAGEMENT

Fruits and vegetables are one among the most consumed commodity throughout the world, either used raw or processed to produce value - added products. Due to continuous population rise and enhanced technological advancements, there has been an increase in food wastage globally. According to Food and Agriculture Organization report (FAO, 2019), around 14 percent of the food produced is wasted during post-harvest stage at global level and the developing countries account for 44 percent of the 1.33 billion tonnes of global food loss per annum with continuous increasing amount [239]. Globally, India lies at second position for the production of fruits and vegetables after China, accounting for 12 percent of global fruit and vegetable production. However, according to Central Institute of Post-Harvest Engineering and Technology (CIPHET, 2021), 18 percent of India's fruit and vegetable production is wasted annually. Fruit and vegetable (FV) wastes are produced in huge quantities at every step of whole food supply chain, viz., collection, distribution, market, storing and processing, majority of this waste ends up as municipal solid waste. Management of this bio-waste is not efficient and structured at places and generally disposed off in landfills or burnt. These unscientific methods lead to loss of nutrients, leachate formation and release of methane gas in landfills that elates the global issue of greenhouse gas emissions (FAO, 2019). Due to high water content and biodegradable organic compounds, FV wastes readily decompose and create negative impact on surrounding environment by producing odors and are unaesthetic [140].

In yester years, there has been a growing concern over the generation, appropriate treatment and nutrient recovery from FV wastes as they contain degradable organic compounds, macro / micronutrients and are non-toxic in nature. Therefore, these wastes have a potential to be utilized efficiently in anaerobic digestion, composting and vermicomposting processes [57],[240],[241]. The composting / vermicomposting is environmentally beneficial in terms of less greenhouse gas emissions and leachate production in comparison to landfilling and anaerobic digestion [242]. Vermicomposting converts complex organic compounds into plant-available inorganic forms like nitrate and phosphate along with formation of humic and fulvic acids [228],[72]. It has been considered as a faster and eco-friendly technology over traditional composting to convert organic waste into enriched compost [243]. During vermicomposting, earthworms increase the feed substrate surface area by fragmenting them with their gizzards, thus positively augmenting microbial activities during process and enhancing waste decomposition [244],[44]. The endo-symbiotic microbes inside earthworm's intestines generate various hydrolytic enzymes to degrade cellulose and phenolic compounds and enhance the waste decomposition process [245]. Many literature studies have suggested vermi-conversion of organic wastes individually and in mixed forms viz. cruciferous vegetables [115], fruit and vegetable waste amended with activated sludge [67], potato biomass [86], apple pomace waste [60], pre-consumer vegetable processing waste [56], tomato waste [246], food waste [213], etc. In view of the above discussion, an attempt was made to convert FV waste into manure via vermicomposting technology. The present chapter is divided into two sections:
8.1 Vermicomposting of mixed fruit and vegetable (FV) waste from commercial and domestic areas
8.2 Potential of vermicomposting in recycling of nutrients from Carrot leaf waste
The detailed discussion on these sections is given below.

8.1 VERMICOMPOSTING OF FRUIT AND VEGETABLE WASTE FROM COMMERCIAL AND DOMESTIC AREAS

Tons of FV waste are generated from fruit and vegetable markets and at household level in the city on daily basis that become a part of municipal solid waste stream. Due to lack of segregation at source of generation, inefficient disposal and management system, nutrients embedded in these wastes are neither quantified nor recovered. To best of authors' knowledge, no such study has been conducted for city's fruit and vegetable market waste vermicomposting in Faridabad city. Thus, an attempt was made to throw light on potential of vermicomposting of fruit and vegetable market waste produced in huge amounts that create nuisance at city level. Vermicompost maturity was established by soil respiration assessment and germination index so that vermicompost produced can be effectively employed as organic manure. This will lead to ultimate diversion of these wastes from going into landfills and recovering valuable nutrients contained in them.

8.1.1 Methodology

a) Materials

Fruit and vegetable waste (FVW) was obtained locally from Fruit-Vegetable Market and domestic areas, New Industrial Township 5, Faridabad (India) in mixed form where discarded fruits and vegetables along with their left-out parts are often left unattended in market place and produce offensive odours. It mainly comprised of a mix of peel off and left-over parts of various fruits and vegetables like apple, banana, papaya, tomato, potato, carrot, cauliflower, cabbage and peas.

Feedstock was diced into small pieces before mixing with cow dung (CD). CD was procured from an animal dairy situated in New Industrial Township 5, Faridabad. The physico-chemical characteristics of FVW and CD prior to start of the experiment are exhibited in Table 8.1. The earthworm, *Eisenia fetida*, used in the study was taken from worm culture prepared in lab.

Table 8.1: Initial physico-chemical characteristics of feedstocks used in different vermireactors (Mean ± SEM; n=3)

Parameters	**Cow dung (CD)**	**Fruit and Vegetable waste (FVW)**
pH	8.4±0.5	7.48 ±0.3
EC (dS/m)	1.61±0.1	2.4±0.01
Ash content (g/kg)	228±2.1	113±1.8
TOC (g/kg)	448±2.5	514 ±3.3
OM (g/kg)	772±3.15	887±4.01
TKN (g/kg)	8.3±0.5	12.1±0.3
TAP (g/kg)	7.0±0.12	4.62±0.05
TK (g/kg)	7.7±0.20	5.42±0.32
C:N ratio	53.9±2.4	42.4±1.88
C:P ratio	64.0±1.5	109.8±2.15
Moisture content (%)	84.0±1.5	89.0±1.8
Total Fe (mg/kg)	1798±9.2	2849±8.8
Total Cu (mg/kg)	78±1.2	56±0.08
Total Zn (mg/kg)	92±1.23	53±0.07
Total Mn (mg/kg)	102±0.78	19.8±0.02
Total Cd (mg/kg)	1.22±0.02	0.5±0.001

b) Experimental Setup

Four feedstock reactors, namely, FV_{25}, FV_{50} and FV_{75} along with CD_{100} as control were set up for vermicomposting of fruit and vegetable market waste. The composition of feedstocks in reactors is as follows:

Vermireactor $CD_{100}(CD_{100})$ – 100%CD
Vermireactor $FV_{25}(CD_{75}FV_{25})$ –75% CD + 25% FV (3:1)

Vermireactor $FV_{50}(CD_{50}FV_{50})$ - 50% CD + 50% FV (1:1)
Vermireactor $FV_{75}(CD_{25}V_{75})$ – 25% CD + 75% FV) (1:3)

The FVW and CD waste were mixed in above ratios on dry weight basis and put into the reactors making the final weight upto one kg each. These reactors were pre-composted for three weeks before the introduction of earthworms for vermicomposting. During this time period, waste mixtures were turned on frequent basis to remove volatile gases and heat during initial decomposition or pre-composting. After 21 days, twenty mature *Eisenia fetida* earthworms (≈300 – 450 mg/worm) were taken from stock culture and introduced in each reactor. All experiments were established in triplicates.

c) Physico-chemical and Biological Analysis

All the parametric quantities were analyzed such as pH, EC, Total Organic Carbon (TOC), Total Kjeldahl Nitrogen (TKN), Total Available Phosphorus (TAP), Total Potassium (TK), Respiration Rate assessment, Total Fe, Cu, Zn, Mn and Cd were determined using standard methodology (Chapter 3). Biological parameters were also evaluated using methods mentioned in Chapter 3.

d) Statistical Analysis:

SPSS 21 was used for statistical analysis of data (as given in chapter 3).

8.1.2 Results and Discussion

As vermicomposting process proceeds, the organic matter contained in waste mix gets mineralized exhibiting changes in physico-chemical characteristics – pH, EC, TOC, ash content, macronutrients (TKN, TAP, TK) and micronutrients (Total Fe, Cu, Zn, Mn and Cd), soil respiration rates and germination index.

a) Changes in Physical Appearance, pH, EC and Ash Content

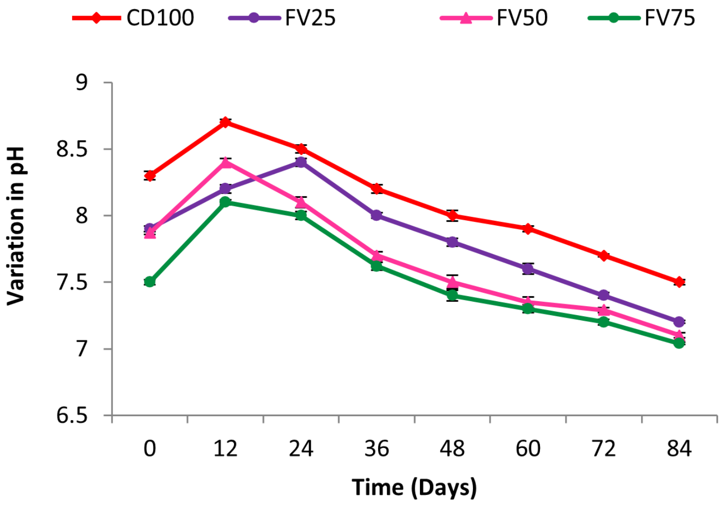
The final vermicomposts in all the feedstocks exhibited dark brown-black color, homogeneous, and more fragmented structure. This is attributed to the gizzard action of earthworms and microorganism's activities fragmenting the waste mixtures and converting them into fine granules like manure. At the onset of experiment, pH value of different feedstocks decreased from initial range of 7.5 ± 0.01 - 8.3 ± 0.03 to 7.0 ± 0.01 - 7.5 ± 0.02 in final vermicomposts after 84 days (Table 8.2).

Table 8.2: Physico-chemical characteristics of feedstocks and vermicomposts produced in different vermireactors

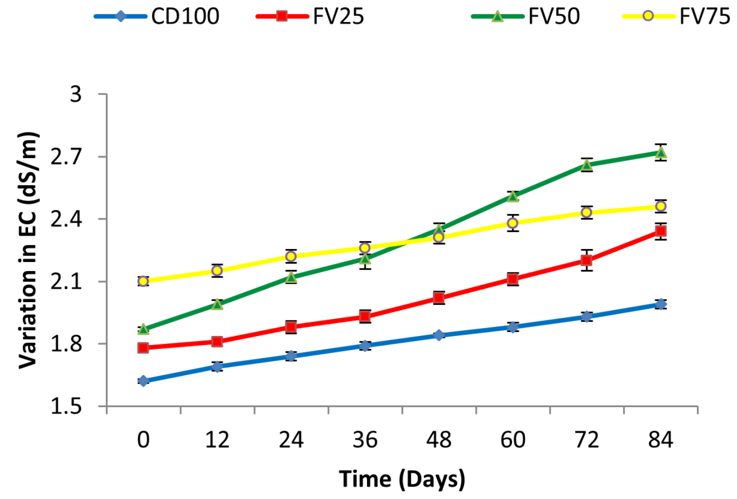
Vermi-reactor	**pH**	**EC (dS/m)**	**TOC (g/kg)**	**TKN (g/kg)**	**TAP (g/kg)**	**TK (g/kg)**	**C/N**	**C/P**
Feedstock (Initial)								
CD_{100}	8.3±0.03a	1.62±0.01a	448±1.11a	8.3±0.13a	7.1±0.22c	7.7±0.03d	53.9±1.23d	63.0±1.13a
FV_{25}	7.9±0.02a	1.78±0.001b	468±1.08b	9.7±0.15b	6.9±0.2c	7.23±0.02c	48.2±1.14c	67.8±1.5b
FV_{50}	7.8±0.01a	1.87±0.01c	478±1.3c	10.1±0.14c	5.8±0.15b	6.68±0.02b	47.3±0.07b	82.4±1.22c
FV_{75}	7.5±0.01a	2.10±0.02d	496±1.25d	13.7±0.11d	5.1 ±0.1a	5.92±0.01a	36.2±1.08a	97.2±1.04d
Vermicompost (Final)								
CD_{100}	7.5±0.02d	1.99±0.02a	315±1.08a	20.1±0.29b	16.2±0.8b	19.8±0.19c	15.6±1.01d	19.4±1.28a
FV_{25}	7.2±0.01c	2.34±0.04b	326±1.02b	23.9±0.28c	17.0±0.28b	17.9±0.03b	13.6±1.2a	19.1±1.64a
FV_{50}	7.1±0.02b	2.72±0.04d	329±1.21c	27.6±0.26d	17.4±0.22c	19.5±0.04c	11.9±1.14b	18.9±1.38a
FV_{75}	7.0±0.01a	2.46±0.03c	396±0.68d	18.5±0.22a	11.2±0.16a	12.1±0.01a	21.4±1.16c	35.3±0.11c

Mean value followed by different letters is statistically different (ANOVA; Tukey's test, $p \leq 0.05$)

pH decrease was significantly different for different vermireactors ($p < 0.05$). The pH drop was highest in vermireactor FV_{50} (9.78%) and least in FV_{75} (6.87%) that suggests better mineralization of nutrient contents in former end product. The pH of the feedstock increased initially and then drop in values with time was achieved (Figure 8.1a). It has been reported in earlier studies that the intial pH increase in feedstocks happens due to organic matter degradation and mineralization of nitrogen/phosphorus compounds and final drop of pH to neutral/near neutral range is attributed to production of humic and fulvic acids owing to earthworm and microbial activities exhibiting vermicompost stability [210],[130], [143],[117],[199].



(a)



(b)

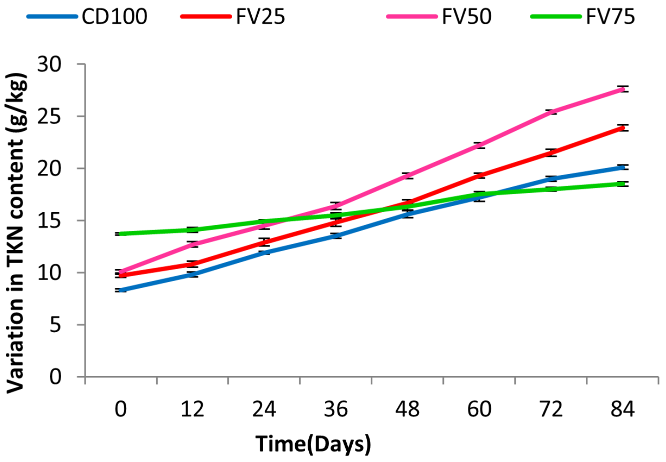
Figure 8.1: a)Variation in pH with time in different vermireactors b) Variation in EC (dS/m) with time in different vermireactors

The EC values show the presence of salts and inorganic ions which can influence the quality of vermicompost. The EC increased at the end of 84^{th} day in all vermireactors. Initially, it was in the range of 1.62 dS/m - 2.60 dS/m in different feedstock combinations and increased significantly ranging from 1.99 - 2.46 dS/m at the termination of experiment (Table 8.2). The increase in EC values was in the order: FV_{50} (45.45%) $>$ FV_{25} (31.46%) $>$ CD_{100} (22.83%) $>$ FV_{75} (17.14%) (Figure 8.1b). Vermireactors were significantly different from each other for increase in EC ($p < 0.05$). Maximum increment in EC values in FV_{50} (50% FVW amended with 50% CD) showed effective organic matter degradation and presence of nutrients in more available forms than rest of the feedstock ratios. Increased EC in final vermicomposts can be owed to production of soluble salts, release of organically bind nutrients into accessible forms and accumulation of inorganic ions due to organic matter degradation [109], [89]. However, EC values in end products in the current study is within the prescribed limits for use in agricultural fields ($<$ 4.0 dS/m). The ash content enhancement of 100 - 146% was recorded in final vermicomposts at the end of experiment with initial levels of 145 - 228 g/kg to final values in range of 316 - 457 g/kg. Significant difference was found among different vermireactors for ash content increase (ANOVA; Tukey's HSD test, $p < 0.05$). The feedstocks being palatable to earthworms get efficiently degraded and mineralized which increases ash level in final vermicompost. The present results are in consistent with previous researches [108],[86].

b) Changes in TKN, TAP and TK Levels

Variation in TKN, TAP and TK with time are given in Figure 8.2 a, b and c. As the process approached towards the end (i.e. 84^{th} day), TKN, TAP and TK levels were found to be greater in vermicomposts than initial feedstocks (Table 8.2). The combined action of earthworms and micro-organisms mineralize the organic matter and release the macro and micro - nutrients in plant available forms. In the present study, TKN levels showed a substantial enhancement of 18.5 - 27.6 g/kg in comparison to 8.3-15.6 g/kg in initial feedstocks. TKN exhibited the following trend $FV_{50} > FV_{25} > CD_{100} > FV_{75}$ at the end of the process. There was 1.35 - 2.73 fold increase in all the feedstock combinations with time, however, the vermireactors FV_{50} (50% CD + 50% FV) and FV_{25} (75% CD + 25% FV) showed higher increase than the control CD_{100} (Figure 8.2a). Statistically significant variation was found for nitrogen content in the vermireactors ($p < 0.05$). The main reasons for the enhancement of nitrogen content during vermicomposting are the breakdown of complex nitrogenous organic molecules, addition of nitrogenous metabolites by vermicast and enzymes released from earthworms [247],[84],[108]. The results are in line with earlier work using other feedstocks amended with cowdung [109]. The TKN enhancements depend upon nitrogen concentration in initial feed stocks [48]. Phosphorus is an essential macro-nutrient and its high concentrations in manure is required for plant growth and metabolism [248]. After 84^{th} day, the vermicomposts of all the reactors showed elevated levels of phosphorus than initial values. Initially, it was in the range of 5.1 - 7.1 g/kg in all the feedstocks, and enhanced upto 11.2 - 17.4 g/kg in final vermicomposts. The highest increase of 3.0 fold was observed in FV_{50} (50% CD + 50% FV) followed by FV_{25} (2.46 fold), CD_{100} (2.28 fold) and then FV_{75} (2.19 fold) at the end of the process (Figure 8.2b). Mean difference for augmented TAP was statistically insignificant ($p > 0.05$) in FV_{25} and CD_{100} but FV_{50} was significantly different from others ($p < 0.05$). The results clearly shows that earthworm's activities increase the decomposition of organic matter into compost provided appropriate mixing of CD and FVW as feedstock. The phosphatase enzymes and phosphate-solubilizing bacteria present in earthworm's gut release phosphorus in soluble forms through mineralization and mobilization of phosphate in substrate thus augmenting TAP in final vermicompost [114]. Earlier research studies also exhibited the similar results that vermicomposting enhances the phosphorus content during vermicomposting [86],[89].

A remarkable increase in TK was registered in all the feedstock combinations with overall 2.02 - 2.91 fold increase in 84 days vermicomposting. TK enhancement from initial levels in vermireactors at the end of experiment is as follows: FV_{50} (6.68 to 19.5 g/kg) $>$ CD_{100} (7.7 to 19.8 g/kg) $>$ FV_{25} (7.2 to 17.9g/kg) $>$ FV_{75} (5.92 to 12.1 g/kg) (Figure 8.2c). The vermireactor with 75% FVW + 25% CD showed least increase in TK as less amount of cow dung has affected waste decomposition. Potassium content was statistically significant for different vermireactors ($p<0.05$) although CD_{100} and FV_{50} were statistically indifferent from one another ($p > 0.05$). The loss of organic matter and total organic carbon enhances potassium values in vermicomposts [154]. In addition, the production of exogenic / endogenic enzymes associated with enteric microorganisms of earthworms enhance the mineralization rate which in turn increases the level of soluble potassium [90].



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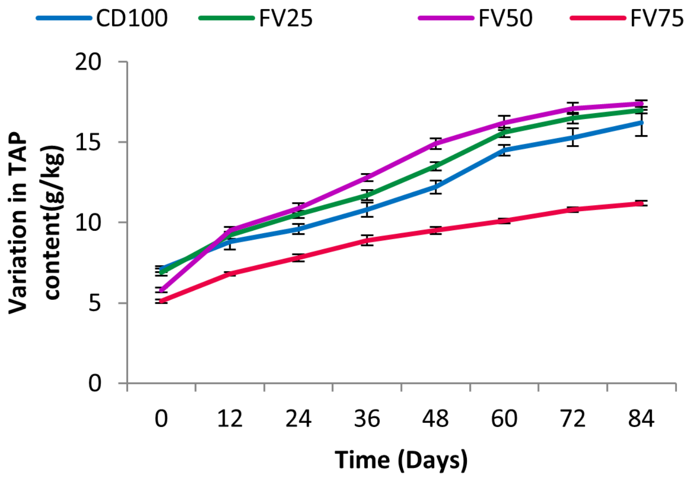

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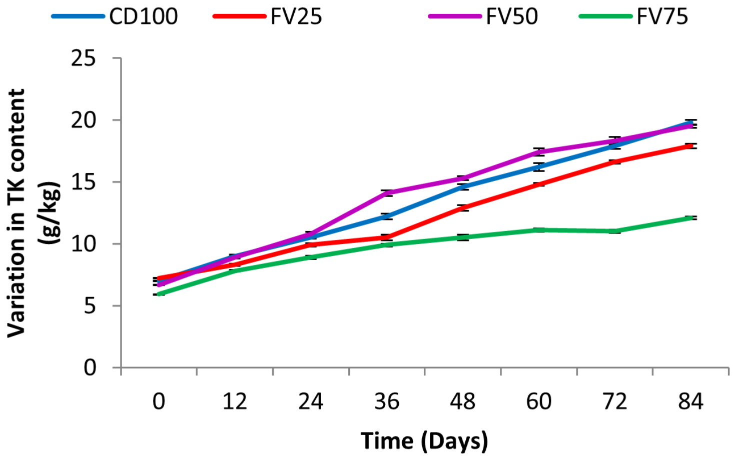


(c)

Figure 8.2: a)Variation in TKN(g/kg) with time in different vermireactors b) Variation in TAP (g/kg) with time in different vermireactors c) Variation in TK (g/kg) with time in different vermireactors

c) TOC and Respiration Rate Assessment

The reduction in TOC indicates organic matter degradation and mineralization which results in proportional release of macro and micro-nutrients in vermicomposts due to combined activity of earthworms and micro-organisms [201]. In the present study, decrease in TOC content in the reactors was observed. TOC ranged from 448 ± 1.11 - 496 ± 1.25 g/kg initially in the feedstocks which reduced to 315 ± 1.08 - 396 ± 0.68g/kg at the end of experiment (Table 8.2). Highest decline in TOC was recorded with time in the reactor FV_{50} (31.17%) followed by FV_{25} (30.4%), CD_{100} (29.68%) and FV_{75} (22.37%) (Figure 8.3). Significant difference was observed in all the vermi reactors for TOC reduction ($p<0.05$). Higher reduction of TOC in FV_{50} and FV_{25} than control CD_{100} may be due to greater microbial activity and faster degradation rate in these vermireactors. Earlier researches also suggested TOC decline in vermicompost upto different extents: 16.37% [93]; 26.1 - 42.8% [65]; 24.8% [111], 24.34 - 38.25% [84]. However, it is notable that even though the reduction of TOC was higher in all vermicomposts, the final values relied upon the initial levels as well as the activities of earthworms and microbes [152]. The trend of TOC loss can be attributed to the respiratory activity and assimilation of carbon by micro-organisms and earthworms in their growth [61],[108]. Furthermore, the reduced TOC contents in final vermicompost showed humic acid richness reflecting compost stability and maturity during the process [249],[61].

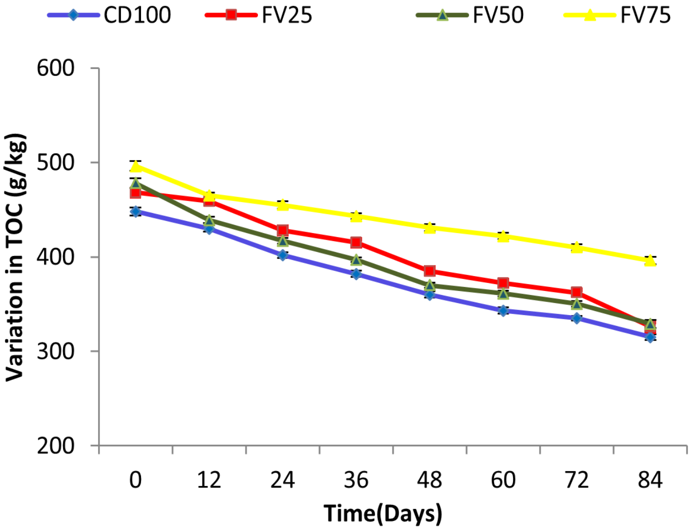


Figure 8.3: Variation in TOC (g/kg) with time in different vermireactors

Respiration rate in terms of measurement of CO_2 evolution during the vermicomposting process reflects the respiratory activities of micro-organisms and earthworms and considered as one of the important stability index of organic composts [120]. It marks the completion of process when vermicompost is ready to harvest and is estimated in terms of $mgCO_2kg^{-1}VC48h^{-1}$. Initially, a vast source of carbon in the form of organic feedstocks activates microbial respiration, thereby increasing the respiration rates. Gradually, the carbon pool gets exhausted due to microbial proliferation and respiration rates also drop [84], [85]. On zeroth day, respiration rate was measured in range of 183 - 199 $mgCO_2kg^{-1}VC48h^{-1}$ and enhanced upto 36^{th} day due to availability of carbon source, i.e., feedstock material in plentiful amount in all the vermireactors, then it finally declined to 62-103 $mgCO_2kg^{-1}VC48h^{-1}$ as observed on 84^{th} day owing to consumption of food by population of microbes (Figure 8.4).

Final respiration rate in the end products marked their stability and maturity and were in the permissible limits of < 120 $mgCO_2kg^{-1}VC48h^{-1}$ [121]. The decline in respiration rates is also related with the reduction of TOC, C:N and nutrient enhancement in the study. Therefore, it is evident from the findings that a stable FV vermicompost can be attained by mixing it with suitable amount of cow dung which favour the earthworm and microbial activities forming ideal environment. Statistical variations were recorded in all vermireactors for loss of respiration rate ($p < 0.05$). Present findings are in concordance with previous results [122],[84], [85].

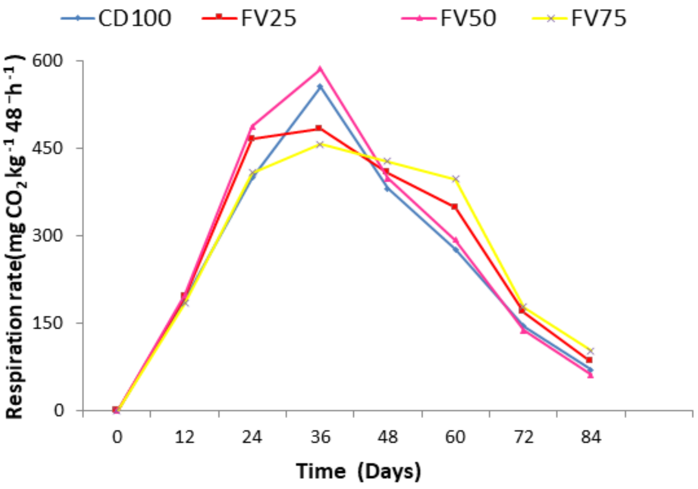


Figure 8.4: Variation in soil respiration rate ($mgCO_2kg^{-1}Vermicompost48h^{-1}$) with time in different vermireactors

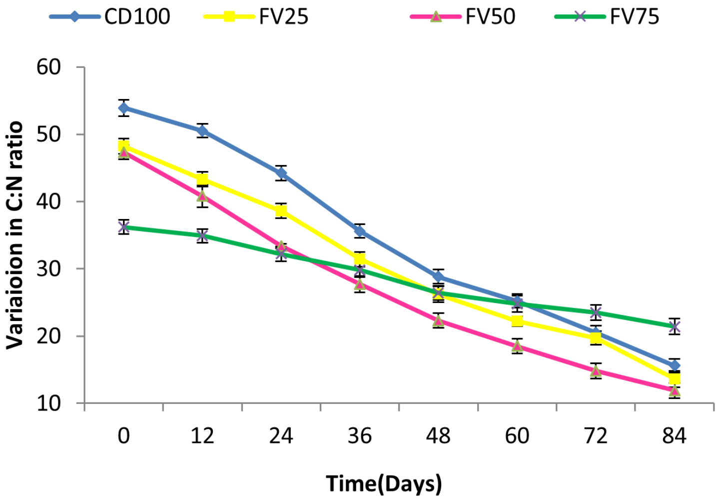
d) C:N and C:P Ratios

The C:N ratio exhibits the extent of organic matter decomposition. In the present study, with depletion of TOC as CO_2 evolution, and subsequent nitrogen loss to lower extents, there is effective degradation of organic wastes and hence marked decrease in C:N ratio. Significant decline of 40.8 - 74.8% was noted in the vermireactors after 84 days of vermicomposting (Table 8.2). Decrease in C:N in the reactors followed the trend: FV_{50} (53.9 to 15.6) $>$ FV_{25} (48.2 to 13.6) $>$ CD_{100} (47.3 to 11.9) $>$ FV_{75} (36.2 to 21.4) (Figure 8.5a). The feed mixtures were statistically different from each other for reduction in C:N levels ($p < 0.05$). Furthermore, the C:N ratio < 20 is reflective of vermicompost stability [117], [118].

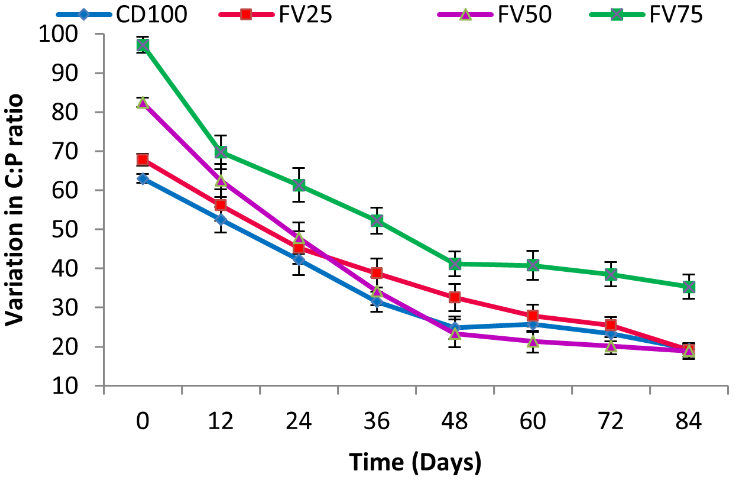
The findings are in line with earlier studies which showed decline in C:N ratio [57],[67]. According to the earlier research studies, the augmentation of nitrogenous compounds, the release of CO_2 and enzymes-microbes-earthworms mediated degradation of organic matter may be ascribed as the prime factors for decline in C:N ratios during the process [33],[88]. At the onset of experiment, C:P ratio was higher (63.0 - 93.8) in initial feedstocks and reduced to 18.9 - 35.3 in vermicomposts as the process is complete (Figure 8.5b). Decline in C:P ratio was suggestive of effective feed stock degradation and higher stabilization. Significant difference ($p<0.05$) was found among all the vermireactors for C:P ratio reduction. The decline of C:N and C:P ratios occurred due to organic carbon loss, increase in N & P via FV addition as well as organic matter degradation in the process. C:P reduction followed by vermi - conversion was also registered by some previous researchers - 20.1 - 44.1 [1]; 21.8 - 37.3 [115].

e) Seed Germination Index for Phytotoxicity Test

Vermicompost maturity can also be established by determining germination index (GI). GI value $>80\%$ marks the non-toxic nature of vermicompost that can be applied as plant manure [98]. GI was estimated in feed stocks on seeds of *Vigna radiata* (moong bean). Initially feed stocks had GI values in range of 23 - 58% indicating their non-suitability for plant application whist GI for vermicomposts produced from different ratios of fruit and vegetable waste and cow dung varied from 83 - 142 %. GI followed the order: 142% (FV_{50}) $>$ 128% (CD_{100}) $>$ 118% (FV_{25}) $>$ 82% (FV_{75}) manifesting vermicompost maturation up to variable extents (Figure 8.6). Relative seed germination for FV_{50}, CD_{100}, FV_{25} and FV_{75} were 99.8%, 93.4%, 81.9 %, 71.8%, respectively. Relative root germination was 70.8% in FV_{50}, 72.9% in CD_{100}, 69.4% in FV_{25} and 86.3%



(a)



(b)

Figure 8.5: a)Variation in C:N ratio with time in different vermireactors b) Variation in C:P ratio with time in different vermireactors

in FV_{75}. The results corroborated with the required germination index $> 80\%$ for plant application. GI for different feed stocks varied significantly from each other ($p<0.05$). The vermicompost prepared from 50 % fruit and vegetable waste possessed high GI as compared to cow dung vermicompost and other proportions of feed stocks thereby determining its use as manure. GI values varied differently indicating different levels of vermicompost maturation owing to varying degree of mineralization and organic matter decomposition. Finally, organic matter degradation results in formation of metabolic products that are more attainable for plant growth [167].

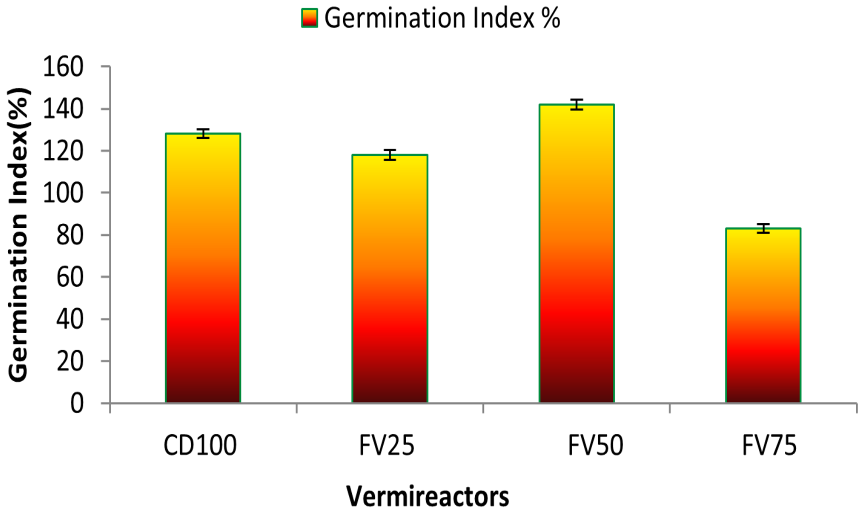


Figure 8.6: Germination Index (%) in different vermireactors

f) Change in micronutrients (Fe, Zn, Cu, Mn and Cd)

Micronutrients viz. Fe, Zn, Cu, Mn and Cd are vital for plant growth in trace quantities and can hinder soil fertility at high concentrations, therefore, it becomes important to assess their levels in vermicompost before its application in agriculture / horticulture. The earlier research studies have shown that trace metal concentrations may increase/decrease after vermicomposting. Increase in trace metal concentration is associated with loss of mass/volume of initial feedstock, organic matter mineralization in presence of earthworms / micro-organisms and / or due to freeing of metal ions from confined state [166],[173],[56]. Earthworms action, the type of waste material used and their physico-chemical properties enhance micronutrient levels in the final vermicompost. On the contrary, some studies have reported that earthworms tend to bio-accumulate trace metals in their tissues or forms organo-metallics preventing metal release during vermicomposting resulting in reduced trace metals concentration after vermicomposting [250],[174],[251].

In the present study, micronutrients have been found to be enhanced in all the vermireactors despite of their mixing proportions and initial content as shown in Table 8.3. Trace metals Fe, Zn , Cu, Mn and Cd had shown manifolds incremental change towards the end of the experiment as 1.41 - 1.63 fold, 1.59 - 1.67 fold, 1.68- 1.84 fold, 1.68 - 1.90 fold and 1.7 - 1.8 fold, respectively. Total Fe content in final vermicompost varied from 2896 - 3965 mg/kg whilst it was 1798 - 2826 mg/kg in initial feedstocks.

Total Zn concentration increased from the initial values of 69.8 ± 1.01 - 94.4 ± 1.23 mg/kg to 111.6 ± 2.15 - 158.5 ± 2.04 after 84 days of vermicomposting. Total Cu concentration ranged from 78.4 - 128.1mg/kg in the beginning of process and reached to 132.4 - 236 mg/kg in final vermicompost. Significant variation was observed between all the four vermireactors for incremental change in Total Fe, Zn and Cu contents ($p<0.05$).

Total Mn levels were found to be higher (36.8 - 194.5 mg/kg) in vermicomposts as compared to prime values (21.8 - 102 mg/kg) irrespective of feed stock proportions. Total Cd levels in waste mixtures ranged between 0.64 ± 0.01 - 1.22 ± 0.04 mg/kg and eventually enhanced to 1.1 ± 0.01 - 2.2 ± 0.05 mg/kg at the end of process. Mean statistical difference among various vermicomposts for increased Mn and Cd content was statistically significant ($p < 0.05$).

In spite of augmentation in trace metals in the final product, level of nutrients registered were confined to the threshold limits, thereby making them usable as potting media / manure in agricultural crops [129],[177],[252]. The results are in concurrence with the previous findings which have shown increment in trace metal concentrations during the process of vermicomposting [115],[86],[93].

Table 8.3: Micronutrient contents in feedstocks and vermicomposts produced in different vermireactors

Vermi- reactor	**Total Fe (mg/kg)**	**Total Zn (mg/kg)**	**Total Cu (mg/kg)**	**Total Mn (mg/kg)**	**Total Cd (mg/kg)**
Feedstock (Initial)					
CD_{100}	1798±9.2a	94.4±1.23d	128.1±1.22d	102±0.78d	1.22±0.04d
FV_{25}	1989±10.5b	88.7±1.12c	119.9±1.10c	46.2±0.93c	1.17±0.02c
FV_{50}	2670± 11.2c	74.1±1.04b	99.3±1.06b	38.1±1.45b	0.85±0.01b
FV_{75}	2826±9.1d	69.8±1.01a	78.4±0.64a	21.8±1.89a	0.64±0.01a
Vermicompost (Final))					
CD_{100}	2896±10.8a	158.5±2.04d	236.0±1.43d	194.5±1.87d	2.2±0.05d
FV_{25}	3258±11.3b	147.6±1.46c	220.2±1.23c	87.3±1.56c	2.0±0.03c
FV_{50}	3781±12.6c	120.0±1.89b	178.4±1.56b	68.1±0.75b	1.5±0.02b
FV_{75}	3965± 10.2d	111.6± 2.15a	132.4±0.98a	36.8±1.02a	1.1±0.01a

Mean value followed by different letters is statistically different (ANOVA; Tukey’s test, $p \leq 0.05$)

g) Change in Earthworm Population, Earthworm Biomass, Growth and Fecundity

In current study, various biological parameters, namely, earthworm population, biomass gain (mg/worm), growth rate/worm/day, fecundity rate (cocoon/worm), etc., were studied for vermireactors and presented in Table 8.4. These parameters emphasize on setting up the suitability of organic feedstock for vermicomposting. Earthworms are the drivers in taking the process forward and producing compost, therefore, palatability of the feed mixtures by worms is driving force in vermicomposting process. In current study, FVW amended with CD provided conducive environment for the growth of *Eisenia fetida* pronounced by increased worm population in all the vermireactors (Table 8.4). The highest worm population was in FV_{50} (75 ± 2.56) followed by CD_{100} (72 ± 3.1) > FV_{25} (70 ± 3.8) > FV_{75} (40 ± 2.34) at the end of experiment. Statistically significant difference was noted in FV_{25}, FV_{50} and FV_{75} whereas vermireactors FV_{25} and CD_{100} were statistically insignificant ($p > 0.05$).

E. fetida achieved highest individual worm biomass in FV_{50} and the minimum in FV_{75} after 84 days of vermicomposting (Figure 8.7). Along the same line, biomass gain was highest in FV_{50} (1313±7.15) and followed the trend $FV_{50} > FV_{25} > CD_{100} > FV_{75}$ with a statistical difference between vermireactors ($p < 0.05$). Similarly, the growth rate was highest in FV_{50} (20.84 mg), followed by FV_{25} (20.64 mg), then control CD_{100} (19.46 mg) and FV_{75} (11.12 mg). FV_{50} and FV_{25} were not statistically different from each other with reference to the growth rate during the process ($p > 0.05$), however, rest of vermireactors showed variations statistically from one another ($p < 0.05$). These results indicate that fruit and vegetable waste added in 25-50% proportions in cow dung supported earthworms with better nutrient content and good amount of organic matter more than control (100 %CD). The reactor FV_{75} (75% FV + 25% CD) showed lowest growth rate that might be due to availability of less quantity of bulking material. Moreover, it supported least number of cocoons (72 cocoons) as compared to other vermireactors (range: 200-240 cocoons). These results exhibited that cow dung amendments in some minimum percentage are essential for optimum growth and reproduction of *E. fetida*.

Maximum biomass gain in FV_{50} and FV_{75} was achieved on 63^{rd} day of the study, while CD_{100} and FV_{25} took 56 days. Similarly, cocoon production / worm was statistically ($p<0.05$) greater in FV_{50} and FV_{25} as compared to CD_{100} and FV_{75}.

Table 8.4: Biological characteristics of feedstocks and vermicomposts (VC) in different vermireactors.

Vermi-reactor	**Earthworm population**		**Individual earthworm biomass(mg)**		**Biomass gain (mg)**	**No. of cocoons**	**Biomass achieved (days)**	**Fecundity (cocoon /worm)**	**Growth rate /worm/day (mg)**
	Feedstock	VC	Feedstock	VC					
CD_{100}	20	72±3.1b	318±2.67a	1576±4.02c	1089± 7.2c	210±1.6b	56	2.91±0.01b	19.46±0.05b
FV_{25}	20	70±3.8b	339±3.12b	1482±3.28b	1156±8.22b	219±2.1c	56	3.08±0.02c	20.64±0.07c
FV_{50}	20	75±2.56c	446±3.25d	1652±7.12d	1313±7.15d	240±3.2d	63	3.2±0.03c	20.84±0.05c
FV_{75}	20	40±2.34a	422±2.22c	1123±2.78a	701±4.1a	72±1.02a	63	1.8±0.1a	11.12±0.03a

Values expressed are mean ± SEM. The different alphabets between treatments within each group differ significantly at $P \leq 0.05$ by Tukey's HSD test.

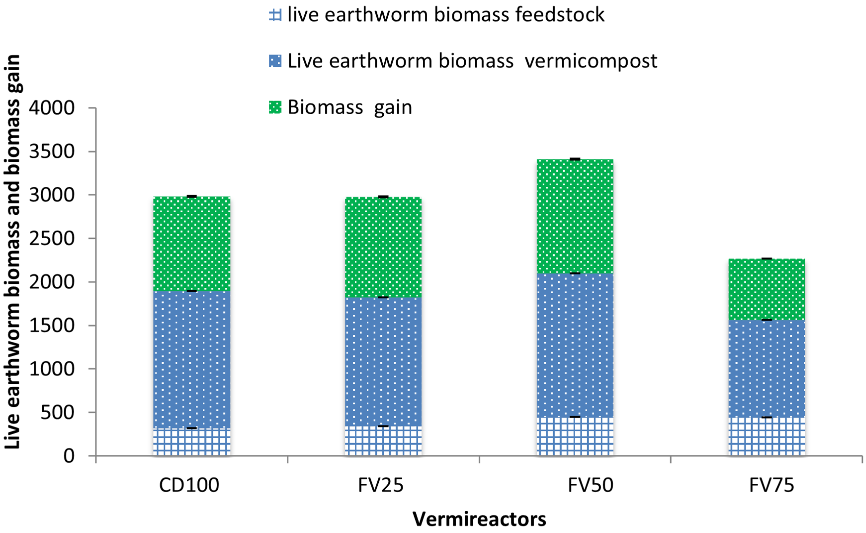


Figure 8.7: Variation in live earthworm biomass (mg/worm) and biomass gain in different vermireactors

It was inferred that growth and fecundity of worms were affected by the quantity of fruit-vegetable waste amended to cow dung. FVW amended in cow dung in suitable proportion (25-50%) favored more growth due to colonization of microbes, good palatability and a decent amount of organic matter as compared to the control, i.e., 100% CD, while more addition of FVW resulted in lower fecundity in earthworms. These findings are in line with the vermicompost characteristics observed in previous sections of current study wherein FV_{50} vermicompost exhibited maximum macro-nutrients, stability and quality compared to other vermireactors. Earlier studies carried out in vermicomposting also reported positive effect of adding FVW in cow dung on growth and reproduction of earthworms [111],[63],[130].

8.1.3 CONCLUSIONS

The present research implies that vermicomposting of fruit and vegetable market waste amended with cow dung is an appropriate technology for efficient nutrient recovery and enhanced growth & reproduction of earthworms. *E. fetida* showed maximum growth and reproduction in vermireactor FV_{50} (50%CD + 50%FV). Stable and mature vermicompost was produced in terms of enhanced nutrients (TKN, TAP, TK) alongwith decline in pH, TOC, C:N, C:P ratios in the final vermicomposts. Respiration rate and phytotoxicity assay test established maturity of vermicompost due to efficient degradation of feed materials. Based on the results of present study, vermicomposting of FVW amended with cow dung at 50-50 ratio is suggested for production of nutrient rich vermicompost employing *E. fetida*. Further, it proved to be an appreciable way to minimize environmental impact of fruit & vegetable waste disposal and recover embedded nutrients contained in them.

8.2 POTENTIAL OF VERMICOMPOSTING IN RECYCLING OF NUTRIENTS FROM CARROT LEAF WASTE

8.2.1 INTRODUCTION

Vegetable crops generate copious amount of residues once the useful portion is harvested. These residues are tender, moist, perishable and have good nutritive values. Leaves of several vegetables like carrot tend to get neglected not only in terms of food wastage but also in loss of valuable nutrients. Carrot (also called as *Daucus carota*) is a biennial plant that belongs to umbellifer family, *Apiaceae*; as the plant of this family is an umbel in which a single flower stalk originates on the stem from a common point. It originated in Asia around North west India. Carrot is a major vegetable crop of India which is grown in states like Haryana, Andhra Pradesh, Karnataka, Punjab and Uttar Pradesh. According to National Horticulture Board, Haryana is the highest producer of carrots with 20.2% share in India, produced 386.3 tons followed by West Bengal (235.3 tons) and Punjab (224.7 tons) in 2021-2022.

Carrot greens / leaves form nearly half of the body weight of carrot and often refused to improvise the root (carrot) shelf life. Carrot tops are abandoned as soon as carrot crop is removed from the field because leaves keep on withdrawing moisture from root and dry out carrot fastly, therefore, it is necessary for preservation of carrots. Merely carrot leaves are used as animal and poultry feed, therefore remain in fields and hardly it reaches homes for eating as a part of salad. Although these are consumed in some countries in moderation due to presence of alkaloids which gives them mild bitterness and trigger allergic reactions; most of the times disposed /dumped in open. Carrot leaves are enriched in nutrients like N, P, K, Ca, Mg, Na, Mn, Zn, Fe and Vitamin C, β-carotene, carbohydrates, proteins and fibers [253]. Wasted organic remains of carrot can be employed for composting /vermicomposting to recover valuable nutrients and maintain soil health. Vegetable wastes have been converted to energy and value-added materials via biological processes like anaerobic digestion, fermentation, composting, vermicomposting, etc. [163],[115].

Vermicomposting is bioconversion of organic substrates through conjoint action of earthworms and microorganisms, into valuable manure known as vermicompost [179],[115]. It is a cost-efficient and sustainable practice employed to manage organic wastes generated from domestic sector, agriculture and industries that are non-toxic. As per literature survey, carrot leaves had not been used for vermicomposting in earlier studies. Thus carrot leaf waste vermicomposting was carried out using cow dung with an aim to regain nutrients in form of vermi-manure. Earthworm species *Eisenia fetida* was engaged in vermicomposting of carrot leaf waste. Vermicomposting potential of carrot leaf waste was assessed by analyzing physico-chemical parameters, nutrient levels and earthworm growth studies.

8.2.2 Methodology

a) Materials

Carrot leaf waste (CRLW) was collected from agriculture fields situated near village Kheri, Faridabad city. Leaves were chopped into 2- 3 cm pieces prior to blending with cow dung (CD). It was obtained from a local dairy. Physico-chemical characteristics of carrot leaf waste and cow dung are presented in Table 8.5. Earthworm *Eisenia fetida* for experiment was randomly picked from the stock culture maintained in lab.

b) Experimental Design

Six Trial Bins (CR_{10} - CR_{50} and CD_{100}) were maintained for carrot leaf waste vermicomposting with CD_{100} as control (Table 8.6). One kg of raw waste (dry weight) was put in each trial bin. Waste mixtures were turned on frequent basis to remove volatile elements and offensive odors. When pre-composting of organic wastes was completed after 21 days, twenty earthworms (weighing $\approx$ 300 – 450 mg/worm) were introduced into each trial bin. Each trial bin was established in triplicates.

c) Physico-chemical and Biological Analysis

Various waste combinations were estimated for physico-chemical parameters like pH, EC, TOC, TKN, TAP, TK, Total Fe, Cu, Zn and Mn using standard methodology (Chapter 3). Earthworm growth parameters were also evaluated using methods given in Chapter 3.

d) Statistical Analysis

SPSS 21 was used for analyzing data statistically (as in chapter 3).

Table 8.5: Initial physico-chemical characteristics of raw waste used in different vermireactors (Mean ± SEM of three replicates). .

Parameters	Cow dung (CD)	Carrot leaf waste (CRLW)
pH	7.9±0.04	6.3±0.02
EC (dS/m)	1.52±0.02	2.43±0.03
Ash content (g/kg)	224±1.56	84±1.48
TOC (g/kg)	450±1.75	531.3±1.62
OM (g/kg)	776±1.80	916±1.96
TKN (g/kg)	8.6±0.05	7.2±0.02
TAP (g/kg)	7.1±0.06	6.8±0.01
TK (g/kg)	7.8±0.11	11.2±0.03
C:N ratio	52.3± 1.23	73.8±0.11
C:P ratio	63.3±1.97	78.1±0.10
Moisture content (%)	84±2.08	83±1.32
Fe (mg/kg)	1124±2.12	108±0.02
Zn (mg/kg)	93.2±0.05	9.9±0.003
Cu (mg/kg)	44.2±0.02	0.86±0.001
Mn (mg/kg)	52.1±0.01	1.98±0.001

Table 8.6: Composition of raw waste (Cow dung and Carrot leaf waste) .

Trial Bin	CD + CRLW	CD (%)	CRLW(%)
TB1 CD_{100}	500g	100	0
TB2 CR_{10}	450g+50g	90	10
TB3 CR_{20}	400g+100g	80	20
TB4 CR_{30}	350g+150g	70	30
TB5 CR_{40}	300g+200g	60	40
TB6 CR_{50}	250g+250g	50	50

8.2.3 Results & Discussion

During vermicomposting, earthworms' degradative action bought remarkable change in the physico-chemical characteristics of carrot leaf waste (Table 8.7). The final vermicasts produced were homogeneous, fine, earthy and enriched with nutrients.

a) Changes in pH, EC, TOC and Ash Content

Th pH of feed mixture determines the decomposition rate of organic matter during process. In the present study, the pH of carrot leaf feed mixtures decreased significantly than their respective raw waste mixtures and was in the range 6.9 - 7.4 at the end of process. Moreover, the trial bins were significantly varied from one another for pH values ($p < 0.05$). Percentage decrease was observed in the range of 2.2 - 45.91% in all the trial bins with maximum decrease in cow dung alone. The pH reduction might be due to formation of nitrites and nitrates along with production of organic acids and evolution of carbon dioxide as an outcome of earthworm and microbial activities [41], [87]. The pH levels of 7 - 8 (nearly neutral) are considered ideal depicting mineralization and stabilization of waste materials [117]. EC of raw waste was in the range of 1.67 - 2.36 dS/m, while it ranged from 2.42 - 3.44 dS/m in vermicasts after 75 days (Table 8.7). EC increase may be owed to production of salts, ammonium and inorganic ions as well as release of non-available nutrients into accessible forms [89]. EC of the vermicasts produced was within the permissible limits (<4dS/m) and can be used as organic fertilizer. The levels of EC in all trial bins showed significant variations in final vermicasts ($p < 0.05$). Incremental change of 4.6 to 98.2% was recorded in all the trial bins. Previous studies have also shown an increase in EC during vermicomposting [168],[86].

The TOC content was found to be reduced in vermicasts from their initial raw materials. TOC content indicates degradative ability of organic waste used in vermicomposting and showed reduction in the present study. Initially, TOC ranged from 441 - 494 g/kg which declined to 262 - 376 g/kg at the completion of process. About 23.8- 40.5% TOC decrease was noted in trial bins consisting of different combinations. TOC decline might be linked to accelerated rate of carbon mineralization and organic matter decomposition in all the feed stocks due to greater activity of microorganisms and enzymes present in earthworms [254]. Highest TOC drop (40.5%) was registered in CD_{100} followed by CR_{10} feed mixture (30.1%). TOC content was statistically significant among different trial bins ($p<0.05$). Organic carbon reduction decreased with increase in carrot leaf content. Carbon pool utilization by earthworms and microorganisms as energy source and part of respiration resulted in loss of carbon [87].

Ash content enhancement suggests efficient waste decomposition, mineralization and vermicompost maturity. Ash contents followed an increasing trend towards the completion of vermicomposting process and augmented from initial levels of 148 - 238 g/kg to final values in range of 352 - 547g/kg. Earlier literature studies also reported an increase in ash levels at the end of vermicomposting process [108],[93]. Raw wastes' palatability to earthworms marked efficient degradation and mineralization that resulted in enhanced ash levels in final vermicompost. Significant difference was found among different trial bins for ash content increase ($p<0.05$).

b) Changes in TKN, TAP and TK

TKN, TAP and TK enhanced from their initial values as organic matter gets mineralized along with exhaustion of carbon pool during the course of vermicomposting [173]. Change in TKN, TAP and TK are represented in Table 8.7. Significant increase in TKN was recorded in all the trial bins when compared to initial raw wastes. TKN content was considerably higher in vermicasts (16.7 - 28.5 g/kg) from their starting values (7.87 - 9.9 g/kg). There was 2.12 - 2.87 fold increment in all the combinations depending upon their initial values. TKN levels among different trial bins were significantly variable ($p<0.05$). Escalation in nitrogen content can be owed to efficient nitrogen mineralization, organic carbon depletion, excretory materials and mucus production as well as reduction in raw materials' mass and nitrogen in initial waste and bulking agents [87],[84]. Blending cow dung with carrot leaf waste assisted in increasing nitrogen in vermicast and as concentration of bulking agent decreased, nitrogen increase was also less. Present findings corroborate with previous studies that suggest increased TKN of green waste vermicompost [90], [111].

TAP in all the trial bins were found to be escalated from previous levels as the process proceeds towards the completion. Initially phosphorus content in various trial bins ranged from 6.9 - 7.8 g/kg and reached to 11.3 -17.4 g/kg in vermicasts (Table 8.7). About 1.63 - 2.28 times increase in phosphorus levels in all the trial bins was recorded and it depended upon initial phosphorus concentration. Statistically significant variation was found among different trial bins for increased TAP levels. ($p<0.05$). Phosphorus increase can be attributed to organic matter decomposition by earthworm and microbial activity during vermicomposting and soluble phosphorus released by phosphate solubilizing bacteria in earthworm's gut. Utilization of humic acid by microorganisms in course of organic matter degradation release phosphorus in raw wastes [84]. TAP increment was recorded in fruit and vegetable waste vermicomposts by various researchers [246], [67].

After 75 days of vermicomposting, TK levels were remarkably higher (20.9 - 26.5 g/kg) than raw wastes (8.7 - 11.1 g/kg). The trial bins were significantly different from each other with regard to potassium levels ($p < 0.05$). About 2.05 - 2.66 fold increase was recorded in carrot leaf vermicomposts and it relied on initially higher potassium levels in raw waste mixtures. The trial bin with 50% carrot leaf had shown minimal increase in TK due to less organic matter reduction. Our findings exhibited that carrot leaves blended with cow dung had profound potassium levels in finished vermicasts. Earlier studies also marked significant enhancement in potassium concentration in final vermicasts [111],[84], [85].

c) Changes in C:N and C:P Ratio

The maturity and stability of manure may be estimated by C:N and C:P ratios which mark the rate of organic matter decomposition. The C:N ratio declined from levels of 44.5 - 62.7 in raw feed mixtures to 9.1 - 22.5 in vermicomposts produced (Table 8.7) as carbon is lost in the form of CO_2 with subsequent nitrogen decrease to lower extent. The C:N decline in different trial bins was: CD_{100} (44.5 to 9.1) $>$ CR_{10} (49.3 to 11.9) $>$ CR_{20} (54.5 to 14.03) $>$ CR_{30} (58.7 to 16.8) $>$ CR_{40} (61.6 to 19.9) $>$ CR_{50} (62.7 to 22.5). Significant difference was recorded for C:N reduction among different trial bins ($p<0.05$). The C:P ratio in initial raw waste was in range of 56.5 - 71.5 that finally descended to 17.9 - 33.7 in vermicasts produced from carrot leaf waste (Table 8.7). C:P ratio deceleration suggests effective degradation hence greater stability of vermicomposts than raw wastes and was significantly different from each other ($p<0.05$). With increase in carrot leaf waste content and decrease in cow dung, C:P reduction was more marked in different trial bins.

d) Changes in Micronutrient Level (Fe, Zn, Cu, Mn)

Micronutrients are important for plant development and nutrient balance. Thus estimation of micronutrients in vermicompost is essential prior to its use as an organic fertilizer. High concentration of micronutrients is toxic to plants and animals and therefore it becomes important to know the increase in their levels after vermicomposting. Vermicomposting comes out to be a sustainable and environmentally sound technique for obtaining bio-fertilizer with enhanced nutrient levels. Our study showed a manifold change in the concentration of micronutrients in all the trial bins up to variable extents (Table 8.8). Many studies reported an increase in micronutrient contents towards the end of vermi-transformation [93], [140],[115]. Enhanced level of micronutrients rely on the action of earthworms, the type of waste material employed for vermi-processing and their physico-chemical properties. Some researchers have reported that decline in waste mass and volume due to worm activity raises the micronutrient contents at the end of experiment [56], [115].

Enzymes produced in the worm's gut increased Fe content in final vermicasts. A notable increase in Fe was recorded in each trial bin in spite of raw waste combinations. Fe content ranged from 627 – 1128 mg/kg at the starting of experiment and escalated to 702 -1759 mg/kg after 75 days of vermicomposting. Fe concentration increased 1.11 - 1.55 folds in final vermi casts and a significant difference was observed between all the trial bins ($p< 0.05$). Incremental change of 1.55-2.47 times was observed for Zn in all the waste combinations irrespective of the waste proportions in various trial bins. Zn content increased from range of 58.3 - 94.4 kg/g in initial waste mixtures to 90.9 - 234.1 mg/kg in the end products. Significant difference in various trial bins was found for Zn levels ($p<0.05$). Cu concentrations enhanced from initial levels ranging from 13.4 – 49.7 mg/kg to 16.1 - 97.4 mg/kg in final vermicasts.

Table 8.7: Physico-chemical characteristics of raw waste and vermicast produced in different Trial Bins (Mean ± SEM of three replicates).

Trial Bins	**pH**	**EC (dS/m)**	**TOC (g/kg)**	**Ash Content (g/kg)**	**TKN (g/kg)**	**TAP (g/kg)**	**Tk (g/kg)**	**C/N**	**C/P**
				Raw waste (Initial)					
TB1 CD_{100}	7.91±0.02f	1.67±0.01a	441±1.63a	238±1.65f	9.9±0.02f	7.8±0.04a	8.7±0.02a	44.5±1.04a	56.5±1.28a
TB2 CR_{10}	7.74±0.03e	1.75±0.02b	454 ± 1.46b	217±1.48e	9.2±0.05e	7.6±0.02a	9.3±0.01b	49.3±1.12b	59.7±1.33a
TB3 CR_{20}	7.58±0.01d	1.86±0.01c	469±2.12c	191±2.01d	8.6±0.04d	7.4±0.01a	9.5±0.02b	54.5±1.19c	63.3±1.12b
TB4 CR_{30}	7.47±0.01c	2.04±0.03d	476±1.44d	179±1.97c	8.1±0.03c	7.3±0.02a	10.1±0.01c	58.7±1.10d	65.2±1.20b
TB5 CR_{40}	7.32±0.02b	2.18±0.03e	487±1.78e	160±1.84b	7.98±0.03b	7.1±0.01a	10.6±0.04c	61.6±1.34e	68.5±1.76b
TB6 CR_{50}	7.10±0.01a	2.36± 0.03f	494± 1.92f	148±1.94a	7.87±0.03a	6.9±0.01a	11.1±0.02d	62.7±1.25f	71.5±1.44c
				Vermicast (Final)					
TB1 CD_{100}	7.44±0.02f	3.31±0.01e	262±1.51a	547±3.08f	28.5±0.18f	16.5±0.05e	20.9±0.04a	9.1±1.07a	17.9±1.07a
TB2 CR_{10}	7.38±0.03e	3.44± 0.02f	317±1.44b	454±3.32e	26.5±0.18e	17.4±0.04f	24.8±0.08d	11.9±1.02b	18.6±1.02b
TB3 CR_{20}	7.31±0.02d	2.79±0.01d	341±1.91c	412±3.02d	24.3±0.34d	15.8±0.03d	23.6±0.03c	14.03±1.06c	21.5±1.08c
TB4 CR_{30}	7.24±0.03c	2.53±0.03c	354±1.67d	389±3.2c	21.0±0.16c	14.4±0.04c	26.5±0.02e	16.8±1.11d	25.0±0.06d
TB5 CR_{40}	7.12±0.02b	2.42±0.03a	369±1.9e	364±3.11b	18.5±0.12b	13.2±0.02b	23.0±0.01c	19.9±0.88e	28.2±1.14e
TB6 CR_{50}	6.94±0.02a	2.47±0.03b	376±1.48f	352±3.04a	16.7±0.07a	11.3±0.05a	22.8±0.01b	22.5±1.23f	33.7±1.08f

Different alphabets in each parameter shows statistically significant difference (ANOVA, Tukey's HSD test, $p \leq 0.05$)

Table 8.8: Micronutrient content in raw waste and vermicast produced in different Trial Bins (Mean ± SEM of three replicates).

Trial Bins	Total Fe (mg/kg)	Total Zn (mg/kg)	Total Cu (mg/kg)	Total Mn (mg/kg)
Raw waste (Initial)				
TB1 CD_{100}	1128±11.2f	94.4±3.42f	49.7±0.97f	56.8±0.80f
TB2 CR_{10}	1044±10.7e	88.7±2.87e	45.3±0.90e	47.9±0.31e
TB3 CR_{20}	962±8.8d	74.1±3.11d	40.9±1.14d	40.1±0.09d
TB4 CR_{30}	885±9.1c	69.8±1.82c	30.8±0.56c	33.3±1.01c
TB5 CR_{40}	794±7.4b	62.9±1.87b	26.4±0.32b	26.9±0.05b
TB6 CR_{50}	627±7.2a	58.3±1.74a	13.4±0.08a	17.4±0.50a
Vermicast (Final)				
TB1 CD_{100}	1759±11.4f	234.1±5.63f	97.4±1.18f	95.4±1.87f
TB2 CR_{10}	1584±12.2e	189.2±3.45e	84.6±1.07e	82.6±1.56e
TB3 CR_{20}	1398±10.8d	159.6±2.28d	66.8±1.10d	69.4±0.75d
TB4 CR_{30}	1170±9.9c	134.2±2.08c	49.8±0.08c	59.6±1.02c
TB5 CR_{40}	995±8.2b	119.7±3.0b	30.8±0.04b	34.4±0.07b
TB6 CR_{50}	702±8.8a	90.9±1.89a	16.1±0.07a	27.1±0.03a

Different alphabets in each parameter shows statistically significant difference (ANOVA, Tukey's HSD test, $p \leq 0.05$)

Mean statistical difference among various vermicomposts for increased copper content was statistically significant ($p < 0.05$). In comparison to initial levels (17.4 – 56.8 mg/kg), Mn escalated to 27.1 - 95.4 mg/kg in all the trial bins. Statistically significant difference was found among the vermicasts prepared ($p < 0.05$). Vermi-treatment enhanced micronutrient content in vermicast produced from all the combinations of carrot leaf and cow dung were within the allowed limits to be used as an organic fertilizer in agricultural and horticultural applications [177],[129].

e) Change in Biological Parameters (Biomass Gain, Earthworm Population, Earthworm Growth and Fecundity)

Biological parameters were assessed to know the efficacy of raw waste in vermicomposting as feed stock for earthworms (Table 8.9). Earthworm population at the end of vermicomposting process marks its success [91]. Biomass gain, growth status, fecundity and cocoon production are important determinants of feed acceptability by earthworms and hence good vermicompost. Initially, live earthworm biomass ranged from 336 - 448 mg/worm at the end. It increased maximally to 821 - 1534 mg/worm with highest biomass gain of 1178 mg/worm after 75 days of vermicomposting. Different trial bins showed statistically significant variation for maximum live biomass in carrot leaf vermicomposts ($p<0.05$). CD had shown more growth due to its good palatability, accumulation of microbes and presence of organic matter. Increase in earthworm biomass was recorded as: CD_{100} (1178mg/worm) > CR_{10} (1086mg/worm) > CR_{20} (984 mg/worm) > CR_{30} (861mg/worm) > CR_{40} (663mg/worm) > CR_{50} (432mg/worm).

Biomass gain decreased with increasing proportion of carrot leaves as higher percentage affected earthworms' growth. Biomass gain by earthworms in suitable feedstock has been reported by other authors also [63],[61],[115]. In the present study, 20 earthworm individuals were introduced for vermi - conversion of different proportions of carrot leaves and cow dung. CD as bulking material in 10-30% carrot leaves provided conducive environment for earthworms. Maximum *Eisenia fetida* population was evident in CD_{100} (64 ± 3.4) followed by CR_{10} (58 ± 3.8), CR_{20} (53 ± 5.6) and CR_{30} (42 ± 2.9). Least population increase at the termination of experiment was found in CR_{50} due to least amount of cow dung and more proportion of carrot leaf waste. Population increase was more marked in trial bin CD_{100} which can be attributed to better acceptability of raw waste. Difference between TB2 & TB3 and TB5 & TB6 was statistically insignificant for the final earthworm population ($p< 0.05$), however, statistical difference was found in TB1 and TB4 from other combinations.

Earlier research also suggested rise in earthworm population as the vermicomposting process ends [90]. Highest cocoon number was noticed for CD_{100} (239 ± 7.4) preceded by CR_{10} (205 ± 8.9), CR_{20} (160 ± 5.2), CR_{30} (106 ± 4.1), CR_{40} (45 ± 4.0) and CR_{50} (26 ± 6.7). Availability of organic matter and nutrients in CD favored earthworm fecundity and cocoon production. Addition of CD in appropriate proportions can favor earthworm growth and fecundity. Mean difference for cocoon production was statistically significant for all trial bins ($p<0.05$).

Growth rate reflects earthworm growth in raw waste mixtures marking the fate of vermicomposting process and relies on the chemical nature of raw material as well as amendments like cow dung [93]. 100% CD had the highest growth rate (mg weight/worm/day) as it supported earthworms with good nutrient content and organic matter. CR_{50} showed least growth rate that might be due to less amount of cow dung as bulking agent. Growth rate trend in different trial bins followed the order: CD_{100} (21.81 mg/worm/day) $>$ CR_{10} (20.11mg/worm/day) $>$ CR_{20} (13.66 mg/worm/day) $>$ CR_{30} (11.9 mg/worm/day) $>$ CR_{40} (7.36 mg/worm/day) $>$ CR_{50} (4.8 mg/worm/day). Statistically significant variation was found in carrot leaf vermicomposts for growth rate comparison ($p<0.05$).

Organic contents that are easy to metabolize are supportive in earthworm growth and fecundity. Fecundity rate (cocoon/worm) was good (2.52- 3.8) up to 30% CRLW and was affected in higher proportions of carrot leaves. Fecundity rate, viability of cocoons produced and survival of earthworms is dependent on the nature of waste materials.

Table 8.9: Biological characteristics of raw waste and vermicast in different Trial Bins (Mean ± SEM of three replicates)

Vermi-reactor	Earthworm population		Individual earthworm biomass(mg)		Mean Biomass gain (mg)	No. of cocoons	Biomass achieved (days)	Fecundity (cocoon /worm)	Growth rate /worm/day (mg)
	Raw waste	Vermicast	Raw waste	Vermicast					
TB1 CD_{100}	20	63±3.4d	346±3.8b	1524±7.6e	1178±7.9f	239±7.4f	54	3.8±0.06f	21.81±0.05f
TB2 CR_{10}	20	58±3.8c	423±4.2e	1534±8.3f	1086±8.2e	205±8.9e	54	3.53±0.05e	20.11±0.04e
TB3 CR_{20}	20	53±5.6c	448±4.8f	1432±6.4d	984±6.8d	160±5.2d	72	3.02±0.04d	13.66±0.02d
TB4 CR_{30}	20	42±2.9b	336±6.1a	1197±5.6c	861±5.6c	106±4.12c	72	2.52±0.05c	11.9±0.01c
TB5 CR_{40}	20	29±4.0a	410±3.6d	1073±3.2b	663±4.6b	45±4.03b	90	1.55±0.06b	7.36±0.02b
TB6 CR_{50}	20	24±2.2a	389±6.7c	821±4.3a	432±2.5a	26±3.7a	90	1.08±0.03a	4.8±0.04a

Different alphabets in each parameter shows statistically significant difference (ANOVA, Tukey’s HSD test, $p \leq 0.05$)

8.2.4 CONCLUSIONS

Carrot leaves amended with cow dung is enriched with nutrients and found to be feasible for vermicomposting when used in moderate proportions. 10-30 % of carrot leaves can be effectively used in vermicomposting as it favors earthworm growth and fecundity. Carrot leaf vermicomposts had increased macro & micro nutrient levels and ash contents but reduced TOC, C:N and C:P. Higher proportions were not so efficient in supporting earthworm growth whilst demonstrated enhancement in NPK levels specially potassium content. It might be due to good potassium contents in waste materials initially. Vermicomposting of carrot leaf waste is a novel study in context as it has not been tried previously as feed stock for earthworms and can be availed to regain nutrients packed in carrot leaves. Vermicomposting comes out to be a sustainable and environmentally sound technique for obtaining bio-fertilizer with enhanced nutrient levels from carrot leaves.

Chapter 9

VERMICOMPOSTING OF RICE RESIDUE INTO VALUABLE PRODUCT VERMICOMPOST USING COW DUNG AND LEAF LITTER AS AMENDMENTS

9.1 INTRODUCTION

Agricultural residues are generated after the economic portion of crop is harvested in the fields and generally comprises of stalks, straws, cobs, husk etc. These are often accumulated as piles around the field either left for decomposition on their own or burnt. Rice *(Oryza sativa)* residue / straw is the discarded biomass of rice after harvesting is accomplished. About 80% part of rice crop gets wasted and ill dumped in fields [248] and this relies on the height at which rice crop is being cut. Remaining portion of rice crop is either burnt or left as such for degradation. Globally, India is the second largest producer of rice with production of 124 million metric tons on annual basis in year 2021 (Statista Research Department, 2022). Rice residue can be used for composting and carbonization for conditioning of soils, production of bio energy and for industrial materials recovery such as silica and bio-fiber [255].

Collection of rice residue on manual basis is laborious and costly task for farmers and affects soil fertility if left as such as sufficient time is needed for its effective decomposition [256] to contribute in soil fertility. Rice residue is rich in potassium and can be used as soil amendment but it requires effective time to decompose. In Haryana state too, due to slow decomposition rate, most of rice is burnt openly in fields by farmers leading to air pollution and subsequent health impacts. In spite of ban on burning of rice straw, farmers consider this as the only option for disposal and management thus posing a threat to air quality (smog production) and loss of potential nutrients [257], if left in fields, sets breeding ground for pests and spread diseases [258]. Due to practical implications, farmers tend to follow this practice, it cannot be used for other purposes [259] and a vast source of nutrients get wasted every year along with negative impact on environment. Thus, there is a need to find sustainable solutions for rice residue management.

On the other hand, leaf litter forms the profound part of sub - urban and urban areas and often found heaped up in fields, street & road sides, gardens and parks. There is no separate collection and transportation of leaf litter to any treatment facility, however, carried to landfills unknowingly as an unavoidable part of municipal solid waste [198], decomposes naturally occupying land resource or burnt up in piles leading to air pollution [260]. Leaf litter decomposes and release nutrients [261] that can enrich soil and uptaken by plants for growth. Thus, leaf litter is a rich source of nutrients for soil and can be converted into bio manure by efficient composting / vermicomposting process.

The current research was planned to establish suitability of rice residue and leaf litter in combination as potential feed substrate for earthworms to carry out vermiconversion. Vermicomposting is a promising technique to recover and recycle nutrients from organic portion of wastes back to the soil [262] that employs earthworms to bio-transform the waste materials into an effective manure to increase soil fertility [235],[263]. Earlier studies had focused on vermicomposting of rice waste using different amendments such as Lim et al. [64]; Yan et al. [257]; Shak et al. [264]; Sharma and Garg [93]; Zhi-Wei et al. [88]) as well as leaf litter /garden waste by Gajalakshami et al. [207]; Li et al. [130]; Karwal and Kaushik [89] and Sharma et al. [83] separately whilst very few studies have been performed on co-management of rice residue and leaf litter.

An effort was made to use leaf litter available in fields as an organic amendment for rice residue and reduce the amount of cow dung used in the process. Problem of rice residue and leaf litter generated in copious amounts at local level has been addressed in the study with a belief to set a stage for their simultaneous management and recovery of nutrients.

9.2 MATERIALS AND METHODS

9.2.1 Earthworms, Cow Dung, Rice Residue and Leaf Litter

Earthworm *Eisenia fetida* was taken from the stock culture maintained in laboratory. Cow dung (excrement) was taken locally from a dairy farmhouse. Rice residue was imported from agricultural fields of Faridabad after harvesting of rice crop. Due to slow decomposition rate, most of rice is burnt by farmers leading to air pollution. Rice residue was mixed with leaf litter to reduce proportion of cow dung. Leaf litter was collected from JC Bose UST campus and comprised of mix of fallen leaves of Neem, Jamun and Ashoka trees. The feed materials were analyzed for their physicochemical parameters - pH, electrical conductivity (EC), organic matter (OM), ash content, total organic carbon (TOC), macronutrients – total kjeldahl nitrogen (TKN), total available phosphorus (TAP), total potassium (TK) and micronutrients (Total Fe, Mn, Zn, Cu & Pb) individually (Table 9.1).

9.2.2 Experimental Design

In a prelim experiment, seven vermi containers containing different proportions of Rice residue and cow dung were vermicomposted for 84 days with the help of earthworm *Eisenia fetida*. The best ratio of these vermi containers was found to be with 30% Rice residue + 70% Cow dung in terms of nutrient content and earthworm growth which was considered in the present study. Another waste material leaf litter was added in the vermi-boxes. Eight vermi-boxes were set up with 30% rice residue mixed with 10 -70% leaf litter (Table 9.2). Twenty earthworms were introduced into different vermiboxes after 3 weeks of pre-composting. Experiment was carried out for 63 days and all the physico-chemical parameters were evaluated.

9.2.3 Physico-chemical Analysis and Vermicompost Maturity Indices

The analytical procedures were followed as mentioned in chapter 3.

9.2.4 Biological Parameters

The biological parameters related to earthworm growth and productivity were analyzed as mentioned in chapter 3.

9.2.5 Statistical Analysis

The parametric values were represented as mean of triplicates ± Standard error of mean and analyzed using ANOVA, Tukey's HSD, $p<0.05$.

Table 9.1: Physico-chemical characteristics of initial Cow Excrement (CE), Rice . residue (RR) and Leaf litter (LL) employed in vermicomposting (n=3; mean ± SEM)

Parameters	Cow Excrement (CE)	Rice Residue (RR)	Leaf Litter (LL)
pH	8.1±0.06	7.52 ±0.20	6.65±0.04
EC (dS/m)	2.26±0.04	1.22±0.03	1.38±0.03
Ash content (g/kg)	186±1.44	145±1.20	213.8±1.58
OM (g/kg)	814±1.60	855.1±1.02	786.1±1.08
TOC (g/kg)	472.1±1.32	496±1.25	456±1.20
TKN (g/kg)	8.2±0.03	9.84±0.04	13.5±0.02
TAP (g/kg)	7.4±0.02	3.33±0.04	2.94±0.03
TK (g/kg)	7.8±0.04	20.71±0.03	4.78±0.01
C:N ratio	52.1± 1.28	27.6±0.01	33.79±0.02
C:P ratio	59.8± 1.18	42.9±0.03	155.1±0.01
Moisture content (%)	83±0.11	19.6±0.25	82.3±0.8
Total Cu (mg/kg)	28.2±0.03	29.1±0.1	20.4±0.002
Total Fe (mg/kg)	1541±1.4	356±2.40	1098±2.08
Total Zn (mg/kg)	87±0.12	16.3±0.06	6.2±0.04
Total Pb (mg/kg)	26.4±0.03	4.5±0.04	7.12±0.02
Total Cd (mg/kg)	3.25±0.05	2.38±0.01	0.20±0.06

Table 9.2: Composition and ratio of CE, RR and LL in different Vermi-boxes)

Vermi Box (VB)	Nomenclature	Vermi Box composition			Feed material ratio
		CE(%)	**RR(%)**	**LL(%)**	
VB-I	LL_0	70	30	—	7:3:0
VB-II	LL_{10}	60	30	10	6:3:1
VB-III	LL_{20}	50	30	20	5:3:2
VB-IV	LL_{30}	40	30	30	4:3:3
VB-V	LL_{40}	30	30	40	3:3:4
VB-VI	LL_{50}	20	30	50	2:3:5
VB-VII	LL_{60}	10	30	60	1:3:6
VB-VIII	LL_{70}	—	30	70	0:3:7

9.3 RESULTS AND DISCUSSION

9.3.1 Effect on pH and EC

On 0^{th} day, pH ranged from 7.20 ± 0.02 - 7.96 ± 0.02 in different vermi - boxes. The 63 days of vermicomposting reduced pH levels in all the vermi-boxes varying from 6.70 ± 0.03 - 7.34 ± 0.02 (Table 9.3). Highest pH reduction was recorded in VB-IV (7.85%), followed by VB-V (7.75%), and least in VB - VIII (6.9%). pH levels were in the near neutral range in all the vermi-boxes which explained organic matter degradation along with organic acids generation via earthworm and microbial action. Humic and fulvic acid formation reduces pH to slightly acidic or neutral. Previous studies have also recorded decrease in pH level at the completion of vermicomposting process [64],[93]. No significant difference was seen in VB-I, VB-II and VB-III with respect to change in pH levels while VB-IV, VB-V, VB-VI, VB-VII and VB-VIII showed significant difference ($p < 0.05$).

Experimental findings showed an increase in EC in all the vermi-boxes irrespective of varied feed material combinations. At 0^{th} day, electrical conductivity varied from 1.34 dS/m - 2.24 dS/m in experimental vermi-boxes (VB I - VB VIII). EC instigated in all the vermi boxes ranging from 2.28 - 3.42 dS/m after 63 days of vermicomposting which is within the safe limits (<4dS/m) for agronomic applications (Table 9.3). The order of increment in EC values was registered as: VB-IV (70.2%) > VB-V (58.7%) > VB-III (56.9%) > VB-VI (54.7%) > VB-VII (54.3%) > VB-VIII (53.0%) > VB-II (48.8%) > VB-I (47.7%). The EC increase was more effective in vermicomposting of 30% RR + 30% LL + 40% CD. This indicates that the rate of organic degradation depends upon the addition of bulking agent in suitable proportions. Increment in salts followed by organic matter loss and further production of mineral ions resulted in increased EC [117],[109]. Conversion of organically binded nutrient elements to accessible forms, production of soluble salts, ammonium and other inorganic ions due to combined activites of earthworms and micro-organisms enhanced the value of EC. Different vermi-boxes were significantly variable from each other for increment in EC except for VB-II & III ($p<0.05$).

9.3.2 Effect on TOC and Ash Content

All the vermi-boxes showed the trend of decline in comparison to initial feed material after 63 days of vermicomposting. TOC content dropped from 465 ± 1.8 - 509 ± 1.02g/kg in initial combinations to 333 ± 1.03 - 231 ± 0.03g/kg in final vermicomposts (Table 9.3). Decrease of 28.3 - 54.6% was noticed in various vermi-boxes based on organic carbon utilization by earthworms and microorganisms. Feed combinations with high proportion of leaf litter showed less TOC decrement. This might be due to more microbial and earthworm activity required for leaf litter breakdown [219]. More carbon reduction was observed when leaf litter was added to rice residue along with cow excrement in comparison to first part of experimentation where rice residue was mixed with cow excrement only (24.3 - 32.0%). This suggests that nature and amount of amending materials affects vermicomposting process. Earlier studies also reported decline in TOC of 32.2 - 52.8% [265]; 39.9 - 48.2% [93]; 46.3% [130], 24.34 - 38.25% [84]. Thomas et al. [205] reported 16.68 to 58.59% reduction in TOC during vermicomposting of different types of agricultural residues. Earthworms in conjugation with microbes consume carbon pool as an energy source, release carbon dioxide as a result of respiration and other activities and reduced TOC at the end of vermicomposting process. Use of leaf litter and CE as bulking materials increased earthworm and microbial activity and improved decomposition of rice residue. The difference among all the vermi boxes for TOC drop was statistically significant ($p<0.05$).

Earthworm and microbial activity enhanced feed material decomposition and so as the ash content in comparison to the initial feed materials. Ash content was in the range of 122 ± 1.08 - 19 ± 1.16g/kg and raised to levels of 432 ± 1.12 - 475 ± 1.13 g/kg. Low mineralization might lead to less increase in ash contents in some vermi-boxes [154]. No significant variation was observed in vermi-boxes with respect to enhanced ash content in vermicomposts produced from different feed combinations.

Table 9.3: Physico-chemical characteristics of CE + RR + LL and final vermicompost in different Vermi-boxes (Mean ± SEM, n=3)

Vermi Box (VB)	pH	EC (dS/m)	TOC (g/kg)	Ash Content (g/kg)	TKN (g/kg)	TAP (g/kg)	Tk (g/kg)	C/N Ratio	C/P Ratio
Feed material 0th(day)									
VB-I	7.96±0.02h	2.24± 0.1c	465 ± 1.8	198±1.16h	8.4±0.02a	7.8±0.04h	12.9±0.01a	55.3±1.28h	59.6±1.13a
VB-II	7.89±0.02g	2.11±0.04b	469± 1.92	191±1.11g	9.38±0.02b	7.52±0.02g	14.1±0.02b	50.0±1.25g	62.36±1.08b
VB-III	7.74±0.01f	2.02±0.02b	475± 1.09	181±1.20h	10.36±0.01c	6.94±0.03f	15.3±0.01c	45.84±1.12f	68.4±1.42c
VB-IV	7.64±0.03e	1.95±0.03a	482± 1.67	169±1.44ef	11.38±0.03d	6.47±0.05e	16.7±0.03d	42.3±1.32e	74.49±1.3d
VB-V	7.58±0.01d	1.82±0.01a	487±1.05	160±1.14d	12.3±0.01e	5.91±0.02d	17.9±0.02e	39.5±1.20d	82.4±1.01e
VB-VI	7.41±0.02c	1.70± 0.02	496± 1.12	144±1.03c	13.4±0.02f	5.64±0.02c	19.1±0.002f	37.0±1.16c	87.9±0.09f
VB-VII	7.33±0.01b	1.62±0.01a	499± 1.16	139±1.11b	15.29±0.03g	5.12±0.01b	20.31±0.03g	32.6±1.42b	97.4±1.23g
VB-VIII	7.20±0.02a	1.49±0.06a	509±1.02	122±1.08a	16.2±0.01h	5.03±0.02a	22.4±0.001h	31.4±1.08a	101.1±0.87h
Final Vermicompost 63rd(day)									
VB-I	7.34±0.02g	3.31±0.02g	333±1.03h	454± 1.23c	22.8±0.01d	12.6± 0.01g	19.6±0.03a	14.6± 0.96d	24.4±1.28b
VB-II	7.28±0.03f	3.14±0.01e	325±0.09g	432± 1.12a	25.8±0.03e	11.2± 0.02f	20.6±0.06b	12.5± 1.21c	29.0±1.04c
VB-III	7.26±0.02f	3.17±0.02e	318±1.12f	443±1.20b	28.6± 0.02f	10.2± 0.03e	21.8±0.05c	11.1±1.05b	31.1±2.97d
VB-IV	7.04±0.04e	3.22±0.02f	304±0.06e	453±1.34c	32.1±0.02g	13.3± 0.02h	28.9±0.06h	9.47±1.15a	22.8±1.04a
VB-V	7.01±0.03d	2.89±0.04d	289±0.05d	457± 1.42c	23.6±0.01d	7.86±0.02d	26.7±0.03g	12.2±1.0c	36.7±1.11e
VB-VI	6.86±0.03c	2.63±0.02c	278±0.03c	465±1.01c	22.2±0.03c	7.45±0.01c	25.2±0.01f	12.5±1.08c	37.3±0.92f
VB-VII	6.79±0.02b	2.50±0.01b	254± 0.04 b	469±1.09cd	20.1±0.03b	6.39±0.01b	22.2±0.04d	12.6±1.02c	39.7±1.64g
VB-VIII	6.70±0.03a	2.28±0.02a	231±0.03a	475±1.13d	16.7±0.02a	5.20±0.001a	23.1±0.06e	13.8±1.34d	44.4±2.89h

Mean value followed by different letters is statistically different (ANOVA; Tukey's test, $p \leq 0.05$)

9.3.3 Effect on TKN, TAP and TK Content

Vermi-conversion of feed materials lead to organic matter mineralization and depletion of carbon pool thus resulting in amplification of nutrients (NPK) from the previous levels [173]. Initial and final values of TKN, TAP and TK are presented in Table 9.3. Remarkable surge in TKN was recorded in all the vermi-boxes in comparison to initial feed materials. TKN levels were considerably higher in the final vermicompost (16.7 - 30.1 g/kg) from initial feed combinations (8.4 - 16.2 g/kg). There was 1.03 – 2.82 fold increment; highest increase was observed in VB-IV (from 11.38 to 32.1 g/kg) followed by VB-III (from 10.3 to 28.6 g/kg) and VB-VIII showed minimum increase (from 16.2 to 16.7g/kg) (Figure 9.1). Highest increment in VB-IV containing 30 % rice residue along with 30% leaf litter might be due to good content of nitrogen in feed materials initially and effective mineralization. As the amount of leaf litter increased and cow excrement decreased, nitrogen escalation was minimum and therefore VB-VIII without cow excrement showed least hike in nitrogen levels. Appropriate amount of cow excrement was required to sustain rice residue and leaf litter vermicomposting. About 1.2 – 2.9 fold increase in total nitrogen was registered by Sharma and Garg [93] during vermicomposting of rice residue and paper waste. Significant difference was found for nitrogen content in all the vermi-boxes except for VB-I and VB-V ($p < 0.05$). Rise in nitrogen contents can be attributed to efficient nitrogen mineralization, degradation of organic carbon, production of excretory materials and mucus along with decrease in feed mass and presence of nitrogen in feed materials and bulking agents [154]. Blending rice residue with leaf litter and cow excrement helped in increasing nitrogen concentration in vermicompost and as the amount of cow excrement decreased, nitrogen increase was also less marked. CE and other organic amendments influence the rise in TKN levels [84].

TAP in all the combinations were found to be slightly more than the starting materials. Initial phosphorus content was between 5.03 – 7.8 g/kg and increased to 5.2 - 13.6 g/kg in end products (Table 9.3). About 1.03 to 2.05 times increase in phosphorus levels was observed with highest increase of 2.05 fold in VB-IV containing CD, RR and LL in 4:3:3 ratio and lowest increase (1.03 fold) in VB-VIII having RR and LL in ratio of 0:3:7 (Figure 9.1). Increase of 1.03 fold TAP was recorded for garden waste by Li et al [130]. Rise in phosphorus can be attributed to organic matter decomposition by earthworms and microbes and soluble phosphorus released by phosphate solubilizing bacteria in earthworm's gut in course of vermiconversion. With increase in leaf litter content, phosphorus content increase was less owing to less amount of phosphorus in initial feed materials. Phosphorus gets converted into plant available forms during vermicomposting [266] and increased plant growth and metabolism when applied in the field [195]. Mean difference in all the vermi-boxes for increased TAP was statistically significant ($p<0.05$).

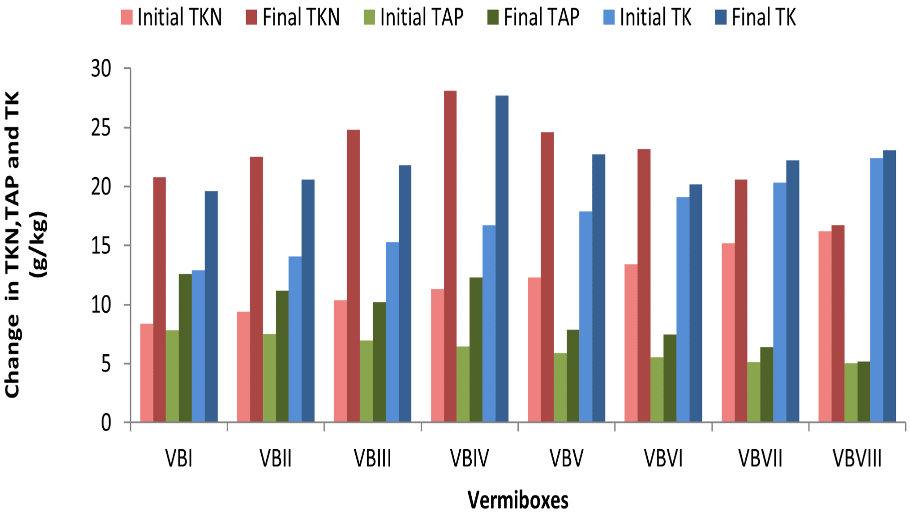


Figure 9.1: Changes in TKN, TAP and TK (g/kg) in different Vermi-boxes

After vermicomposting of 63 days, TK concentration was magnified than initial feed materials in all the eight vermi-boxes up to variable extents. There was 1.02 - 1.7 times increment in potassium levels at the end of experimentation. At the onset of vermicomposting, potassium content varied in range of 12.9 - 22.4 g/kg and increased to 19.6 - 28.9 g/kg after vermicomposting (Table 9.3). Rice residue and leaf litter without cow excrement had shown minimal increase in TK whereas highest increment was noted for 30% RR amended with 30% LL and 40% cow excrement (Figure 9.1). Potassium content among all the vermi-boxes showed significant variation ($p<0.05$). Previous studies are indicative of escalated potassium content in final vermicompost [111]. Our findings showed that addition of leaf litter in combination with cow excrement to rice residue had improved potassium levels in final vermicompost.

9.3.4 C:N & C:P Ratios

The initial values of C:N ratio were in between 31.4 - 55.3 and dropped to 9.47 - 14.6 in final vermicomposts (Table 9.3). C:N ratio shows rate of degradation of organic waste materials and followed a declining trend in all vermi-boxes as the process proceeded towards completion: VB-IV (77.6%) > VB-III (75.1%) > VB-II (75%) > VB-I (73.5%) > VB-V (69.1%) > VB-VI (67%) > VB-VII (61.3%) > VB-VIII (56.05%) (Figure 9.2). Previous reports have also noted reduction in C:N ratio of the vermicomposted feed materials owing to organic matter mineralization, respiratory loss of carbon dioxide and enhancement of nitrogen levels during the process [230], [93]. High content of leaf litter with less addition of cow dung showed least decline in carbon to nitrogen ratio as leaf litter might limit the degree of decomposition as compared to VBs having less leaf litter .VB-III & IV differ significantly from rest of the vermi-boxes ($p<0.05$) although other VBs were statistically indifferent from each other for reduction in C:N levels. A C:N ratio below 20:1 is regarded ideal for compost maturation and thus stabilization of finalized products [118].

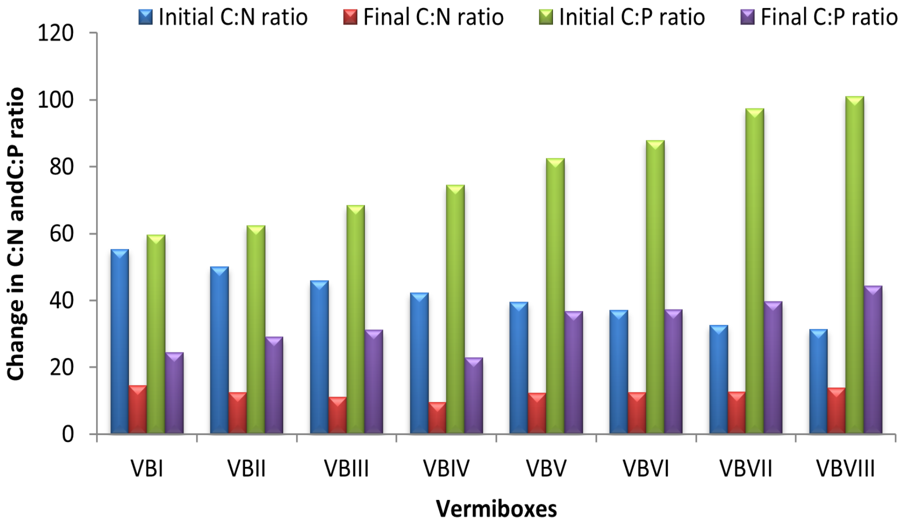


Figure 9.2: Changes in C:N and C:P ratio in different Vermi-boxes

In the present study, drop in C:P ratio significantly varied among all the seven vermiboxes ($p< 0.05$). At zeroth day (start of experiment), C:P levels were between 59.6 - 101.1 and following the trend of decline reached to the levels in the range of 22.8 - 44.4 after the termination of experiment (Figure 9.2). Phosphorus from binded forms is converted into its available form in final vermicompost. Yan et al. [257] also noted escalated amounts of total phosphorus in vermicompost obtained from grass clippings, rice straw and sago waste. C to P ratio of 15:1 is prime for better absorption by plants [12].

9.3.5 Effect on Micronutrient Levels (Fe, Zn, Cu, Pb, Cd)

Micronutrients, viz., Fe, Cu, Zn, Pb and Cd are important for plant development in trace amounts, therefore, it is imperative to know their level of increase or decrease after vermicomposting of feed materials. The study showed manifold change in the micronutrients' level of all the vermi-boxes but to variable extents (Table 9.4). Fe as an important micro-element helps in a plants' biological processes and biosynthesis of chlorophyll. Enzymes produced in the worm's gut increase the concentration of Fe in final vermicompost during organic matter degradation. Fe concentration significantly increased by 1.01-1.20 fold in final vermicomposts and a significant statistical difference was found among all vermi boxes ($p<0.05$). On zeroth day, Fe content ranged from 985 ± 7.75 - 1648 ± 11.8 mg/kg and increased to 1041 ± 6.67- 1889 ± 12.2 mg/kg on 63^{rd} day. Zn maintains hormone balance and is involved in cell division.

Incremental change of 1.66 - 2.02 times was observed for Zn levels in all the combinations and raised to 19.0 ± 0.32 - 141 ± 2.45 mg/kg from the initial levels 11.5 ± 0.23 - 89.2± 2.78 mg/kg. Significant variations in various vermi-boxes were found for Zn levels ($p< 0.05$). Cu is essential for photosynthetic processes and aids in enzyme synthesis.

Cu content enhanced from 12.1 ± 0.34 - 21.7 ±1 .75 mg/kg to 13.0 ± 0.31 - 26.0 ± 0.67 mg/kg in final products owing to Cu containing enzymes that might have increased Cu concentration. Mean statistical difference among various vermicomposts produced in all combinations for increased copper content was statistically significant ($p<0.05$). In comparison to initial levels (11.60 ± 0.42 - 30.2 ± 1.25 mg/kg), Pb content raised to 13.6 ± 0.84 - 47.1 ± 0.34 mg/kg in all the feed combinations irrespective of different proportions. Statistically significant difference was found among the feed mixtures ($p<0.05$) with an increase of 1.17 - 1.61 fold. Cd levels followed a trend of decrease in vermi-boxes and registered 1.15 - 1.54 fold decrement with final levels of 0.59 ± 0.01 - 2.17 ± 0.05 mg/kg in final vermicomposts.There was a significant variation in all the boxes for change in Cd levels ($p<0.05$). Many studies showed an increase in micronutrient content [93] as the process ends owing to release of organically bound metals into free forms due to mineralization of organic materials by earthworms [166],[173]. The micronutrient levels were well within the permissible limits for its use as an organic fertilizer in agricultural and horticultural applications [129].

Table 9.4: Micronutrient levels in initial feed mix and final vermicompost in different Vermi-boxes (Mean ± SEM, n=3) .

Vermi Box(VB)	**Total Fe (mg/kg)**	**Total Zn (mg/kg)**	**Total Cu (mg/kg)**	**Total Pb (mg/kg)**	**Total Cd (mg/kg)**
Initial feed mix 0th(day)					
VB-I	1648±11.8h	89.2±2.78h	21.7±1.75e	31.2±0.14h	3.08±0.07h
VB-II	1557±12.2gh	75.2±1.5g	20.8±2.45e	27.8±0.34g	2.73±0.08g
VB-III	1466±11.5f	60.5±1.56f	19.2±0.23de	25.5±0.18f	2.39±0.05f
VB-IV	1370±9.3e	48.3±1.1e	18.4±1.67d	22.6±0.67e	2.04±0.04e
VB-V	1271±10.4d	32.3±1.18d	16.8±1.02cd	20.2±0.88d	1.72±0.06d
VB-VI	1176±8.90c	28.4±0.98c	15.7±1.78c	17.85±0.60c	1.36±0.01 c
VB-VII	1080±8.67b	19.3±0.67b	14.5±0.54b	14.5±0.54b	1.04±0.02 b
VB-VIII	985±7.75a	11.5±0.23a	12.1±0.34a	11.60±0.42a	0.68±0.04a
Final Vermicompost 63rd(day)					
VB-I	1889±12.2h	141±2.45h	26.0±0.67h	47.1±0.34h	2.17±0.02h
VB-II	1797±11.4g	115±1.89g	24.9±0.82g	43.5±0.26g	2.04±0.02g
VB-III	1701±10.6f	97.5±1.34f	23.2±1.18f	41.1±0.42f	1.98±0.01f
VB-IV	1644±10.1e	77.2±1.2e	22.8±1.08e	35.0±0.54e	1.32±0.02e
VB-V	1487±9.8d	64± 1.13d	19.8±1.38d	26.6±1.04d	1.21± 0.02d
VB-VI	1386±8.2c	48.8±0.87c	17.8±1.40c	22.3±0.18c	1.14±0.02c
VB-VII	1144±9.1b	33±0.56b	16.2±1.3b	17.94±0.84b	0.98±0.01b
VB-VIII	1041±6.67a	19.0±0.32a	13.0±0.31a	13.6±0.84a	0.59±0.01a

Mean value followed by different letters is statistically different (ANOVA; Tukey's test, $p \leq 0.05$)

9.3.6 Effect on Earthworm Growth and Productivity

a) Effect on Earthworm Biomass

Initial mean live earthworm biomass varied from 254 ± 3.28 to 345 ± 4.20 mg/worm and increased to 905 ± 2.9 to 1461 ± 5.4 mg/worm after 63 days of vermicomposting (Figure 9.3). Different vermi-boxes exhibited statistically significant variation for live biomass ($p < 0.05$) except for VB-VII & VIII. Increase in biomass was slow during the first week and gradually pacified after 2^{nd} week, maximum biomass was achieved on 56^{th}day (VBs III, IV and V) and on 63^{rd} day (VBs I, II, VI ,VII and VIII) (Table 9.5). As soon as worms get acclimatized to feed environment, feed palatability increases thereby accelerating the weight of earthworms [111].

CE: RR : LL in ratio of 4:3:3 had shown more growth owing to increased palatability of rice residue blended with leaf litter and cow excrement due to addition of high organic matter and nutrient content. Leaf litter and cow excrement favored growth due to microbial communities, palatability and more organic matter, however, higher leaf litter content and less cow excrement was not that much favorable for biomass gain. Biomass gain was significantly different in all vermi- boxes ($p< 0.05$) and ranged from 560 ± 3.8 - 1168 ± 9.9 mg/worm and followed the order: 1168 mg (VB-IV) > 1156 (VB-III) > 1153 mg (VB-I) > 1145mg (VB-II) > 989 mg (VB-V) > 876 mg (VB-VI) > 654 mg (VB-VII) > 560 mg (VB-VIII). Biomass gain in different vermi-boxes can be seen in Figure 9.3. Minimum gain in biomass was recorded in VB-VIII containing higher proportion of LL and no proportion of CE. It showed that nature and amount of amending materials play an important role in better biomass gain.

b) Effect on Earthworm Population

Leaf litter as bulking material in addition to CE provided more conducive environment for earthworms, hence *Eisenia fetida* population was more evident in VB-IV (130 ± 2.9) preceded by VB-III (127 ± 4.8) (Table 9.5). Least population increase (63 ±2 .2) at the completion of experiment was noticed in VB-VIII due to zero percent cow excrement and high proportion of leaf litter, henceforth, better acceptability of feed materials (CE: RR: LL) in ratio of 4:3:3. Difference between the vermi-boxes I, II and V and VB III and IV were statistically insignificant for the final earthworm population ($p<0.05$).

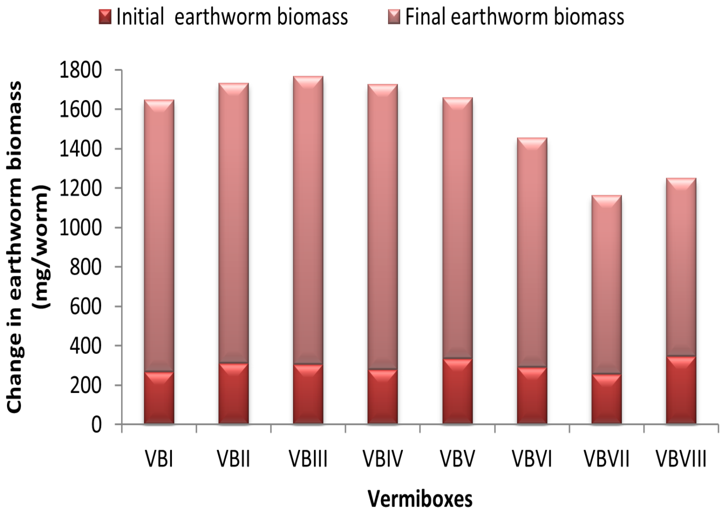


Figure 9.3: Change in Mean live earthworm biomass in different Vermi-boxes

c) Effect on Cocoon Production

Mean difference for cocoon production was statistically significant for all vermi boxes ($p < 0.05$). Highest cocoon number was recorded for VB-IV (452 ± 7.1) preceded by VB-III (410 ± 5.9g), VB-II (376 ± 6.3), VB-I (358 ± 7.4), VB-V (337 ± 3.2), VB-VI (206 ± 2.8), VB-VII (142 ± 1.9) and VB-VIII (77 ± 1.67) (Table 9.5). Nutrient content in VB-IV due to addition of LL with CE was in favor of earthworm fecundity and cocoon production. Fecundity rate, viability of cocoons produced and survival of earthworms are dependent on the nature of waste blends. Rice residue when mixed with leaf litter and cow excrement in appropriate proportions can favor earthworm growth and fecundity. Leaf litter as amendment reduced the amount of cow dung to be used where rice residue is to be treated through vermicomposting.

d) Effect on Earthworm Growth Rate (mg /worm /day)

In current research, VB-IV had the highest growth rate (mg weight/worm/day) in which addition of 30% LL + 40% CE in 30% RR supported earthworms with better nutrient and organic matter content. This can also be explained by decrease of total carbon and organic matter in VB-IV. Growth rate in VB-IV was also better than VB-I with 7:3:0 ratio of CE:RR:LL. Vermi-box VIII showed least growth rate that might be due to absence of cow excrement and high amount of leaf litter as bulking materials.

Table 9.5: Biological characteristics of initial feed mix and final vermicompost in different Vermi Boxes (Mean ± SEM, n=3)

Vermi-reactor	**Earthworm population**		**Individual earthworm biomass(mg)**		**Mean Biomass gain (mg)**	**No. of co-coons**	**Biomass achieved (days)**	**Fecundity (cocoon /worm)**	**Growth rate /worm/day (mg)**
	Initial	Final	Initial	Final					
VB-I	20	118±5.6d	268±3.7b	1381±8.4d	1153±10.8f	358±7.4e	63	3.03	18.30±0.05e
VB-II	20	120±4.5d	312±4.4f	1421±7.3e	1145±12.2e	376±6.3f	63	3.14	18.17±0.08e
VB-III	20	127±4.8e	305±6.2e	1461±5.4g	1156±10.3f	410±5.9g	56	3.23	18.34±0.5e
VB-IV	20	130±2.9e	279±3.2c	1447±6.5f	1168±9.9g	452±7.1h	56	3.47	20.85±0.11f
VB-V	20	112±4.0d	335±4.5g	1324±8.07c	989± 7.8d	337±3.2d	56	3.01	17.66±0.06d
VB-VI	20	102±3.4c	289±3.02d	1165±7.2b	876±7.2c	206±2.8c	63	2.02	13.90±0.03c
VB-VII	20	86±2.6b	254±3.28a	908±4.6a	654±6.4b	142 ±1.9b	63	1.65	10.38±0.05b
VB-VIII	20	63±2.2a	345±4.20h	905±2.9a	560±3.8a	77±1.67a	63	1.22	8.8±0.02a

Mean value followed by different letters is statistically different (ANOVA; Tukey’s test, $p \leq 0.05$)

Growth rate trend in different vermi units was in order: VB-IV (20.85 mg/worm/day) > VB-III (18.34 mg/worm/day) > VB-I (18.30 mg/worm/day) > VB-II (18.17 mg/worm /day) > VB-V (17.66 mg/worm/day) > VB-VI (13.90 mg/worm/day) > VB-VII (10.38 mg/worm/day) > VB-VIII (8.80 mg/worm/day) (Figure 9.4).

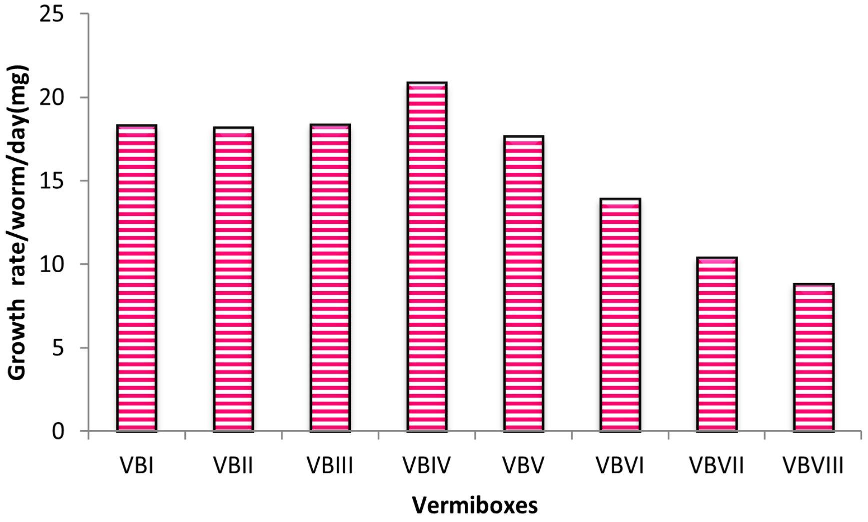


Figure 9.4: Growth rate mg/worm/day in different Vermi-boxes

Statistically significant variation was found in vermi-boxes IV, V,VI, VII and VIII for growth rate comparison ($p<0.05$) whereas VB-I, II and III were statistically insignificant from one another. In spite of high ligno-cellulosic content in leaf litter, earthworm mediated decomposition could be achieved when 30% rice residue was blended with 40% cow excrement and 30% leaf litter as bulking material.

9.4 CONCLUSIONS

Experimental study evidenced that rice residue which is presumably dried, can be mixed in shredded form with leaf litter and cow excrement and processed through vermicomposting. Rice residue and leaf litter were acted upon by microbes and earthworms in cow excrement environment for enhanced degradation. Some amount of cow excrement can be replaced by partially decomposed leaf litter to improve earthworm and microbial activity. Leaf litter after blending with cow excrement provided environment suitable for earthworm growth and fecundity. Vermicompost obtained from all the combinations was mature enough to be used in agricultural applications as supported by maturity indices (TOC, ash content and C:N ratio). Higher amount of leaf litter with less cow excrement was not favorable for earthworm growth. Nutrient levels were remarkably higher than the initial feed materials. 30% rice residue blended with 30% leaf litter and 40% cow excrement came out to be the best combination to obtain good quality vermicompost with nutrient augmentation.

Chapter 10

VERMICOMPOSTING OF RICE WEED *ECHINOCHLOA CRUS-GALLI* FOR SUSTAINABILITY

10.1 INTRODUCTION

Echinochloa crus-galli, commonly known as Barnyard grass, cock spur grass or water grass, is a semi-aquatic weed that belongs to family *Poaceae* and genus Echinochloa with 250 known species all over the world. Native to Europe and India, it is one of the world's ruinous weeds which have invaded grasslands, coastal forest areas, agricultural fields and roadsides of Asia, Australia and America (FAO, 2014). It was initially inducted for fodder in these regions. *E. crus-galli* weed is a persistent competitor of rice crop due to fast growth, rapid germinating ability, imitation of rice characteristics particularly during early growth and great plausible allelopathy [167]. In addition, it is considered among the top 15 herbicide resistant weeds, responsible for reducing rice yields [267] along with other crops like maize, soybean, lucerne, root crops, orchards [268]. This annual grass about 1.5 cm in height has smooth, hairless and thickened culms with lateral branches, tufted stem and fibrous root system. With high invasiveness, super capacity to compete with rice, significant allelopathy and strong herbicide resistance, this weed is one of an important environmental invading species in India too.

While competing with rice, *E. crus-galli* produces 5000 - 7000 seeds that are capable of dispersion to far off places due to their more buoyancy than rice seeds [269], another aspect is that these seeds have different time of germination which relies on suitable environmental conditions. Therefore, its control becomes troublesome for agriculturalists and scientists. Besides using several control methods of clean cultivation, hand weeding, use of pathogens, use of allelopathy, and sound biological strategies are required to manage these weeds on site where they are produced. Earlier several researchers have employed different methods for managing aquatic, semi-aquatic and terrestrial weeds, viz., biogas production from *Ipomoea*, *Eicchornia* [270], biopolymer production from *Parthenium* and *Eicchornia* [271], etc. Trending innovative alternative methods include use of weed biomass as feed material in composting and vermicomposting thus converting them to a valuable resource. Many vermicomposting studies have been carried out for some invasive weeds including water hyacinth [215], *Parthenium hysterophorus* [78] *Pistia stratiotes* [127], *Hydrilla verticillata* [270], *Lantana camara* [110], *Ageratum conyzoides* [84],[87], duck weed(*Spirodela*) [85], *Ipomoea* [111], etc.

Vermicomposting is a bio-degradative process performed by earthworms jointly with microorganisms to convert waste materials into a stabilized vermicompost. Feedstock quality and earthworm species employed in vermi-conversion has a great impact on amount and quality of manure formed. Earthworm *Eisenia fetida* does a marvellous job of organic waste degradation due to its palatability for large variety of wastes, high fecundity, wide temperature tolerance and faster vermi-conversion. Incorporation of blending material in form of animal dung or any other substrate is pre-requisite for getting vermicompost of good manurial quality as well as to sustain vermicomposting. As per the available literature, no single study has been done on harnessing the potential of *E. crus-galli* weed in vermicomposting to provide a cost-effective and eco-friendly solution for its management. This perilous rice weed has been found in peri-urban areas (agricultural fields) of Faridabad city (Haryana, India) and despite control by burning, manual hoeing and herbicide use, its management is still a nuisance for local farmers. In the light of aforestated information, authors have made a small attempt to divert the attention of scientists and researchers towards sustainable management of rice weed Barnyard grass by earthworm mediated process – vermicomposting. Present investigation is probably the first ever study to vermi-transform *E. crus-galli* and recovering nutrients engaging earthworm *Eisenia fetida*. Several feed mix ratios were tested for suitability of weed *E. crus-galli* for vermi-conversion, increment in nutrient levels, effect on fecundity and earthworm growth, assessing maturity of vermicompost through evaluation of ash content, C:N & C:P ratios and respiration rate. This comprehensive study can lay a foundation for vermi-conversion of pernicious rice weed *E. crus-galli* and henceforth its subsequent management.

10.2 MATERIALS AND METHODS

10.2.1 Collection of Earthworms, Cow Dung and Weed *E. crus-galli*

Earthworm *Eisenia fetida* was maintained as stock culture in lab conditions for use in the vermicomposting experiment. Fresh cow dung (urine free) was procured from a local dairy farm. Weed *E. crus-galli* (EC) was collected from agricultural fields, Faridabad city, Haryana (India). EC and CD were analyzed individually (Table 10.1) and in combination for their physico - chemical characteristics – pH, electrical conductivity, organic matter (OM), ash content, total organic carbon (TOC), macronutrients - total kjeldahl nitrogen (TKN), total available phosphorus (TAP), total potassium (TK) and micronutrients (Total Fe, Mn, Zn, Cu & Pb).

10.2.2 Experimental Design and Vermicomposting

Seven vermi-experiment set ups in combination of 1/4, 2/3, 1/1, 3/2 and 4/1 with two controls 100% CD and 100% EC were established in triplicates (Table 10.2). Each vermi-experiment contained one kg feedstock on dry weight basis. After three weeks of pre-decomposition, 20 earthworms (individual weighing $\approx$ 500 - 575 mg) from stock culture were added to each vermi-experiment maintained at an ambient temperature of 20 - 25°C. Experiment was carried out for 63 days with regular turning for maintaining aerobic conditions while regulating 60-70% moisture. Sample from each vermi-experiment was drawn, dried in air, finely grounded and placed in air tight vials for further evaluation. Physico-chemical parameters (on dry weight basis) and biological parameters (on fresh weight basis) of vermicomposts prepared from *E.crus-galli* and cow dung were analyzed.

Table 10.1: Initial Physico-chemical characteristics of Cow dung(CD)and *Echinochloa. crus-galli* (EC)

Parameters	**Cow dung (CD)**	***Echinochloa crus-galli* (EC)**
pH	8.14±0.01	6.76±0.02
EC (dS/m)	1.84±0.02	2.86±0.03
Ash content (g/kg)	228±2.3	272±2.8
TOC (g/kg)	447.7±3.1	422.2±3.0
OM (g/kg)	772±8.2	728±7.8
TKN (g/kg)	8.8±0.02	9.1±0.01
TAP (g/kg)	7.3±0.01	5.32±0.02
TK (g/kg)	7.9±0.02	7.34±0.02
C:N ratio	50.8±4.8	46.3±4.2
C:P ratio	61.3±3.2	79.3±3.8
Moisture content (%)	85±1.8	73±1.02
Fe (mg/kg)	1204±12.2	1372±14.8
Mn (mg/kg)	77.3±2.2	134±1.6
Zn (mg/kg)	91.2±3.2	19.7±0.08
Cu (mg/kg)	22.8±1.8	30.5±1.01
Pb (mg/kg)	31.6±2.01	28.4±1.98

10.2.3 Physico-chemical Analysis and Vermicompost Maturity Indices

E. crus-galli (EC) and cow dung (CD) as well as feed mixtures (EC+CD) were evaluated for pH, electrical conductivity, organic matter, ash content, TOC, TKN, TAP, TK and micronutrients ((Total Fe, Mn, Zn, Cu & Pb) (Table 10.3). The analytical procedures were followed as mentioned in chapter 3.

Table 10.2: Composition and ratio of feed mix (Cow dung and *Echinochloa crus-galli*). in different vermi-experiments

Vermi Experiment (VE)	Nomenclature	Composition (EC%+CD%)	Ratio of feed mix
VE1	CD_{100}	100%	0/1
VE2	EC_{20}	20% +80%	1/4
VE3	EC_{40}	40% +60%	2/3
VE4	EC_{50}	50%+50%	1/1
VE5	EC_{60}	60% +40%	3/2
VE6	EC_{80}	80%+20%	4/1
VE7	EC_{100}	100%	1/0

10.2.4 Earthworm Growth Parameters

Vermicompost samples were analyzed for biological characteristics as per methods given in chapter 3.

10.2.5 Statistical Analysis of Data

Statistical analysis of data was done as per chapter 3.

10.3 RESULTS AND DISCUSSION

Earthy brown, homogeneous and nutrient enriched vermicompost was prepared from all the feed mixes of EC + CD. Out of seven vermi-experiments, VE7 (EC_{100}) was unable to sustain earthworm population and resulted in mortality of worms; therefore, this setup was abandoned in the study. In present investigation, significant mass reduction in the range of 2.2 - 3.03 fold was recorded in all the feed mixes of weed *E.crus-galli* and cow dung with highest drop in mass levels of VE3 (EC_{40}).

10.3.1 Change in pH, Electrical Conductivity and TOC

pH is an important parameter to decide the fate of organic waste degradation in vermicomposting process as it affects earthworm and microbial action. In the experiment, initially pH was within the range of 7.32 - 8.06 which tend to decrease in all the experiments near the completion of vermicomposting process. pH in final vermicomposts was within the range of 6.98 - 7.5 (Table 10.3). Difference among various vermi-experiments for pH change was statistically different for $CD4_{100}$, EC_{20}, EC_{40} and EC_{50} ($p < 0.05$) whereas significant difference was not observed in EC_{20} & EC_{30} and EC_{60} & EC_{80}. This shifting of pH may be attributed to conversion of ammonical nitrogen to nitrites and nitrates together with organic acids production as a result of combined action of earthworms and microbes [91]. Ideal pH for mineralization and feed mix decomposition is in range of 7-8. Maximum percentage decrease (8.26 %) was recorded in EC_{40} whereas least decrease (4.64%) in EC_{80} was observed (Figure 10.1).

Electrical conductivity is reflective of vermicompost suitability and manure quality in plant application. A continuous increasing trend in electrical conductivity was found in all the vermi- experiments in the present study. The increase was from initial values of 1.54 - 2.58 dS/m to 3.02 - 3.96 dS/m in final vermicompost presented in Table 10.3 and percentage increase have been given in Fig 10.1. The maximum allowable limits for electrical conductivity are considered as <4 dS/m which is non-toxic for agronomic use and is one of the recommended organic compost quality standard [141].

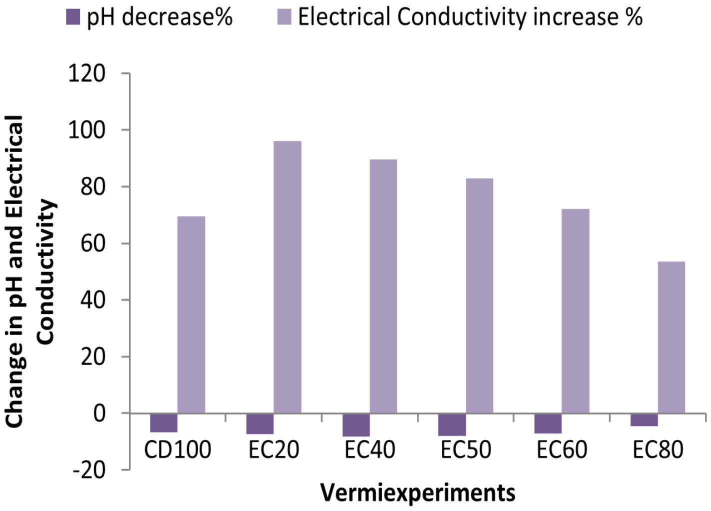


Figure 10.1: Change in pH and electrical conductivity in different vermi-experiments

An increase in electrical conductivity can be owed to release of bound nutrients into more available forms along with soluble salts, production of ammonium and inorganic ions during the degradation of initial feed mix [179],[272]. Decomposition of organic matter leads to production of ammonium, phosphate, and potassium ions thereby increasing electrical conductivity.

Table 10.3: Physico-chemical characteristics of initial feed mix (Day 0) and final vermicompost (Day 63) produced in different vermi-experiments (Mean ± SEM, n=3)

Vermi Experiment	**VE 1 CD_{100}**		**VE 2 EC_{20}**		**VE 3 EC_{40}**		**VE 4 EC_{50}**		**VE 5 EC_{60}**		**VE 6 EC_{80}**	
Parameters	**Day 0**	**Day 63**	**Day 0**	**Day 63**	**Day 0**	**Day 63**	**Day 0**	**Day 63**	**Day 0**	**Day 63**	**Day 0**	**Day 63**
pH	8.0±0.04e	7.5±0.03d	7.7±0.03c	7.2±0.02b	7.8±0.04d	7.21±0.01b	7.9±0.02f	7.31±0.03c	7.6±0.02b	7.05±0.01a	7.3±0.01a	6.9±0.02a
EC	1.87±0.02c	3.17±0.04b	1.54±0.01a	3.02±0.02a	1.72±0.02b	3.26±0.03c	2.12±0.04d	3.8±0.05d	2.23±0.02e	3.84±0.03d	2.58±0.05f	3.96±0.02d
Ash content	236±2.8a	531.6±3.7a	241±2.1b	601.3±3.8d	245±2.02c	86.4±4.2c	252±1.6d	531.4±2.1a	258±1.8e	528.9±2.3a	267±3.2f	537.8±2.6b
TOC	443±5.2c	271.7±3.4c	440±4.5c	231.3±2.7a	437.9±3.8c	239.9±2.9b	433.8±2.6b	271.8±1.8c	430.3±1.9b	273.3±1.6c	425.1±1.65a	268.1±1.2c
OM	764±3.1e	468.4±2.5d	758.5±4.0d	398.7±2.3a	755±2.3d	413.6±0.4b	748±2.4c	468.6±1.8d	742±3.02b	471±2.43e	733±2.35a	462.2±1.9c
TKN	8.6±1.40a	13.6±1.42a	12.8±1.25c	21.5±2.28f	11.2±1.04b	18.4±2.21e	11.4±1.87b	17.9±2.10d	10.8±1.02b	16.5±2.03c	10.7±0.09b	15.9±2.3b
TAP	7.5±1.4a	12.8±1.42a	7.8±0.87a	15.2±1.08c	8.1±0.78a	14.8±0.98b	8.8±1.11a	15.9±2.31c	8.9±0.80a	13.5±1.23a	9.0±0.56a	11.8±0.98a
TK	7.9±0.89a	21.3±2.8a	8.2±0.88a	25.2±2.14b	8.4±1.04a	27.6±2.67b	8.6±0.68a	23.3±1.45a	8.8±1.02a	22.2±2.3a	8.9±0.98a	20.1±1.45a

Values are in g/kg except EC (dS/cm) and pH. Mean value followed by different letters is statistically different (ANOVA; Tukey's test, $p \leq 0.05$)

Significant difference was observed among CD_{100}, EC_{20} & EC_{40} ($p < 0.05$) and EC_{50} & EC_{60}, but latter are statistically indifferent from each other ($p>0.05$). Increase in electrical conductivity has been also reported in earlier literature studies.

TOC reduction marks the decomposition of organic matter in vermicomposting process as organic carbon is consumed by microbes and earthworms as a part of their respiratory processes. Yuvaraj et al.[141] attributed reduction of TOC in vermicompost to combined action of microbes and earthworms, organic carbon assimilation into biomass of earthworms and CO_2 evolution in the decomposition process. In the present study, TOC decreased from 425.1 - 443.3 g/kg to 231.3 - 273.8 g/kg in final vermicomposts (Table 10.3). There was 36.4 - 47.4% reduction in different vermi-experiments towards the completion of process. TOC reduction was also reported in earlier studies and in present study it was found to be more than 24.34 - 38.25% by Gusain and Suthar [85], 20.7 - 30.7% by Devi and Khwairakpam [110], 27.3 - 35.3% by Devi and Khwairakpam [87]) and lower than 69.8 - 78.5% by Boruah et al.[90]. Difference between $VE1(CD_{100})$, $VE2(EC_{20})$ and $VE3(EC_{40})$ was statistically significant ($p<0.05$) whereas difference in VE4 (EC_{50}), VE5 (EC_{60}) and VE6 (EC_{80}) was not significant for TOC reduction.

10.3.2 TKN, TAP and TK Profile

TKN values enhanced in all the vermi-experiments from initial levels of 8.6 - 12.8 g/kg to 13.6 - 21.5 g/kg in final vermicompost at the end of experiment (Table 10.3). Difference among different vermi-experiments was statistically significant for TKN increase ($p<0.05$). Profound increase of 48.5 - 67.9% recorded in vermi-experiments is indicative of high nitrogen mineralization in feed mixes of EC + CD. Highest increment was observed in VE2 (EC_{20}) and least ascend was found in VE7 (EC_{80}) irrespective of initial contents. It followed the trend EC_{20} (67.9%) $>$ EC_{40} (64.2%) $>$ CD_{100} (58.1%) $>$ EC_{60} (57.0%) $>$ EC_{50} (52.7%) $>$ EC_{80} (48.5%). Increment in TKN can be due to organic matter mineralization and addition of mucus and nitrogenous excretory substances in vermicompost and depends upon initial nitrogen content in feed mix along with decomposition rate. Gusain and Suthar [84] documented 59.6 - 69.9% increase in nitrogen content for weed *Ageratum* combined with cow dung. Increase in nitrogen was also reported by other researchers previously [273]. An increase in TAP was recorded in all vermi-experiments up to different extents. Initially, TAP values varied from 7.5

- 9.0 g/kg and enhanced to 11.8 - 15.9 g/kg towards the completion of process (Table 10.3). Augmentation in TAP values can be attributed to combined activity of microbes and earthworms along with phosphatase enzyme and phosphate solubilizing bacteria thus helping in solubilization of organically bound phosphorus into soluble forms [41].

An increase of 31.1 - 94.8 % was recorded in CD + EC combinations. Decomposition of organic matter converts phosphorus in its soluble form via action of organic acids formed in initial feed mix. The variation in different vermi-experiments can be owed to initial phosphorus content in feed mix as well as different earthworm activities. Difference among VE1 (CD_{100}), VE2 (EC_{20}) & VE3 (EC_{40}) was statistically significant ($p < 0.05$) whereas VE4 (EC_{50}), VE5 (EC_{60}) & VE6 (EC_{80}) were insignificantly different from each other with respect to phosphorus content.

TK content enhanced significantly in all the vermi-experiments and found higher in vermicomposts (20.1 - 27.6 g/kg) prepared from different combinations of EC + CD when compared with initial values (7.9 - 8.9 g/kg) (Table 10.3). A 2.25 - 3.28 fold increase was recorded in TK in the end products which may be attributed to efficient joint activity of microbes and earthworms that resulted in effective waste degradation. Organic matter reduction and release of potassium enhanced levels of potassium in final vermicompost. Difference in vermi-experiments for potassium increase can be due to variation in organic matter mineralization rates and loss of organic matter via CO_2 respiration [274]. Potassium values were not statistically different from each other ($p>0.05$) although VE2 (EC_{20}) and VE3 (EC_{40}) (statistically indifferent from each other) were significantly different from rest of the vermi-experiments.

10.3.3 Change in Micronutrient Content

Micro-nutrients (Fe, Mn, Zn, Cu, Pb) are essential for plant growth at low levels and can hinder fertility of soil affecting the plant growth at high levels preceded by bioaccumulation paving their way into food chain. Thereby, it becomes important to substantiate the concentration of these micro-nutrients/trace metals before agricultural application. Vermicomposting may increase or decrease the level of trace metals. It can be either due to mass / volume reduction [173], organic matter degradation [275], liberation of free metal ions from organically bound state [166], adherence/chelation of metals to humic acids limiting their reduction [75] or concentration of trace metals by earthworms

[174].

Previous studies have reported increase as well as decrease in micronutrients for above mentioned reasons. In the present study, EC + CD vermicomposts have shown an increment in micronutrients (Fe, Mn, Zn, Cu, Pb) in comparison to initial feed mix in all the vermi-experiments in spite of foremost values and feed mix composition (Table 10.4). Fe content in the feed mix was in the range of 1212 - 1287 mg/kg and escalated to 1342 - 1520 mg/kg in final vermicomposts. There was 9.58 - 12.25% increase in Fe content in vermicomposts obtained from different compositions. There was significant variation among different vermi-experiments for increase in Fe content ($p < 0.05$).

Total Mn levels raised from initial values of 80.2 - 141 mg/kg to final values of 275.2 - 343.2 mg/kg and showed an increase of 123.5 - 243.1%. No statistical significant difference was recorded for increase in Mn levels among different vermi-experiments ($p > 0.05$). Zn showed an increment over initial content (21.7 - 93.5 mg/kg) and was found in the range of 214.9 - 291.4 mg/kg in final vermicomposts. An increase of 96.2 - 234.3% in Cu content was recorded for all the combinations of EC + CD. Both Zn and Cu levels showed significant difference in final vermicomposts ($p < 0.05$).

Initially Pb was in the range of 30.2 - 33.5 mg/kg and was found to be enhanced (51.7 - 67.2 mg/kg) in final vermicomposts with no significant difference among the vermi-experiments ($p > 0.05$). Although there was escalation in all the micronutrients at the end of the process, vermicomposts produced from *E.crus-galli* and cow dung mix were within the acceptable limits for composts [129] and is stipulated for use in agronomic and horticultural purposes .

10.3.4 Vermicompost Stability and Maturity Indices

a) Ash Content

Ash content enhanced after 63 days of vermicomposting in vermi-experiments from their initial levels. Incremental change in ash content is suggestive of vermicompost maturity due to effective degradation and mineralization of feed mixture and conversion of organic materials into inorganic forms. Initially ash contents varied between 236 - 267 g/kg and raised to 528.9 - 601.3 g/kg as the process was completed (Table 10.3).

Table 10.4: Micronutrient contents in initial feed mix and final vermicompost in different vermi-experiments (Mean ± SEM, n=3)

Vermi Experi-ment	**VE 1 CD$_{100}$**		**VE 2 EC$_{20}$**		**VE 3 EC$_{40}$**		**VE 4 EC$_{50}$**		**VE 5 EC$_{60}$**		**VE 6 EC$_{80}$**	
Micro-nutrients	**Day 0**	**Day 63**	**Day 0**	**Day 63**	**Day 0**	**Day 63**	**Day 0**	**Day 63**	**Day 0**	**Day 63**	**Day 0**	**Day 63**
Fe (mg/kg)	1212±8.5a	1342±6.4a	1245±6.8b	1395±7.2b	1287±7.8c	1440±5.9c	1322±5.7d	1484±4.4d	1356±6.8e	1512±6.1e	1387±5.6f	1520±4.8f
Mn (mg/kg)	80.2±4.2a	275.2±5.4a	92.4±4.8b	316.4±5.8b	109.0±5.1c	323.5±6.4c	118.2±4.8d	343.2±3.1d	130.4±4.1e	334.4±5.6c	141±3.89f	5.2±4.2b
Zn (mg/kg)	93.5±2.56f	220.5±3.0b	79.9±4.1e	214.9±4.2a	65.4±3.4d	291.4±3.8f	44.8±2.65c	242.8±2.1c	31.0±1.01b	251.0±1.8d	21.7±1.02a	262.7±3.2e
Cu (mg/kg)	23.9±2.1a	46.9±2.2a	25.8±1.7a	56.8±2.2b	26.9±1.9a	72.9±2.3c	28.8±1.15a	88.8±2.6d	30.6±1.3b	102.3±2.5e	32.4±1.02b	91.0±2.04d
Pb (mg/kg)	33.5±1.03a	51.7±1.7a	32.9±0.8a	52.3±0.16a	32.1±1.1a	55.8±2.0ab	31.7±0.9a	57.4±1.0b	30.8±1.10a	63.7±2.1c	30.2±0.8a	67.2±0.6d

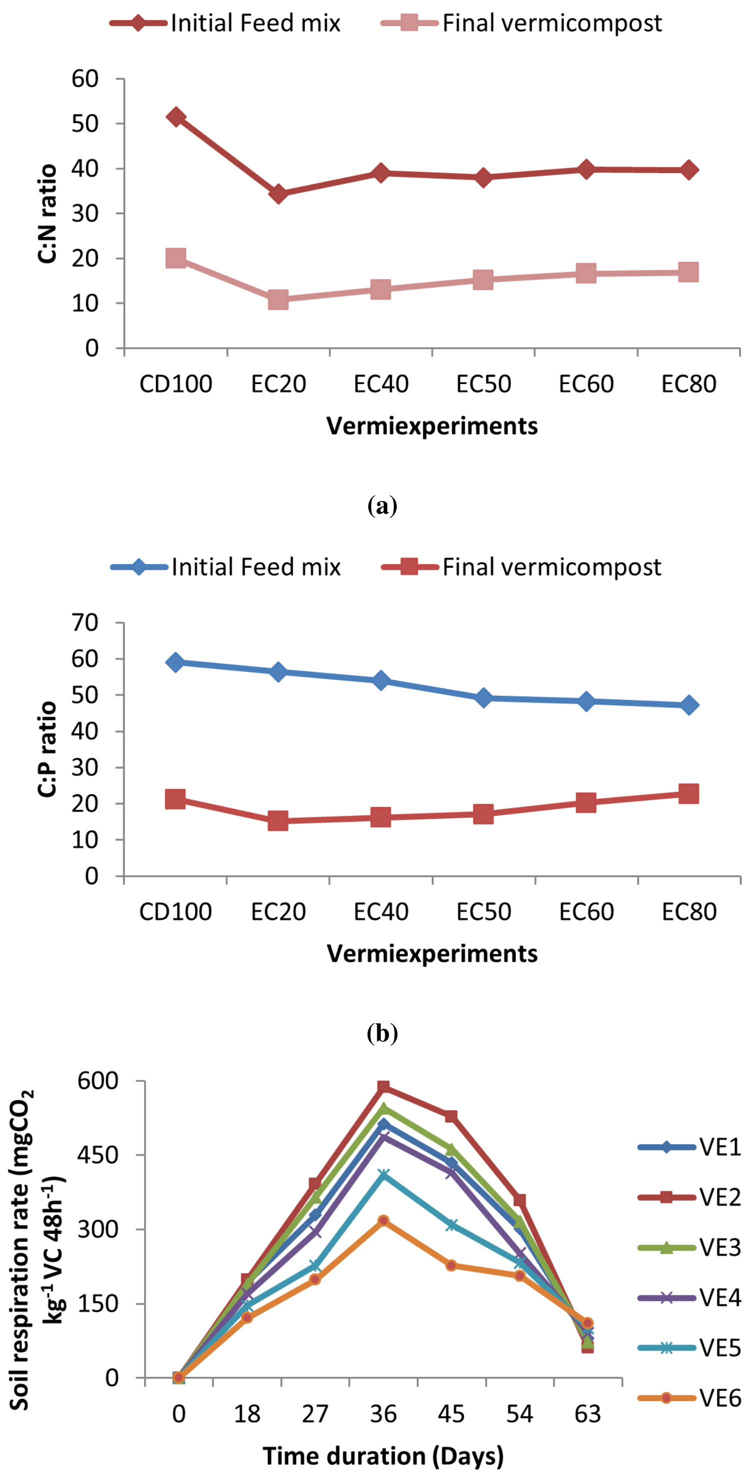
Mean value followed by different letters is statistically different (ANOVA; Tukey's test, $p \leq 0.05$)

Percent increase in ash content was highest in EC_{20} (149.5%) and least in EC_{80} (101.4%). Order of percent increase was: EC_{20} (149.5%) $>$ EC_{40} (139.3%) $>$ CD_{100} (125.5%) $>$ EC_{50} (110.8%) $>$ EC_{60} (105%) $>$ EC_{80} (101.4%).

More is the rate of organic matter decomposition due to surplus amount of feed mix available, higher the increase in ash levels at the completion of vermicomposting. Remarkable increase in ash content was also recorded by earlier researchers [276] but lower than present findings. About 57.49 – 67.33% increase was recorded in *Ageratum* and CD mixtures [84] that is lower than EC+CD mix in present investigation. Statistically significant difference for ash content was observed in VE1(CD_{100}), VE2 (EC_{20}) and VE3 (EC_{40}) ($p < 0.05$), whereas VE4 (EC_{50}), VE5 (EC_{60}), and VE6 (EC_{80}) were not statistically different from each other.

b) C:N and C:P Ratios

C:N ratio is an important index of vermicompost stability/ maturity and establish its use for agronomic purposes. The C:N ratio decreased in all the vermi-experiments at completion of vermicompost process. C:N decrease may be attributed to increased nitrogen levels and reduced organic matter content. Microbial respiration results in loss of carbon due to combined degradative action of microbes and earthworms as well as greater stabilization and mineralization of feed mix [143]. The C:N ratio of the final vermicompost is also influenced by nitrogen and carbon content of initial feed mix. It decreased from initial range of 34.3 - 51.5 to 10.7 - 19.9 in all vermi-experiments after 63 days cycle of vermicomposting (Figure 10.2a). The vermi-experiments VE2 (EC_{20}), VE3 (EC_{40}) and VE4 (EC_{50}) had final C:N ratio below 15 whereas C:N ratio < 20 was observed for VE1(CD_{100}), VE5 (EC_{60}) and VE6 (EC_{80}) suggesting the use of *E. crus-galli* as feed mix for earthworms to have mature vermicompost. C:N values varied significantly among different vermi-experiments ($p < 0.05$). Present findings can be correlated with the previous studies [110] which recorded 62% decrease in C:N value. C:N ratio for *Ipomoea* weed varied between 16.5 - 23.6 in final vermicomposts [111]; 9.35 - 18.92 for *Ageratum* and cowdung mix [84] and 9.90 - 23.84 for duck weed [85]. Percent decrease in C:N ratio from their initial levels varied between 57.5 - 68.8% in final vermicompost. The C:N ratio in the final product must be ≤ 20 for agronomic application and reflects vermicompost stability [252] whereas mature compost with C:N < 15 is considered most preferable [90].



(a)

(b)

(c)

Figure 10.2: a) C:N ratio b) C:P ratio in initial feed mix and final vermicomposts c) Change in Respiration rate ($mgCO_2kg^{-1}VC48h^{-1}$) with time

C:P ratio showed decreasing trend in all vermi-experiments due to decline in TOC that can be owed to combined action of microbes and earthworms as a part of their respiratory and assimilatory activities. Initially, C:P ratios ranged from 47.2 - 59.0 in different vermi-experiments that varied between 15.2 - 22.7 towards the completion of vermicomposting process (Figure 10.2b). Decrease in C:P might be due to loss of carbon and organic matter stabilization in different feed mixes of EC+CD and continuous release of available phosphorus from binded forms to mobile forms [152]. There was 51.8 - 73.03% decrease in C: P levels in final vermicompost. Significant difference was observed between VE2 (EC_{20}), VE3 (EC_{40}) and VE4 (EC_{50}) ($p<0.05$) but VE1 (CD_{100}), VE5 (EC_{60}) and VE6 (EC_{80}) did not differ significantly ($p>0.05$) for overall decrease in C: P ratio.

c) Respiration Rate Assessment ($mgCO_2kg^{-1}VC48h^{-1}$)

Respiration rate is reflective of high microbial activity during vermicomposting period, marks the completion of decomposition process and is taken as an important index of vermicompost maturity. Respiration rate is measured as $mgCO_2kg^{-1}VC48h^{-1}$. Earthworms fasten the growth and activity of microorganisms in feed mix that enhances the rate of respiration as the process of degradation initiates. The respiration rate instigated in all the vermi-experiments due to readily available organic materials for microbial action at the onset. Highest respiration rate ($mgCO_2kg^{-1}VC48h^{-1}$) was recorded on 36^{th} day: 587 (EC_{20}); 545 (EC_{40}); 513 (CD_{100}); 486 (EC_{50}), 410 (EC_{60}) and 317 (EC_{80}) (Figure 10.2c).

Vast carbon pool in the feed mix acts as a decent source of energy to activate microbial respiration, hence accelerates rate of respiration. As soon as the carbon source depletes due to consumption of feed materials by population of microbes, respiration rate declines towards the end. Final respiration rates after 63 days were in the permissible levels of 120 $mgCO_2kg^{-1}VC48h^{-1}$ [121] and ranged from 42 - 98 $mgCO_2kg^{-1}VC48h^{-1}$ which marked vermicompost maturity in the finished products. Significant variation was observed in all the vermi-experiments for respiration rates ($p < 0.05$) Present results corroborates with earlier findings. Gusain and Suthar [84] had reported respiration rates of 34 - 70.1 $mgCO_2kg^{-1}VC48h^{-1}$ in weed *Ageratum* and 61 - 100 $mgCO_2kg^{-1}VC48h^{-1}$ in duckweed rich vermicomposts [85].

d) Changes in Earthworm Growth and Fecundity in EC + CD mix

Earthworm population indicates potentiality of the feed mix used in vermicomposting and is affected by feed acclimatization, earthworm growth in feed environment and fecundity. Final earthworm population at the completion showed the following trend: EC_{40} (126) > EC_{20} (118) > CD_{100} (108) > EC_{50} (98) > EC_{60} (74) > EC_{80} (50) and found to be significantly different from each other. Initial live earthworm biomass was in the range of 545 - 575 mg/worm and increased to 1136 - 1336 mg/worm after 63 days of vermicomposting (Table 10.5). It was inferred that blending of weed *E. crus-galli* with cow dung enhanced the digestibility of feed mix by the earthworms and thus boosted earthworm biomass up to different extents.

Highest live biomass among different feed mixes followed the order: EC_{40} (1336) > EC_{20} (1299 mg) > CD_{100} (1288mg) > EC_{50} (1258 mg) > EC_{60} (1202mg) > EC_{80} (1136mg). Maximum increase of 2.40 fold was recorded in EC_{40} followed by EC_{20} and CD_{100} with 2.36 fold increase in biomass. Difference between vermi-experiments was statistically significant for earthworm biomass gain ($p < 0.05$).

No. of cocoons produced in different vermi-experiments followed the order: EC_{40} (435 ± 0.52) > EC_{20} (400 ± 0.42) > CD_{100} (336 ± 0.41) > EC_{50} (256 ± 0.34) > EC_{60}(100 ± 0.26) > EC_{80} (63 ± 0.11). The values in all the vermi-experiments were significantly different from each other ($p < 0.05$). Presence of nutrients and organic matter in EC + CD mix has supported good earthworm growth and cocoon production. The earthworm growth is suggestive of utilization of weed *E. crus-galli* as feed mix for vermicompost production from different proportions. Fecundity rate (cocoon/worm) was highest (3.45 ± 0.05) in 40% EC than other combinations and least in 80% EC (Table 10.5). Fecundity of earthworms in cow dung and *E. crus-galli* feed mix were significantly different from each other ($p < 0.05$). Earthworm growth rate was found between 11.44 - 18.57 mg/worm/day in current research. The earthworm growth and fecundity suggested that *E. crus-galli* can be efficiently utilized as feed material for earthworms when amended in suitable proportions.

Table 10.5: Biological characteristics of initial feed mix and final vermicompost in different vermi-experiments (Mean ± SEM, n=3)

Vermi Experiment / Biological Parameters	VE1 CD_{100}	VE2 EC_{20}	VE3 EC_{40}	VE4 EC_{50}	VE5 EC_{60}	VE6 EC_{80}
Earthworm population (Initial feed mix)	20	20	20	20	20	20
Earthworm population (Final vermicompost)	108±1.32d	118±1.72e	126±1.56f	98±1.45c	74±1.32b	50±1.23a
Live earthworm biomass (mg) (Initial feed mix)	545±2.56a	549±2.87b	556±3.12c	565±3.52d	572±3.75e	575±3.91e
Maximum Live earthworm biomass (mg) (Final vermicompost)	1288±3.97d	1299±4.11e	1336±4.02f	1258±3.92c	1202±3.45b	1136±3.65a
Net Biomass gain (mg)	743±3.14d	750±3.21e	780±3.6f	693±2.91c	630±2.88b	561±2.68a
No. of cocoons	336±0.41d	400±0.42e	435±0.52f	256±0.34c	100±0.26b	63±0.11a
Fecundity (cocoon/worm)	3.11±0.04d	3.38±0.03e	3.45±0.05f	2.61±0.03c	1.35±0.01b	1.31±0.01a
Maximum Biomass achieved (days)	42	42	42	42	49	49
Growth rate/worm/day (mg)	17.69±0.03d	17.85±0.04e	18.57±0.04f	16.50±0.03c	12.85±0.02b	11.44±0.02a

Mean value followed by different letters is statistically different (ANOVA; Tukey's test, $p \leq 0.05$)

10.4 CONCLUSIONS

Rice weed *E.crus-galli* was found to be a potential substrate for earthworms. Present findings imply that vermicompost prepared from 20 - 80% of weed blended with cow dung has shown a significant increment in TKN, TAP, TK and micronutrients in all the vermi-experiments with exception of 100% EC which showed earthworm mortality. The most efficient proportions were 20 - 50% EC with highest fecundity and earthworm growth in 40% weed mass. All the mixing ratios have performed very well and met compost quality standards i.e. pH: 6.5 - 7.5, EC$<$ 4dS/m, TKN $>$ 0.8%, TAP$>$ 0.6%, TK $>$ 0.4%, C:N ratio $<$ 20 [252] for agronomic use. Respiration rate was found to be 42 - 98 $mgCO_2kg^{-1}VC48h^{-1}$ that was well within the recommended limits. Thus vermicomposting has demonstrated its likeliness for entire usage and on site management of *E.crus-galli* in a sustainable way.

Chapter 11

POT CULTURE STUDY TO ASSESS THE EFFECT OF VERMICOMPOST ON *TAGETES ERECTA* AND *CATHARANTHUS ROSEUS*

Exaggeration of inorganic fertilizers in plant growth has smashed natural fertility of soil making it devoid of useful nutrients. There is a need to cut down the use of chemical fertilizers and adopt a sustainable option for plantation that includes use of nutrient - enriched organic amendment. Organic wastes can be converted into vermicompost which is fine, homogeneous, porous, well- aerated material with good water holding capacity [11]. Stabilized vermicompost has balanced amount of nutrients in plant available forms like nitrates, available phosphorus, soluble potassium, etc. that can retain soil fertility. Although focus of plant cultivation has been on food plants, plants of ornamental beauty are cherished all over the world. It is important to have continuous production of these plants with better morphology as demand for ornamental plants is increasing. Application of compost for their production can certainly restrict the use of chemical fertilizers benefitting soil and environment [277]. Vermicompost as an environment-friendly fertilizer can boost ornamental plant growth [278]. Vermicompost as potting medium has proved to be effective in growth of ornamental plants such as *Geranium, Pegasus patio, Marigold,* etc. [279],[280],[95]. Earlier researches have shown the effects of applying vermi-manure on ornamental plants. Vermicompost has remarkable effect on marigold and petunia and up to 40% VC increased number of flowers per plant, a prime aspect of ornamental plant cultivation [281],[280]. 75 - 100% VC application increased plant height in *Impatiens walleriana* [282] while affected plant growth in *Pegasus patio* rose on applying 60% VC [283]. An increase in flowering, plant height, flower diameter, root, and stem biomass was noted on 40% VC application to marigold [95]. Vermi-stabilization results in formation of mature vermicompost with reduced carbon to nitrogen/phosphorus ratio and good levels of nutrients. On one hand, vermicompost can be used as organic fertilizer for crop and plant growth [284] and on other hand, huge amount of organic waste materials can be recycled to cope with the problem of waste management [285]. In view of the above, pot culture studies were carried to study the effect of vermicomposts produced in the present research on plants. The results have been produced in the following sections:

11.1 Influence of vermicompost on growth and flowering of Marigold plant *(Tagetes erecta)*

11.2 Effect of vermicompost on growth and productivity of Sadabahar plant *(Catharanthus roseus)*

11.1 INFLUENCE OF VERMICOMPOST ON GROWTH AND FLOWERING OF MARIGOLD PLANT *TAGETES ERECTA*

11.1.1 Introduction

Tagetes erecta, (commonly known as Marigold plant) a flowering species from family *Asteraceae*, is widely used as an ornamental plant in India. Commercially, marigold cultivation has attained importance as garden, festive and cut flower. Marigold flower contains essential oils that is a rich source of antioxidants [286]. Yellow to orange red color flowers are used for natural textile coloration and in food industry due to presence of Lutein [287]. Owing to its increasing importance, very few efforts have been made to cultivate this plant with an organic medium of growth so as to avoid inorganic fertilizers in gardens as well as on commercial scale. Sangwan et al.[95] and Gupta et al.[288] have tested the influence of household waste vermicompost as potting media on marigold and found positive impact on different morphological traits.

As per review of literature, cruciferous vegetable vermicomposts have not been employed as potting media to assess plant growth in pot culture. In view of this, present experiment was designed with an aim to use and compare the influence of cruciferous vegetable waste vermicomposts (30% & 40% cauliflower and cabbage leaf waste vermicomposts) with cow dung vermicompost on ornamental plant marigold. Another objective is to emphasize the use of vermicompost in horticulture industry as an option to current use of inorganic fertilizers and at the same time managing the organic wastes locally.

11.1.2 Materials and Methodology

a) Materials

The soil was collected from J.C. Bose UST campus, Faridabad. It was of silty loam nature with 1.5 g/ kg Nitrogen, 0.3 g/ kg Phosphorus and 1.9 g/ kg Potassium. Soil had less nitrogen and inadequate phosphorus content. Marigold plants in four + a-half leaf stage and nearly same size were bought from Dangwal Nursery, Ajronda, Faridabad city. The vermicompost was prepared in laboratory from cow dung (CD), cabbage waste (CAB) and cauliflower (CAU) leaf waste with blending of 30% and 40% CAU and CAB each as discussed in chapter 5 and used in the present study.

Five potting media (maintained in triplicates) were prepared with soil, cow dung, cabbage and cauliflower vermicompost in different proportions:

P1 - CD vermicompost + Soil
P2 - Cabbage Leaf vermicompost (CAB 30%) + Soil
P3 - Cabbage Leaf vermicompost (CAB 40%) + Soil
P4 - Cauliflower Waste vermicompost (CAU 30%) + Soil
P5 - Cauliflower Waste vermicompost (CAU 40%) + Soil

Effect of CAB and CAU VC as potting media has been investigated and compared keeping ratios of vermicompost and soil same (50% VC + 50% soil) in different potting media treatments.

b) Pot Culture Experiment

The 30% and 40% cabbage and cauliflower vermicomposts prepared in lab (discussed in earlier chapter) were added as potting media in 1:1 to investigate the effect on growth and productivity of marigold plant. Five pot treatments (P1 - P5) were prepared including Soil + Cow dung vermicompost (P1) as control. No other manure was added at any time during the pot studies. Plant height, total number of flower buds and diameter of the largest flower were noted on 15^{th}, 30^{th} and 45^{th} day. After 45^{th} day, roots and shoots were detached to quantify fresh root and shoot biomass. Photos of pot culture experiment on marigold plant are given at the end of the chapter.

11.1.3 Results and Discussion

Effect of Potting Media on Growth Parameters of Marigold Plant

Growth parameters like plant height, count of flowers and flower buds, diameter of largest flower, shoot biomass and root biomass of different potting media treatments were recorded at 15^{th}, 30^{th} and 45^{th} day. Figure 11.1 depicts the plant height in different potting media treatments at different times in the study. Maximum plant height was recorded in P4 (22.8 cm) containing 30% CAU VC followed by P2 (20.5 cm) with 30% CAB VC and P1 (19.7 cm) having CD VC after 45 days. This can be owed to high nutrient availability for growth of plants in vermicomposts. Plant height is the most common morphological trait to estimate performance of test plants [289]. Increase in plant height is linked with high concentration of nutrients in vermicompost [290]. Pots with 40% CAU VC (P5) and 40% CAB VC (P3) application had shown less plant height as compared to others. Previous studies also reported an increase in plant height on applying vermicompost as potting media [280],[291].

The trend of number of flower buds in different potting media was: P4 (18) $>$ P2 (16) $>$ P1(14) $>$ P5(12) $>$ P3 (10) (Figure 11.2). Diameters of biggest/largest flowers in potting media treatments have been shown in (Figure 11.3). Flower diameter varied from 5.2 - 8.4 cm in different pot treatments. Biggest flower diameter was 8.4 ± 0.50 cm in 30% CAU vermicompost treated pot and least diameter was 5.2 ± 0.12 in 40% CAB VC. Diameter of flower in CD vermicompost was more (7.2 ± 1.28) than 40% CAB and CAU VC. Sangwan et al. [95] and Khattak et al. [292] had also recorded increase in flower diameter after vermicompost application.

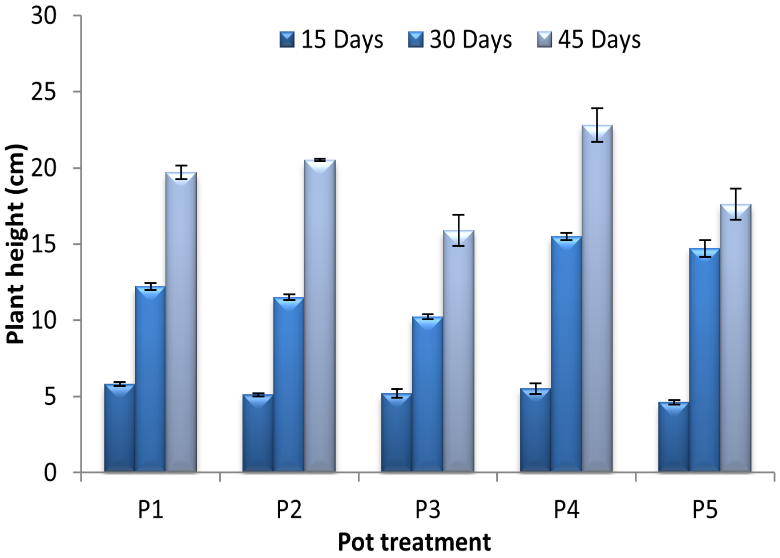


Figure 11.1: Height of Marigold plants in different pots during the study

30% CAU vermicompost mixed with soil enhanced plant height, number of flower buds and diameter of biggest flower due to higher content of nutrients required by plant for its growth as compared with other pot treatments. Nitrogen helps to increase the growth of plant tops. Phosphorus content which was low in soil was found to be increased in vermicompost and hence promote flowering in experimental pots. Increased potassium content ensures optimum plant growth and improves flower quality. Low potassium in soil can make plant wilt easily, therefore when supplemented in form of potting media, vermicompost can help the plants grown for their flowers and fruits. Cabbage and cauliflower vermicomposts in appropriate amount aids in overall plant growth and favors the performance of marigold plants.

Number of flowers, flower diameter, flower yield of *Chrysanthemum morifolium* and *Matricaria* plants was found to be increased [293],[294]. Gupta et al.[288] have also reported that marigold growth and yield enhanced after applying vermicompost in proper amounts. Fresh shoot and root biomass are presented in Figure 11.4 and Figure 11.5. Maximum shoot biomass was recorded in P4 (32.5 ± 1.23g) and minimum in P3 (20.6 ± 1.12 g). Shoot biomass increase was in the following order: P4 (CAU 30 VC) > P2 (CAB 30 VC) >P1 (CD VC) > P5 (CAU 40 VC) > P3 (CAB 40 VC) owing to decent concentration of nutrients. High shoot biomass can sustain high rate of photosynthetic activity [295]. In similar manner, root biomass was recorded to be highest in potting media treatment: P4 (7.6 ± 0.18) > P2 (7.0 ± 0.15) >P5 (6.8 ± 0.1) > P1 (6.2±0.2) >P3 (5.1 ± 0.22). High phosphorus levels can aid in increasing root biomass [296]. Increased root biomass enhances plants' ability to take nutrients from soil [297].

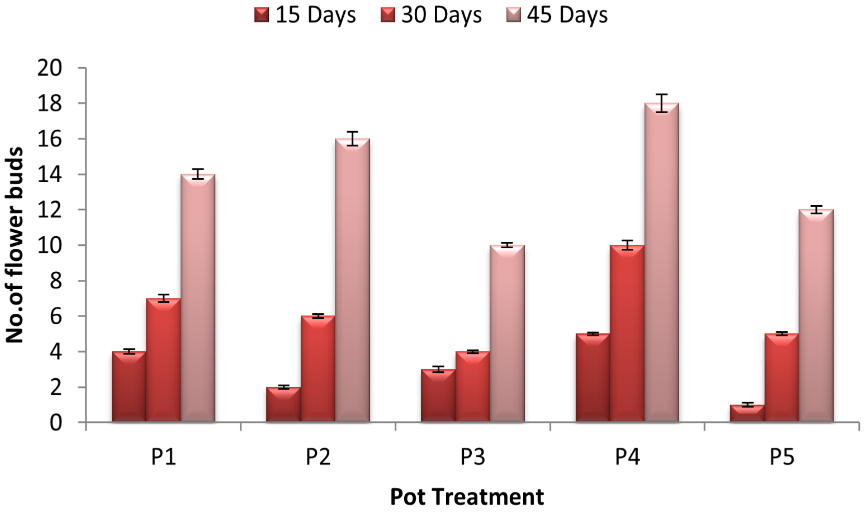


Figure 11.2: Number of flower buds in marigold plant during the study

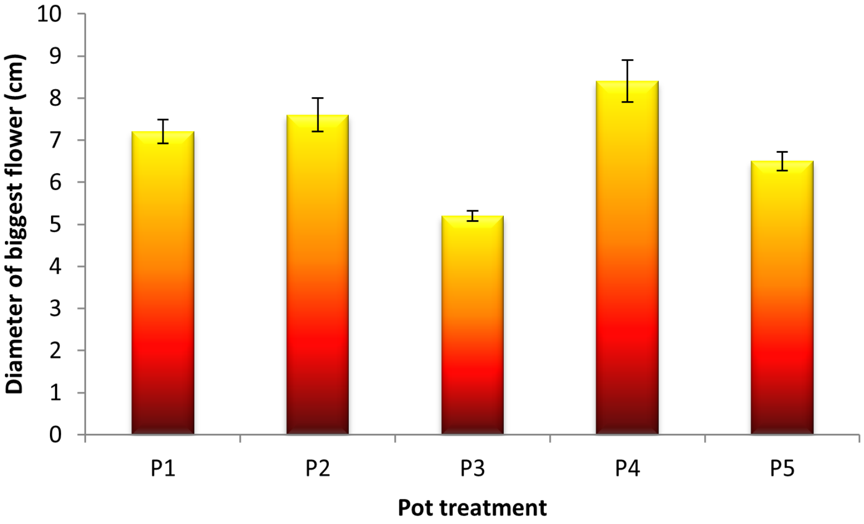


Figure 11.3: Diameter of biggest flower of marigold plant in different pot treatments

Present study employed marigold as test plant and affirms that cabbage and cauliflower vermicomposts (prepared from 30% CAB/CAU and 70% CD) in 1:1 ratio with soil had positive impact on growth and productivity of marigold plant. The pot with 30% CAU VC has shown better performance than CAB and CD VC; hence can be used successfully as manure.

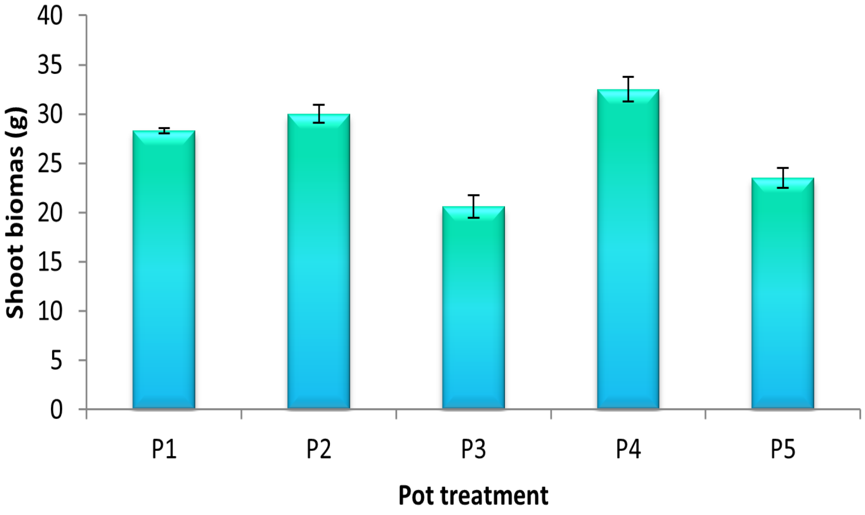


Figure 11.4: Shoot biomass (g) of marigold plant in different pot treatments

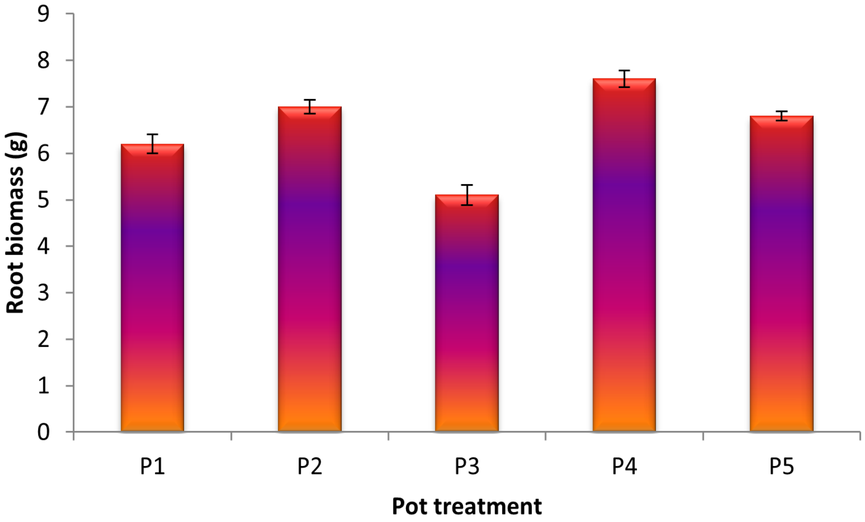


Figure 11.5: Root biomass (g) of marigold plant in different pot treatments

11.1.4 Conclusions

In the present study, all the potting media treatments showed good growth with best results in pot treated with vermicompost prepared from 30% cauliflower waste followed by 30% cabbage leaf waste as compared to cow dung vermicompost and 40% of cauliflower and cabbage leaf wastes although cow dung vermicompost was better than later. Plant height, number of flower buds, biggest flower diameter, shoot biomass and root biomass was found to be maximum in pot containing 30% cauliflower waste vermicompost followed by 30% cabbage leaf waste vermicompost that implies presence of macro- and micro- nutrients for plant growth in these vermicomposts. Thus, organic manure prepared from cruciferous vegetable waste can be used as an alternate to inorganic fertilizers to enhance growth and yield of marigold plant. Efficient nutrient uptake had positive effect on growth and productivity and none of the treatments showed any frenetic effect on marigold plant.

11.2 EFFECT OF VERMICOMPOST ON GROWTH AND PRODUCTIVITY OF SADABAHAR PLANT *CATHARANTHUS ROSEUS*

11.2.1 Introduction

As an ornamental plant of medicinal importance [298], cultivation conditions of *Catharanthus roseus* can be improvised with use of vermicompost. *Catharanthus roseus*, commonly known as Sadabahar / Periwinkle, as species of *Apcynaceae* family is an ornamental plant with great medicinal value. This perennial plant is naturalized from Subtropical Asia to Africa and America with its nativeness to Madagascar. Besides its use as traditional herbal medicine for preventing diabetes and stomachache [299], *Catharanthus roseus* is exploited for chemical extracts to treat cancer. Vinblastine and Vincristine are the two main anticancer alkaloids among hundreds of alkaloid compounds found in Catharanthus [300].

Very less studies are available on effect of VC on *Catharanthus*, therefore the present study aimed to study the influence of Household waste vermicompost application on it. Another waste material, fly ash, was also tried as soil amendment along with vermicompost in some of the pot treatments. Fly ash can be applied as soil amendment as it contains high concentration of potassium, Iron, Zinc etc. and increase yield in plants [301]. It can increase performance of plants by improving soil health. In view of this, performance of *Catharanthus* was also tested using fly ash in varied amounts alongwith VC.

11.2.2 Materials and Methodology

The soil was collected from JC Bose UST campus, Faridabad. It was of silty loam nature with 1.5 g/ kg Nitrogen, 0.3 g/ kg Phosphorus and 1.9 g/ kg Potassium. Soil had less nitrogen and inadequate phosphorus content. Household solid waste (HSW) and cow dung (CD) was prepared as mentioned in Chapter 4 and the physico-chemical characteristics of raw materials and vermicomposts have been presented in Table 4.8 and 4.10. The vermicompost produced from the best ratio of HSW and CD, i.e., 40% HSW in CD (chapter 4) was taken in the study. Fly ash was also tested as an amendment along with HSW vermicomposts for pot studies to assess the effect on plant growth. It was collected from a local construction site at NIT, Faridabad. The physico-chemical characteristics of fly ash were as follows: pH - 8.7 ± 0.02; EC - 1.52 ± 0.01dS/m; Ash Content - 678 ± 2.12 g/kg; TOC - 167 ± 1.02g/kg; OM - 32.2 ± 1.2 %; TKN - 0.1 ± 0.001 g/kg; TAP - 0.006 ± 0.002 g/kg; TK - 3.4 ± 0.01 g/kg; Fe - 1326 ± 9.9 mg/kg; Zn - 234 ± 1.76 mg/kg; Cu - 126 ± 3.2 mg/kg; Mn - 78 ± 1.78 mg/kg; Pb - 3.8 ± 0.2 mg/kg. Medicinal plant *Catharanthus roseus* (Sadabahar) saplings (size 1 - 1.3 cm) in a four leaf stage were bought from Dangwal Nursery at Ajronda, Faridabad.

11.2.3 Experimental Design

Eleven Potting media (maintained in triplicates) were prepared by mixing soil with vermicompost and fly ash in different proportions. The arrangement of potting media treatments has been presented in Table 11.1. Vermicompost prepared from household solid waste was applied as organic manure to medicinal plant Sadabahar *(Catharanthus roseus)* and effect on its growth and productivity was assessed. No other manure was added at any time during the pot studies. 100% soil as potting media was taken as control. Shoot length, count of leaves, flowers, diameter of the biggest/largest leaf and flower were recorded on 20, 40 and 60^{th} day of the experiment. Photos of pot culture experiment have been shown at the end of the chapter.

11.2.4 Results and Discussion

Effect of potting media on morphological traits of Sadabahar plant:

Morphological characters of Sadabahar plant like shoot length, total number of leaves, total number of flowers, diameter of the biggest leaf and flower in different potting media treatments were recorded on day 20, 40 and 60 of the experiment. Initial shoot length of saplings in all the potting media treatments was between 1 - 1.2 cm. Shoot length increased to maximum in T3 (28 cm) containing 75% VC followed by T5 (22.5 cm) and T10 (15.5 cm) as compared to control T1 (100% soil) (Figure 11.6). This might be because of presence of nutrients (NPK) in vermicomposts. It was found in the study that the pots without application of vermicompost had shown less shoot growth.

Previous studies also recorded an increase in shoot height/plant height on applying vermicompost as potting media [302],[288],[95],[291].

Table 11.1: Combination of soil, household waste vermi- compost and flyash in varied proportions

Pot Treatments	Soil (%)	Household vermicompost (HSW VC) (%)	Fly ash (FA) (%)	Soil:VC: FA
T 1 (Control)	100	0	0	4:0:0
T 2	75	25	0	3:1:0
T 3	25	75	0	1:3:0
T 4	50	25	25	2:1:1
T 5	50	50	0	2:2:0
T 6	25	50	25	1:2:1
T 7	75	0	25	3:0:1
T 8	0	75	25	0:3:1
T 9	0	100	0	0:4:0
T 10	0	50	50	0:2:2
T 11	50	0	50	1:1:2

At the zeroth day, average number of leaves was 4 - 5 in different pot treatments. 75% vermicompost treated plants (T3) had shown maximum number of leaves (22) after 60 days and T5 and T10 had recorded 20 leaves (Figure 11.7). Least number of leaves was observed in treatments without vermicompost application. Maximum number of flowers (15) were noticed in T3 having 75% HSW vermicompost and it was 3 times more than control. Other pot treatments T5 (50% HSW + 50% soil) and T10 (50% HSW + 50% fly ash) had shown 9 and 6 flowers, respectively. Fly ash contains micro and macro nutrients and along with vermicompost could improve plant performance.

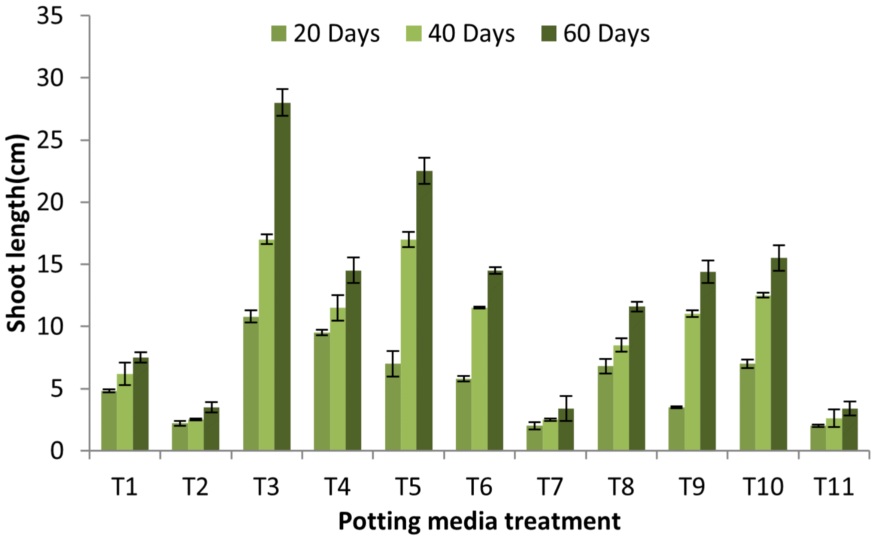


Figure 11.6: Shoot length in Sadabahar plants grown in different potting media treatments

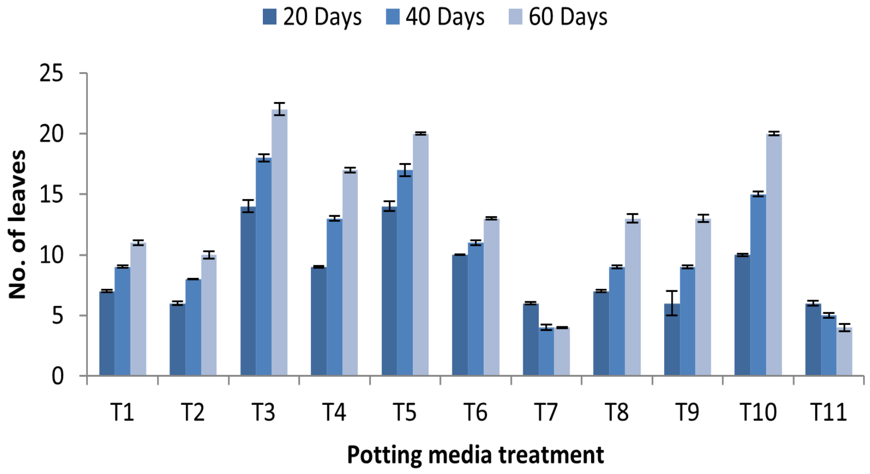


Figure 11.7: No. of leaves in Sadabahar plants grown in different potting media treatments

No significant difference was found among T3 and T5 for diameter of biggest leaf and showed 1.8 fold increase in leaf size over control. Both treatments recorded leaf diameter of 5.2 cm followed by T10 (4.5 cm) (Figure 11.8). Smallest diameter was noted in T11 with 50% soil and 50% fly ash without applying vermicompost. Diameter of largest flower in all potting media combinations are shown in Figure 11.9. Biggest flower diameter was 5.4 cm in 75%vermicompost treated pot and was 5.4 times more than control. 50% vermicompost with soil and fly ash separately also showed 5.1 times and 5.0 times increase in diameter over the control. Pots with less growth of flowers had less flower diameters. Results corroborate with the findings of Sangwan et al. [95] and Khattak et al.[292].

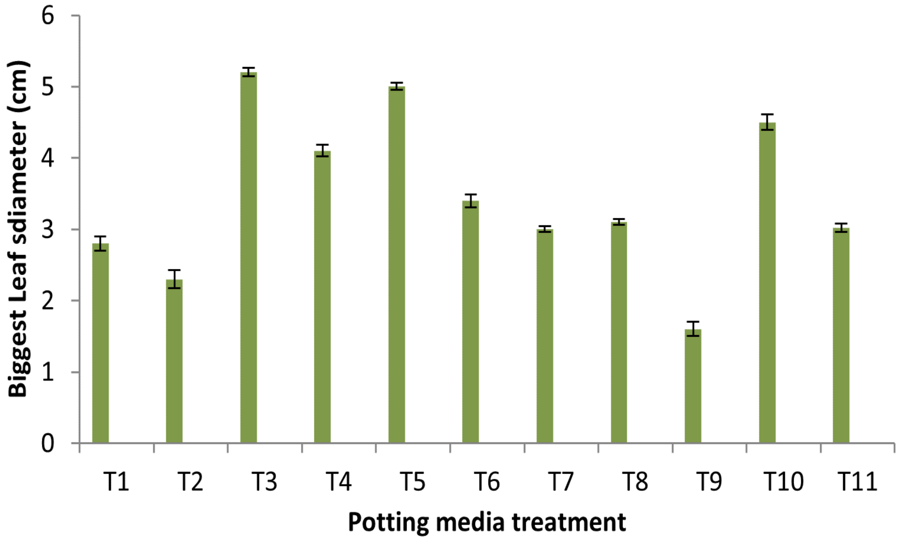


Figure 11.8: Diameter of biggest leaf in Sadabahar plants grown in different potting media treatments

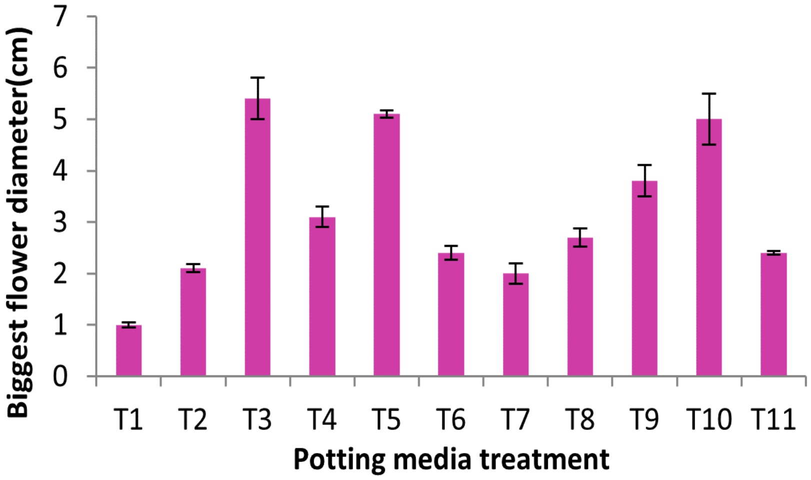


Figure 11.9: Diameter of biggest flower in Sadabahar plants grown in different potting media treatments

Addition of 50 - 75% of HSW vermicompost in potting media favored performance of Sadabahar plants owing to the presence of nutrients required for the growth and productivity. Present study used Sadabahar as test plant and found that above mentioned concentration had no declining effects on plants' growth and productivity. These plants flourished well in vermicompost treated environments.

11.2.5 Conclusions

Present study was conducted with an aim to evaluate the effect of household solid waste on growth, quality and productivity of an ornamental and medicinal plant *Catharanthus roseus* (Sadabahar). 11 different potting media treatments were prepared with different proportions of soil, household solid waste vermicompost and fly ash including 100% soil as control for analysis of plant growth parameters for 60 days. 75% vermicompost has shown maximum shoot length (28 cm), greatest number of leaves (22) and flowers (15). Number of flowers was 3 times more than control. Biggest leaf diameter was 5.2 cm that was 1.8 times more than 100% soil whereas flower diameter was 5.4 times more in 75% VC. Pots without VC amendment had shown less growth parameters. Fly ash added along with VC in appropriate amounts also enhanced shoot height, number and size of leaves and flowers. 50 - 75% HSW vermicompost favored growth and can be effective application dose for performance of *Catharanthus roseus* due to presence of nutrients that are requisite for its growth and productivity. Amendment of vermicompost as potting media had concording effect on morphological traits of *Catharanthus roseus* thus promoting its organic production for medicinal use such as deriving powerful anticancer drug. However, proportion of vermicomposts to be added should be determined before field application.

Some photographs during the experiment are as below:

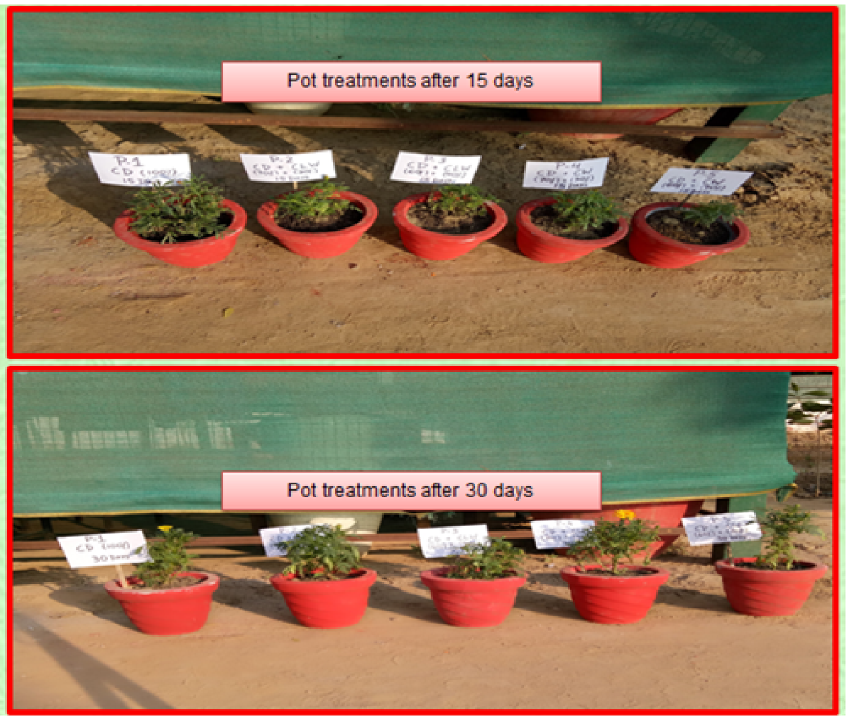


Figure 11.10: Effect of potting media on Marigold plant (*Tagetes erecta*) after 15 and 30 days

Figure 11.11: Effect of potting media on Marigold plant (*Tagetes erecta*) after 45 days

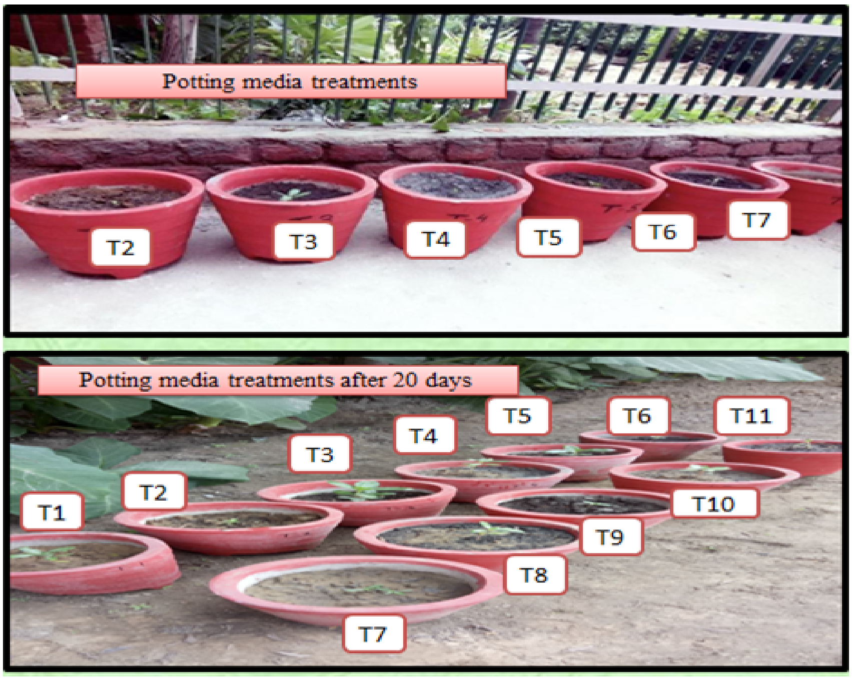


Figure 11.12: Potting media addition in Sadabahaar plant (*Catharanthus roseus*) and effect after 20 days

Figure 11.13: Potting media effect on Sadabahaar plant (*Catharanthus roseus*) after 40 and 60 days

Chapter 12

CONCLUSION AND SCOPE FOR FUTURE RESEARCH

The present research study “Potential of Vermi-technology in solid waste management” is an insight in providing sustainable solutions for city’s solid waste management. The urban cities are facing a mammoth of challenges in handling plenteous mass of waste generated and potential threat to environment and peoples’ health. A cocktail of biodegradable and non-biodegradable waste is found lying everywhere aggravating the problem that should be addressed on a serious note. In Faridabad city (India), major fraction of municipal solid waste stream has a load of organic waste materials from residential, market, agricultural and industrial sources, the present study focuses on conversion of this wet organic waste into vermi-manure after source - segregation of waste generated. Closing the nutrient loop by recycling the organic fraction of the waste stream into vermicompost and applying it to agriculture will not only reduce the amount of waste finally going to landfills, but will also improve soil quality. Study can be concluded with the following points:

i Per capita waste generation in Faridabad city was found to be 0.448 kg/capita/day as per the compositional analysis. The household solid waste generation rates (kg/capita/day) in the city are directly proportional to the income status of households, while the family size, i.e., number of persons in a household has no direct effect on the per capita per day waste generation rates.

ii The highest waste component was the biodegradable fraction of the household solid waste (47.2%), followed by non-recyclable (35.5%) and recyclable fraction (17.45%). By proper source segregation of the household solid waste, a significant portion (≈65%) of the solid waste - biodegradable and recyclable components can be segregated and moved away from the landfills for the final disposal thereby reducing the cost of transportation and waste volume.

iii Organic wastes generated from different sources like Household organic waste, cruciferous vegetable waste (agro-based industrial waste), banana leaf waste, fruit and vegetable market waste, bakery sludge (industrial waste), carrot leaf waste, rice residue (agricultural waste), *Echinochloa crus-galli* (rice weed) can be effectively used as feed materials individually and in combination with other organic wastes for earthworms at different proportions and can be managed through vermicomposting technology.

iv As 100% of waste material used in study was not able to support earthworms, there was a need to add an organic amendment in form of cow dung (most suitable substrate for earthworms as revealed by literature studies). For good growth and fecundity, cow dung was added in suitable amounts to carry out the experiments. Other organic amendments (Fruit and Vegetable waste and leaf litter) were also successfully tried as blending material in different wastes.

v The organic fraction of household solid waste mixed up to 40% with cow dung proved to be a suitable substrate for the vermicomposting process employing the earthworm *Eisenia fetida*. The final vermicomposts obtained were nutrient rich, odor free, more mature and stabilized.

vi 40% of cauliflower and cabbage residual biomasses mixed with cow dung can be efficiently used for vermicompost preparation due to nutrient availability and good germination index for *Vigna radiata*. Banana leaf waste, another organic waste in the study, with 20 - 40% proportion mixed with cow dung in vermireactors showed decent results of waste mineralization and worm growth.

vii 30% rice residue mixed with 30% leaf litter and 40% cow dung is a good option for vermicomposting and can be transformed into nutrient-enriched manure. The process helps to mitigate the effects of rice residue burning if adopted by local farmers.

viii Infusion of fruit - vegetable waste upto 25 - 50% in bakery sludge can help to improve macro and micro nutrient levels in the end product and decreased the amount of cow dung to be added as organic amendment. Greater respiration rate affirms fast degradation of bakery sludge blended with fruit-vegetable waste and an accelerated germination index value is an exhibitive of matured vermicompost that can be applied for agronomic purposes.

ix Vermicompost prepared from 25 - 50% fruit-vegetable waste mixed with cow dung has shown good nutrient content and earthworm growth. Carrot leaves that are often under-utilized can be converted to nutrient rich manure after mixing with cow dung in appropriate amounts. If prime purpose is to obtain nutrient enriched manure, 30% carrot leaf waste can be effectively used. As higher percentage of carrot leaves affects earthworm growth and biomass gain, it is not suggested for cultivating earthworms.

x Local rice weed *Echinochloa crus-galli* can be effectively managed through vermicomposting. Vermicomposting was completed in short time of 63 days as compared to other wastes with decent mineralization and decomposition. Vermicomposting reduced the weed mass by 2.2 - 3.03 folds.

xi Macronutrients (Nitrogen, Phosphorus and Potassium) and micronutrients were found to be increased in final vermicomposts prepared from organic waste materials up to different extent depending upon the initial feed substrate.

xii Pot culture studies were carried out to assess the suitability of prepared vermicompost as organic manure for medicinal and ornamental plants. The growth and productivity of *Catharanthus roseus* and *Tagetes erecta* was found to be enhanced in vermicompost, obtained from household solid waste and cauliflower-cabbage waste biomass respectively, when added in an appropriate proportion to the soil. The plants showed better growth, height, shoot biomass, root biomass, number of flowers and flower size.

xiii A prototype Four bin Vermicomposter has been developed (suited for a family of 4 - 6 persons) for continuous processing of household solid waste. With this, no organic material will be wasted thereby managing household organic solid waste. It is compact and small-sized vermicomposter which can be placed in a suitable corner in any household. If applied in the households, a significant portion of organic waste can be shifted to resource recovery rather than going to landfills.

xiv The vermicomposting experiments with the solid organic wastes from different origins yielded excellent results in terms of reduction in organic pollutant loading in the environment. There was a 2.2 - 4.8 times reduction in total amount of initial waste mixtures at the end of process. This indicates overall reduction in environmental pollution. Moreover, the end product obtained in the process, vermicompost, is a nutrient rich fertilizer which can be used in agricultural fields.

xv It is inferred that the vermicomposting technology can be effectively integrated in the overall solid waste management system of Faridabad city in a decentralized manner at household and city level.

As only segregated biodegradable waste can be composted through the process, decentralization of solid waste collection might lead to economically viable and profitable vermicomposting. To achieve waste segregation at the point of generation, proper training for the employees of Municipal Corporation and private contractors is desired who are directly involved in waste collection and segregation practices. In addition to this, the communities should be educated on the rudiments of handling the wastes and segregating it in their own bins at different levels such as household, shop and establishment level. Proper training for vermicomposting process should also be provided through various awareness campaigns, educating the students and public masses.

The organic component of segregated waste can be put to utilization and resource recovery by vermicomposting technology in a decentralized manner i.e., the waste can be converted into vermicompost at the point of generation itself by installing vermicomposting systems at the household, community or city level. It will result in decreasing the overall waste load in the city as well as resource recovery in terms of vermicompost produced will be fully achieved.

12.1 CONTRIBUTION OF RESEARCH

Solid waste management rules 2016 by the Government of India emphasize on source segregation and managing waste at the source of generation through composting, bio methanation, refuse derived fuel, etc. Also, Swachh Bharat Mission (started in 2014) focussed on improving solid waste management by behaviour change among citizens and motivating them for source-segregation of waste. About 40 - 45% of the solid waste generated is organic in nature, can be segregated and composted and thus provides a solution for organic waste management. Household and every waste generator should segregate their waste where bio-degradable organic waste can be converted into vermicompost.

Present study is novel as vermicomposting studies of biodegradable organic waste in Faridabad city has not been carried out yet. Further, vermicomposting studies of some organic wastes like cruciferous vegetable residual biomass, carrot leaf waste, rice weed *Echinochloa crus-galli*, bakery sludge amended with fruit and vegetable waste, rice residue amended with leaf litter and banana crop waste biomass are either limited or not done previously. Vermi-Technology can be included in solid waste management plan of Faridabad city in a decentralized manner to divert and reduce the load of organic waste from landfills and help in urban sanitization. On the other hand, vermicompost produced is mature enough to be used as biofertilizer and reduce the cost and toxic effects of chemical fertilizers.

Current study has contributed to the development of a prototype vermicomposter suited for a family of 4 - 6 persons in a household. If this system is commercialized at community level and the households are given proper training for its use in conversion of household solid waste into vermicompost, the present study will be a sustainable milestone in MSW management in Faridabad city (India).

Decentralized waste management is the future and present study can contribute in managing heaps of waste lying here and there in the city through vermicomposting technology which is economically feasible and environmentally sound. Decentralized vermicomposting can be implemented at reduced investment and operating costs. It includes reuse of organic waste at the point of its generation, thereby decreasing the waste quantity for transportation as well as transport costs. This will have a positive impact on the overall municipal solid waste management.

12.2 SCOPE FOR FUTURE RESEARCH

The present research has tried to explore the potential of different types of local urban waste found in abundance for vermicomposting through decentralization. These wastes are a menace at city level and thus an effort has been made to cover some local wastes produced that can be tackled at their source of generation by converting them into valuable resource, i.e., vermicompost.

Every city has its own urban waste production; so further studies can be made for organic waste management in a sustainable manner by public as well as Municipal Corporation. To achieve efficient process outcome, pre-digestion stage should be fastened for reducing the time required for vermicomposting. For this, microbial cultures can be used to pre-treat wastes. Besides this, the studies can be made to improve the feasibility of biological methods at household as well as at community level by developing reactors for efficient waste conversion and vermicompost production. Vermicomposting should be efficiently planned, propagated and commercialized by city authorities for its complete inclusiveness in household waste management/community levels /municipal levels.

In the present study, four-bin vermicomposter has been developed for household solid waste management and it can be used at commercial level for field performance. Impact on plant health can be assessed by using vermicomposts in agricultural fields/farms. MCF and governmental bodies should make ground level efforts for utilization of vermicompost for harnessing its nutrients in horticulture and agriculture so as to decrease the effect of harmful fertilizers making the way for organic manure.

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List of publications out of thesis

Sr. No.	Title of Paper	Name of Journal	Publisher	Volume & Issue	Year	Page Number
1.	**Management of banana crop waste biomass using vermicomposting technology***	Bioresource Technology	Elsevier	Vol.326	2021	12474
2.	**Sustainable treatment and nutrient recovery from leafy waste through vermicomposting****	Bioresource Technology	Elsevier	Vol.347	2022	12639
3.	**Infusion of fruit-vegetable waste biomass into bakery sludge to enhance nutrient availability and vermicompost maturity using *Eisenia fetida******	Biomass Conversion and Biorefinery	Springer	Vol.12	2022	03664-x
4.	**Sustainable utilization and treatment of barnyard grass (*Echinochloa crus-galli*) weed biomass using vermitechnology.******	Tropical Ecology	Springer	Vol.65	2023	00315-8

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***https://doi.org/10.1007/s13399-022-03664-x

****https://doi.org/10.1007/s42965-023-00315-8

LIST OF RESEARCH PAPERS COMMUNICATED

- Monika Mago, V.K. Garg and Renuka Gupta **"Utilization of Fruit and Vegetable waste Biomass for nutrient recovery and sustainable management by Vermicomposting technology"**

- Monika Mago, V.K. Garg and Renuka Gupta **"Development of a prototype vermicomposter: Sustainable Management of Household Solid Waste"**

BOOK CHAPTER

- Monika Mago and Renuka Gupta (2021). **" Vermi conversion of Fruit and Vegetable waste into organic manure: An approach towards Sustainable Solid Waste Management"** in Advances in Environmental Science and Engineering (Editors: M.L.

Aggarwal, Renuka Gupta ,Somvir Bajar ,Vishal Puri) Pp:73-82 (Kripa Drishti Publications , Pune) ISBN : 978-93-90847-18-1

CONFERENCE PAPER PUBLISHED IN JOURNAL

- Renuka Gupta and Monika Mago (2015) **”Dynamics of physical and chemical properties of a Vermicomposting Matrix”** International Journal of Scientific Research, Volume:4, Issue:10; ISSN No 2277-8179

LIST OF PAPERS PRESENTED IN NATIONAL / INTERNATIONAL CONFERENCE

- Presented paper entitled **“Management of Food Waste by Vermicomposting : Moving Forward towards environmental Sustainability”** in two days International Conference on Sustainability of Food: a Global Perspective held from 17th - 18th September 2021 by Manav Rachna Centre for Peace and Sustainability

- Presented paper entitled **“Vermiconversion of Fruit and Vegetable waste into Organic Manure : An approach towards sustainable solid waste management”** in track Advances in Conservation of Natural Resources in National Conference on Advances in Civil Engineering and Environmental Sciences (ACEES - 2021) organized by Department of Environmental Sciences at J.C. Bose University of Science and Technology, YMCA,Faridabad during Jan 14 - 15, 2021

- Presented paper entitled **“Vermicomposting: A Novel process in Sustainable Solid Waste Management”** in International Conference on ‘Environmental Challenges and Solutions’ organized by Manav Rachna International Institute of Research and Studies held from 31st Jan to 2nd February , 2020

- Presented paper entitled **“Sustainable Solid Waste Management: A Step Towards Green India”** in National Conference on ‘New Horizons in Technology for Sustainable Energy (NHTSEE - 2017) organized by Department of Electrical Engineering and Department of Humanities and Sciences at YMCA University of Science and Technology,Faridabad held on March 9 - 10,2017

- Presented paper entitled **“Application of Four Bin Vermicomposter in Organic Waste Management ”** in National Conference on ‘New Horizons in Technology for Sustainable Energy(NHTSEE - 2017) organized by Department of Electrical Engineering and Department of Humanities and Sciences at YMCA University of Science and Technology, Faridabad held on March 9 - 10, 2017

- Presented paper entitled **“Sustainable approach towards development of India: Vermitechnology in Waste Management”** in National Conference on ‘Role of Science and Technology towards Make in India’ organized by YMCA University of Science and Technology, Faridabad. India’ during March 5 - 7, 2016

- Presented paper entitled **“Dynamics of physical and chemical properties of a Ver-**

micomposting Matrix" at National Conference on 'Recent innovations in Applied Sciences and Humanities' (NCASH - 2015) held on 10th October, 2015 at Rawal Institute of Engineering and Technology, Faridabad.

- Presented paper entitled **"An approach to Sustainable Solid Waste Management -Vermicomposting Technology"** in International Conference on "Paradigm Shift in Management and Technology" (PSIMT - 2015) held from 9 - 10 April, 2015 at YMCA University of Science and Technology, Faridabad

- Presented poster at National Conference on **"Emerging Trends in Physics and Material Science"** (ETPMS - 2015) held on 9 - 10 March, 2015 at Chaudhary Devi Lal University, Sirsa.

BEST PAPER AWARD IN CONFERENCES

- 1st position in Oral Presentation for paper entitled **"Management of Food Waste by Vermicomposting : Moving Forward towards environmental Sustainability"** in two days International Conference on Sustainability of Food: a Global Perspective held from 17th - 18th September 2021 by Manav Rachna Centre for Peace and Sustainability

- Best Paper Award for the paper entitled **"Vermiconversion of Fruit and Vegetable waste into Organic Manure: An approach towards sustainable solid waste management"** in track Advances in Conservation of Natural Resources in National Conference on Advances in Civil Engineering and Environmental Sciences (ACEES - 2021) organized by Department of Environmental Sciences at J.C. Bose University of Science and Technology, YMCA, Faridabad during Jan 14 - 15, 2021.

Brief profile of Research Scholar

Monika Mago has worked as an Assistant Professor (Guest Faculty / Contractual basis) in Department of Environmental Sciences at J.C. Bose University of Science and Technology, YMCA, Faridabad (Aug 2017 - June 2020). She had obtained Bachelor's degree (Science) from Kurukshetra University in 1996 and Master's degree in Environmental Sciences from Guru Jambheshwar University, Hisar (Haryana) in 1998. She is pursuing PhD (Environmental Sciences) under the esteemed guidance of Dr. Renuka Gupta, Associate Professor, Department of Environmental Sciences, J.C. Bose University of Science and Technology, YMCA, Faridabad. She has also worked as Visiting Faculty in Eros Institute of Management and Technology, Faridabad (2013 - 2016). She has a teaching experience of 6 years.