The Role of Microflora (Bacteria) and their Relationship with Macrofauna (Earthworms) in Vermicompost: A Review

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Abstract: ***Vermicomposting is a non-thermophilic method of preparing enriched compost. According to some studies, vermicomposting is also a bio-oxidative process of biodegradable waste decomposition. Vermicompost is a natural biofertilizer, which is a finely divided, stable, organic manure with excellent water retention ability, air circulation, high permeability, drainage, activity of microbes and acid neutralizing or alkalinity capacity. It also contains a rich source of nutrients, thereby, increasing soil fertility and growth of plants. Vermicomposting increases the population of beneficial microbes, thereby, improving growth of plants by enhancing the concentration of plant growth regulating hormones and enzymes. They also control the attack of pathogens on plants, attack of pest and nematodes which help in increasing crop yield. Vermicompost has physical, chemical, biological and biochemical properties, which help in the promotion of sustainable agriculture. They also help in domestic, agricultural, industrial, and biomedical waste management, which have hazardous effects on life and environment.***

Keywords: Beneficial microorganisms, Earthworms, Plant-growth promotion, Vermicomposting, Waste management

1. Introduction

Farming is the backbone of Indian economy. Currently, in the world, India is one of the top growers [3]. This sector has seen a steep rise in the recent years. This sector employs the biggest workforce, accounting for a sizeable 18.8 percent (2021-22) in Gross Value Added (GVA) in the country. In the past few years, farming showed an appreciable growth of 3.6 percent in 2020-21 and 3.9 percent in 2021-22 [53].

Earth's surface is mostly covered with soil, which is a thin layer of materials. Soil is formed from disintegration of rocks. Soil consists of organic mass, gases, liquids, minerals, and organisms which together support life [33]. Soil serves as a medium of plant growth, water storage and supply, modifier of earth's atmosphere and habitat for organisms. Soil provides structural support to plants [54]. Various kinds of soils, have different chemical and physical properties. Processes like weathering, activity of microbes and leaching determines the varieties of soil. Plant growth is directly dependent on the structure of soil and indirectly influences on the circulation of nutrients, air, and water to the plants [5].

Soil is essential for farming and the soil nutrients are important for growing crops. Another essential factor for farming is the health of the soil. The use of biofertilizers, nourishes the soil [40].

The extensive use of chemical fertilizers, has led to many problems, like erosion of soil, nitrogen leaching, soil compression, depletion of organic mass, and soil carbon loss. Organic fertilizers such as manure and vermicompost are an essential part in organic farming, as it supplies important minerals. It also improves fertility of the land and crop yield [5].

2. Literature Survey

2.1 Vermicompost

Vermicomposting is a method of producing organic compost that uses earthworms to turn biodegradable waste into high-quality compost that contains worm cast and decayed organic matter [28]. Vermicomposting is a process of bioconversion of biodegradable wastes into highly nutrient-rich fertilizers for plants and soil [54]. Vermicompost is a fine peat-like material with good structure, porosity, aeration, drainage, and moisture-holding capacity that contains important nutrients, and is easily absorbed by the crops [43].

Worm casts have high humus content. They increase the mechanism of mineralization, which enhances availability of nutrients, particularly ammonia and nitrates to the plants. Vermicomposting results in increased microbial diversity and activity. Vermicompost contains plant growth regulators produced by the action of microorganisms, and earthworms, which contributes to increased plant growth, flowering, and higher yields [8].

Vermicompost contains water-soluble nutrients. It nourishes the soil in a way that is easily absorbed by plants. Vermicomposting is used in organic farming. Vermicomposting aids in sewage treatment [8].

2.2 Varieties of Earthworms

In phylum Annelida, there are around 1800 species of

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earthworms grouped into five families and distributed throughout the world. Most common worms in North America, Europe and Asia belong to the family *Lumbricidae* which has about 220 species. Temperate soils have higher percentage of earthworms, which feed directly on organic matter, and low percentage of humus feeders. In tropical soils, the humus feeders predominate over the organic matter feeding worms [14].

In the Indian subcontinent, the earthworms are well defined in three topographical divisions- Himalayan region, Indo-Gangetic plain, and Peninsular region. The Himalayan and Indo-Gangetic plain show sparse earthworm population. The important Indian species are *Plutellus* (*Acanthodrillae*), *Perionyx* (*Megascolicidae*), *Dichogaster* (*Ocnerodrilidae*), *Comarodrilus*, *Megascolex*, *Lennoscolex*, *Nelloscolex*, *Tonoscolex*, *Lampito mauritti*, *Hoplochaetella khadalensis*, *Hoplochaetella kempi*, *Metaphire haulleti*, *Amynthas alexandri*, *Pontoscolex corethrums*, *Drawida kanarensis*, etc. In the above types, only a few are of commercial importance [19].

Overall, earthworms are divided into the following varieties-

Night crawlers:
These are common to northern states and may be picked from fields and lawns at night for commercial fish bait sale. Very popular with fishermen, they are not commonly raised on a commercial basis because they reproduce slowly and require a special production and control producers [14].

Field worms or garden worms:
These are excellent fish bait and are preferred by also want a small number of worms for their own use. These worms are not prolific breeders, so they are not used for commercial enterprises [25].

Manure worms:
These worms are also called as wigglers or angleworms because they show squirming reactions when handled. They are used only for commercial production. They are the most common types grown by successful worm farmers [25].

Red worms:
These worms are another type of manure worms. They differ mainly in their size and color from their larger and darker cousins; and adopted for commercial production [25].

Based on the function of earthworms, they are classified into the following groups- humus formers and humus feeders. Humus formers include surface dwelling worms which mainly feed on nearly 90% organic matter and 10% soil. They are red in color. They are also known as detrivorous worms. Humus feeders includes deep burrowing worms which feed on 90% soil and 10% degraded organic matter. They are faint in color and are useful in making the soil porous and distributing humus throughout the soil [14].

2.3 Ecology of Earthworms

Based on the ecology and vertical distribution in soil biota, earthworms are classified, based on the following ways-

Epigeic:
These worms are surface-dwellers. These worms live on the surface of the soil, which is 3-10cm. Regenerative capacity within a limited time. Normally, they are richly pigmented worms. These worms do not affect the soil as they generally cannot dig. They are efficient agents of communication and fragmentation of leaf-litter, so they are known as phytophagus earthworms. (e.g.- *Eisenia fetida*, *Eisenia andrie*, *Dendrobaena veneta*, *Dendrobaena hortenis*, *Dendrodrilus rubidus* [25].

Endogeic:
These worms stay deep inside the soil, which is 10-30cm. Humic materials and mineral matter present in the soil, act as feed for these worms. Their life cycles are long with limited regeneration capacity and lightly pigmented. Due to feeding habit on humus, they are also called as detritivores. They feed on dead roots and other plant debris in the organic matter, rich surface soil horizon. (e.g.- *Aporrectodea caliginosa*, *Aporrectodea rosea*, *Octochaetona serrata*, *Octolasion lacteum*) [19].

Anecic:
These worms are found in vertical galleries, which measures up to 60-90cm. They create burrows for their movement. These worms are nocturnal (night feeders) which feed on litter, feces, and organic matter. They deposit their own excrements and mucus secretions, at the opening of the galleries. These are called geo-phytophagus earthworms. They are large and dark brown in color. Poor nutrients in the soil and external abiotic factors are the major reasons for the reduction in earthworm population (e.g.- *Lumbricus terrestris*- night crawler) [14].

Figure 1: Species of Earthworms

2.4 Species of Earthworms suitable for Vercomposting

In India, there are more than 300 species of earthworms which have adopted the needs of vermiculture. Efficiency of vermicomposting depends on the amount and types of microorganisms present in the substrate and there is major three species are important and suitable for composting [19].

***Eisenia foetida*:**
It is an exotic species and commonly called “European worm” and considered suitable for vermicomposting because of its rapid growth rate, reproductive potential, and occurrence in rich organic substrates in nature. It is shown that the manure samples inoculated with *Eisenia foetida*

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decomposed more rapidly and showed a higher degree of humification than uninoculated samples [5].

***Eudrilus eugeniae*:**
It is widely used exotic species introduced in India and is commonly called "African Night Crawler" and is distributed throughout the world by earthworm growers as these are one of the best for vermicomposting. It also produces protein meal. It has excellent growth and high conversion rate [1].

***Perionyx sansibaricus* and *Perionyx excavatus*:**
These worms are known indigenous (Indian) species for vermicomposting. These are present in depth ranging from 3-8cm, temperature range between 20-28°C and water content ranging between 20-40%. Southern region of the country as during summer, temperature is not as high as in central and northern India [5].

Table 1: Habitats and ecological niches of earthworms and their characteristics and functions

Types	Habitats	Ecological niches	Characteristics	Functions
Eisenia foetida, Lumbricus rubellus, L. castanus, L. festivus, Eiseniella tetraedra, Dendrodrilus rubidus, Dendrobaena veneta	Epigeics	Superficial soil layers, leaf litters, compost.	Small size, uniform body pigmentation, active gizzard, short life cycle, high reproduction rate and regeneration, tolerant to disturbance, phytophagus.	Efficient bio-degraders and nutrient releasers, efficient compost producers, aids in litter comminution and early decomposition.
Apporectodea caliginosa, A. trapezoids, A. rosea	Endogeics	Top soil or sub soil	Small to large size worms, weakly pigmented, life cycle of medium duration, moderate tolerance to disturbance, geophagus.	Brings about changes in soil's physical structure, can efficiently utilize energy from poor soils, hence, can be used for soil improvements.
L. terrestris, L. polyphemus, A. longa	Anecics	Permanent deep burrows in soil.	Large size, dorsally pigmented, forms extensive, deep, vertical permanent burrows, low reproduction rate, sensitive to disturbance, phytogeophagous, nocturnal.	Forms vertical burrows affecting air-water relationship and movement from deep layers to surface helps in efficient mixing of nutrients.

2.5 Materials for Vermicomposting

Vermicompost can be prepared with any type of biodegradable wastes like vegetable waste, leaf litter, crop residues, weed biomass, waste from agro-industries and biodegradable portion of urban and rural wastes [39].

2.6 Methods of Vermicomposting

In organic waste treatment, earthworms act as surface feeders and function as shredding machine, break up large lumps of materials. They ingest the materials and increase the surface area for better aeration and drying. Thereby, enhancing the activity of decomposing microorganisms [28]. The gut of earthworms is a stable environment. The product is a fine stable odor free material containing rich nutrients from the organic waste, i.e., negative asset into a profit, by producing useful materials and reduces environmental pollution [31]. Vermicompost materials are used as biofertilizers. Vermiculture can be done by using either of the two methods- small scale in containers or specially designed boxes for processing kitchen and garden wastes. Commercial or large scale in farm or municipal garbage. Both the methods are simple and can be easily adapted even in rural areas [30], [31].

2.6.1 Small scale vermiculture technique

Light weight materials like plastic, tin, wood, etc. can be used to make vermiculture boxes or containers. These boxes or containers are easy to handle and can be carried from one place to another. Size of the box varies according to the need and measures, 50cm in length, 35cm in width and 15-20cm in depth, the bottom of the box is provided with a few holes of 50mm in diameter [33]. A plastic screen or a jute cloth lining must be placed on the inside bottom and side of the container before the culture medium is added, to prevent the culture medium from sticking to the box and escape of worms from the holes. But it allows the excess water to drain. Top of the box is covered with jute cloth frame before inoculation of medium and earthworms [30].

2.6.1.1 Recycling of kitchen waste

2.6.1.1.1 Preparation of vermiculture bed

A drainage hole must be made on the lower side of a plastic bucket saving 18-20 litres capacity. 3 inches of soil is layered. Then, 1 inch of vermiculture is layered. Again, 1 inch of soil is layered. A layer of cowdung is sprinkled. Grass cuttings or leaves are used to cover to a thickness of 3 inches [31]. The entire system is gently sprinkled with water. It must be stored in a tub for 3 days (storage removes chlorine from water). As grass and leaves dissolve, add more of the same and continue to maintain 3 inches of this layer. Do not allow the system to get soggy due to excess water. The system will take 6-8 weeks for the earthworms to hatch and stabilize [33].

2.6.1.1.2 Treatment of kitchen waste using vermiculture bed

Kitchen waste must be spread on the vermiculture bed. Initially, only waste vegetable greens (no cooked food waste) on the vermiculture bed. Rock dust or black sand should be sprinkled everyday with food waste [41]. Lime should be sprinkled with fruit peels and non-vegetable. Bad smell indicates overloading. Insects, flies indicate acidity. Allow the vermiculture bed to be airy. If the vermiculture bed is functioning properly, it will not smell. Stir the top layer occasionally. The entire contents are utilized as manure within three months of treatment. Setup a second vermiculture bed using a small portion of the above manure as vermiculture [39].

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2.6.2 Large scale commercial vermiculture farming

Due to improper intensive farming technologies and the application of synthetic manures and pesticides in the soil is increasing. This results in soil becoming dead and unproductive and decreases the production levels. Organic farming in the form of vermicompost obtained from earthworms is the best way to reduce the problems of low productivity [28]. Earthworms improve the decomposition of organic waste and enhance the biological activities in the soil. The production of vermicompost from any biodegradable wastes, i.e., city garbage, agricultural waste, industrial waste by using earthworms and its application in agriculture is the most economical method in keeping the soils alive for sustainable production or productivity [48].

2.6.2.1 Basic requirements

To produce enough vermicompost, the population of earthworm and their multiplication on large scale is essential. For the economic multiplication of earthworms, it is important to fulfil the following basic requirements-

2.6.2.1.1 Selection of suitable species

Most used species of earthworms for vermicomposting are *Eisenia foetida*, *Eudrilus euginiae*, *Perionyx excavitis* [14].

2.6.2.1.2 Suitable and adequate food

A well decomposed food made with organic waste having C:N ratio less than 20 is essential for earthworm breeding. The best feed for the worms is dung of cattle, sheep, horses, pigs or dropping of poultry birds and vegetable waste [15]. Cattle dung can be directly fed to the worms whereas other dung materials or kitchen garbage must be mixed in equal proportions with cattle dung for feed acceptability. For enhanced biomass production, wheat bran, kitchen garbage, and gram bran can be mixed to the dung in 10:1:1:1 ratio. A constant supply of 4 tonnes for 1 day or 30 tonnes for 1 week of biodegradable waste is required at the site [15].

2.6.2.1.3 Adequate moisture

Moisture is an important survival factor for earthworms in the feed. Earthworm has 85% water in their body. Hence, water is the basic need. Water conservation mechanisms are under developed in earthworms. Respiration is aided by body wall, which helps in keeping the body moist and water is lost from the body through semisolid excreta. For proper growth of earthworms in the feed, more than 35% water must be present in the feed [15].

2.6.2.1.4 Temperature

Temperature of the earthworm feed should be in the range between 0°C-35°C and best suitable range is 20-30°C. High temperature such as 735°C results in desiccation of the body, moisture stress and temperature below 0°C stops earthworm activities [25].

2.6.2.1.5 Protection from light

Earthworms are nocturnal animals. They may be injured and killed by exposure to light and affected by ultraviolet wavelength [25].

2.6.2.1.6 Suitable pH

For effective multiplication of earthworms, pH of the feeding materials should be at neutral level, i.e., 7-0 (neutral). The earthworm population is severely affected, if the pH of feed material is <4 and >9 [15].

2.6.2.1.7 Location

The site for multiplication should be shaded and on sloppy land, to avoid accumulation of rain water during rainy season. For best results, the shade should be made of either wood, bamboo, or permanent shade tin. Size of the sheds- 12′ × 10′ × 20′. Earthworms can be multiplied very well in pit, pot and raised beds or on heap of 2′ height filled with decomposed organic waste [44].

2.6.2.1.8 Operation site

Land size measuring around 2000sq.ft. is required for production and storage units to produce 500 tonnes of vermicompost per annum [44].

2.6.2.1.9 Transport

Covered trucks or tractor transport the biodegradable waste from various parts of the villages [39].

2.6.2.1.10 Civil work

Pipe lines with sprayers for watering beds. Exhaust fans are used to remove smell, cooling the shed and for proper air circulation. Vermicompost drying yard (12′ × 6′ × 1′) cement platform with a thatched or high-density interwoven nylon net roof for drying the vermicompost. Store room for processed vermicompost. House for watch and ward. Power supply to run the motors and lighting. Bore wells are used for supply of water [48].

2.6.2.1.11 Machinery

2.6.2.1.11.a Mechanical choppers

Crushers and mixers are used for shredding and crushing of organic waste reduces the volume of the materials. It also improves the feeding rate of earthworms by using mixer, which helps in producing nomogenious material saves time and labour input [39].

2.6.2.1.11.b Mechanical sieves

Motorized density gradient roller drum is used for sieving the vermicompost to separate small earthworms and cocoons [41].

2.6.2.1.12 Man power

Supervisiors (overall supervision of work) and labourers [41].

2.6.2.1.13 Purchase of earthworms

For 125-150 tonnes of organic waste per month to yield 50-55 tonnes of dry vermicompost, 1000kg of earthworms or 10-12lacs of adult earthworms are required. The work can be started with 7lacs of earthworms that can work on organic waste [48].

2.7 Preparation of Vermibed

Preparation of vermibed should be done under sheds like pit, pot or raised beds or heaps; which measures about 6ft length, 3ft wide and 2ft deep. 2ft distance must be maintained between two pits as a footpath for spreading the wastes, spraying the water, collection of vermicomposting, etc [28]. A cut must be made at the two sides of the pit at

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45°, so that there is no chance for soil to fall inside the pit while working. The pit must be filled with enough water so that there is no chance for soil to fall inside the pit while working. The pit must be filled with enough water so that non-essential animals like ants, insects, etc can come out [31]. Then, add pieces of brick to prepare a layer of 2 inches and sprinkle water. On the second day, add 2-inch layer of sand and dry leaves or hay and sprinkle water. On third day, add cow dung, compact and soil along with water so that vermibed is prepared at the level of earth. Then, a layer of 6 inches of partially decomposed wastes, soil and cow dung are added, to prepare a heap like bed with addition of water. The vermibed is ready for inoculation of earthworms. On the next day, add 8-10 earthworms per square feet in vermibed [48].

2.8 Collection of Compost and Separation of Earthworm

When earthworms are released into waste mix (vermibed), they start feeding from the top layer of the waste and move downwards into the medium. Earthworms shift from their own excrements. Within 1- or 2-months earthworms feed actively, assimilate only 5-10% for their growth and the rest is excreted as loose granular rice shaped pellets as worm castings on the surface [8].

Sprinkling of water must be stopped 3-4 days before harvesting because the upper layer becomes dry and in search of moisture they go in deep layers of vermibed. The excrements and left-over feed must be removed, before distributing the bed [8]. It is necessary to wear post mortem gloves while disturbing the vermibed to avoid injury to worms. Worms are harvested by hand sorting. Small conical heaps must be made and left for few hours. Within 6-8 hours, the earthworms move down and settle at the base of the heap as a cluster [33]. This is the easiest way to separate earthworms and the compost. The separated worms are added to the fresh material for continuation of the next cycle. The compost (castings of earthworms) is passed through 3-4mm mesh sieve to separate the unfed materials along with cocoons and young earthworms, which can be added to the fresh materials. After drying the compost in shed or sheds till it is semi-dry can be stored in sacs until marketing or further use [48].

2.9 Vermiwash

Vermiwash is a liquid collected after the passage of water through a column of vermibed. Vermiwash is utilized as foliar spray to enhance plant growth, yield, and control development of diseases [8]. Vermiwash is a collection of excretory products and secretions of earthworms, along with micro-nutrients from soil molecules. Vermiwash is a clear and transparent, pale yellow coloured fluid. Vermiwash is very useful in aquatic productivity. Vermiwash is effective in raising lawns, nurseries, and orchids [8].

2.9.1 Method of Preparation

For preparation of vermiwash, a barrel with 10-100 litres and an outlet for collection of vermiwash, which has different layers from base to top. Prepare a layer of about 25% length of washed and broken pieces of bricks, then, add a layer of 25% washed thick sand, then, add a layer mixture of cow dung, soil, and hay on the top [8]. Sprinkle water on bed and let it go through outlet and this procedure should be continued for 2-3 days so that extra wastes are washed out. Introduce the well grown earthworms (40-50sq.ft.) inside soil layer and then, add 10% layer of cow dung and cover it with a filter paper or muslin cloth. Vermiwash collected from the base of the barrel after sprinkling water through perforated mud or metal pot of 5 litre capacity from the above [28]. Vermiwash is used either as it is or dilution with water or 10% cow's urine. Physiochemical properties of vermiwash are as follows- pH 6.9, dissolved oxygen- 1.14ppm, alkalinity- 70.00ppm, chloride- 110.00ppm, sulfates- 177.00ppm, inorganic phosphate- 50.9mg/L, ammonical nitrogen- 2.00ppm, potassium- 69.00 and sodium- 122.00ppm. Worm castings contains growth regulators like gibberellins (GA3)- 2.75mg/g, cytokinins (IPA)- 1.05mg/g and auxins (IAA)- 3.80mg/g [8].

2.10 Advantages of vermicompost

Vermicompost contains important macro and micro nutrients required by the plants. It aids in higher crop yield, promotes formation of new shoots/leaves, improves valuable properties and shelf-life of the vermicompost [30]. It enhances soil quality like structure of soil, soil texture, air circulation, water-retention ability, and controls erosion of soil. It increases the population of microorganisms with specific functions like solubilization of phosphate, nitrogen fixation, decomposition of cellulose and improves soil environment [42]. The castings of earthworms consist of cocoons of earthworms. The action of earthworms in the soil, maximizes the number of earthworms. Vermicompost prevents nutrient loss and decreases utilization of synthetic manure [30]. Disease causing pathogens and hazardous elements are eliminated from the vermicompost. Vermicompost minimizes pests and diseases. It improves the speed of putrefaction of humus content in soil. Vermicompost contains all essential plant growth promoting factors such as vitamins, enzymes and hormones like auxins, gibberellins [47].

2.11 Role of Earthworms in Vermicomposting

Earthworms are terrestrial oligochaetes which are found in the mud (top soil). They constitute the largest animal biomass in temperate ecosystems. Earthworms have a major impact on soil properties. They modify the arrangement of soil particles, promotes putrefaction of humus content and nutrient cycle [19].

Earthworms improves the ingestion of soil, mixing up different soil components, production of surface and sub-surface castings. It also converts organic biomass to soil humus [25]. Earthworms promote putrefaction of humus content in soil and ingestion of soil through feeding, fragmentation, air circulation, turnover, and dispersion. Earthworms are bio-monitoring species of quality of soil. Presence of earthworms in sufficient quantities shows that beneficial microorganisms and other organisms are found in the top soil. Thus, maintaining the health of soil [43]. Earthworms have a major impact on texture of soil, nutrient recycling, productivity of top soil and crop yield. They help

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maintaining a healthy environment and biodegradable waste management [44].

2.12 Relationship between Earthworms and Microflora of Vermicompost

Earthworms can transform garbage into 'gold' [1]. Earthworms mainly impact the volume of soil, microflora, and fauna; it is known as "drilosphere." Earthworm's gizzard (internal gut) and body create some structures like burrows, chambers, worm castings and casts heap in the mud [4]. Earthworms have a major impact on carbon turnover and soil formation. They participate in decomposition of cellulose and formation of humus. Earthworms feed on biodegradable wastes and use a little part of this for their growth. They release maximum portion of this waste in a half- digested form [43]. A great variety of hormones, enzymes and microorganisms are found in the gizzard of earthworms, which help in the degradation of the partially digested materials into a rich organic manure in a few days (nearly 4-8 weeks) [8].

The alimentary canal of earthworms is a tube-shaped structure. The digestive system of earthworms comprises of the following parts- mouth, buccal cavity, pharynx, esophagus, gizzard, stomach, intestine, and anus [14]. The earthworm's gut contains mucus containing proteins, poly carbohydrates, humus content, minerals, amino acids, and microbes like protozoa, bacteria, and micro-fungi [40].

The earthworm's gut contains humus, which is then transformed to a peat like manure by digestive enzymes, microorganisms, and other substances, which is degraded in the gizzard of earthworms and released as "casts." These worm casts are transformed into "vermicompost" by the action of microorganisms found in earthworm's gut [54]. The gizzard of earthworms provides favorable conditions which stimulates the microorganisms and maturation of seeds by the elevated levels of organic carbon, total carbon, nitrogen, and water content [29]. The gut of earthworms contains a variety of gastric enzymes such as lipase, protease, cellulase, amylase, chitinase, and urease. The microorganisms found in the gizzard of earthworms. The action of earthworms has a major impact on the activity of cellulose and mannose [40].

Earthworms enhance the total area for degradation done by the microbes, which is the functional stage of vermicomposting. The degraded biomass found in the gizzard combines with the gastric enzymes and microorganisms in the gut. Finally, the worm castings are released. The microbes aid in decomposition, which is the stage of maturation (Ananthakrishnasamy, *et. al.*, 2015). The function of earthworms on the top soil is by the creation of extensive burrows which helps in loosening the soil particles and absorbent. The pores enhance root, water permeability, air circulation and drainage [29]. Earthworms increases the health of soil and soil productivity by retaining the beneficial microflora. Thus, earthworms transform unproductive soil and land damaged by mining into productive soil. Hence, earthworms are known as 'Farmer's friend' or engineers of ecosystem [40].

2.13 Range of Bacteria Found in Vermicompost

The function of microorganisms presents in the gizzard of earthworms enhance the uptake of nutrients by plants. They have a major impact on the processes of soil, by degrading litter and this affects the function of microorganisms in soil [8]. Microorganisms and earthworms share a complex relationship. Some special group of bacteria like *Rhizobium*, *Pseudomonas*, *Azospirillum*, *Azotobacter*, *Bacillus*, etc. present in rhizospheric soil, are ingested by the earthworms, thereby, maintaining optimal conditions in the gizzard of earthworms. Hence, the function of earthworms maximizes the amount of plant growth-promoting rhizobacteria (PGPR) in the soil [10]. These special bacteria trigger easy nutrient absorption, increase the amount of growth hormones, 1-aminocyclopropane-1-carboxylate (ACC) deaminase, nitrogen fixation, and suppresses fungal growth [8]. Some bacteria suppress fungal growth with the help of siderophores, fluorescent pigments, antibiotics, and some cell wall degrading enzymes such as glucanases and chitinases [11]. Earthworms have a complex relationship with bacteria present in soil that constitute the drilosphere. Mineralization of organic biomass occurs in the gizzard of earthworms. It also aids in chemical changes in metal ions [9]. Some species of bacteria like *Allolobophora terrestris*, *Allolobophora caliginosa*, and *L. terrestris* are found in the alimentary canal of earthworms. It also has high population of aerobes than soil [13]. The number of beneficial microorganisms found in soil can be increased by earthworms. Some species of earthworms like *Pheretima* and *Eisenia lucens* contains special types of bacteria like *Pseudomonas oxalaticus* and actinomycetes- *Streptomyces lipmanii* were identified from the internal gut of these earthworms [20]. Some anaerobic bacteria help in nitrogen fixation like *Clostridium beijerinckii*, *C. paraputrificum*, *C. butyricum* are present in the gizzard of *Eisenia foetida* [29].

The alimentary canal of earthworm's harbors 'nitrogen-fixing' and 'decomposing microbes' and they present in the excreta along with the nutrients. Speed up the function of microbes in soil by maximizing their number and microbial biomass, thereby enhancing aeration by the burrowing actions [8]. Vermicompost contains large numbers of *Actinobacteria* and *γ-proteobacteria* whereas the traditional compost contains more *α-proteobacteria* and *Bacteroidetes*. Some important species of bacteria found in the vermicompost are as follows- *Rhizobium*, *Azotobacter*, *Nitrobacter*, *Actinomycetes*, phosphate solubilizers, *α-proteobacteria*, *β-proteobacteria*, *γ-proteobacteria*, *Firmicutes*, *Actinobacteria*, *Bacteriodetes* and *Planctomycetes* [29]. The main factors for maximum growth of these microorganisms in earthworms include optimal environment, biodegradable wastes abundant in nutrients which provides energy and functions as a medium for the proliferation of these microbes [46]. Some species of earthworms harbors some specific types of microorganisms in their burrows, casts, or intestines like fluorescent pseudomonas- *L. terrestris*, *L. rubellus*- *Actinobacteria* and *Eisenia foetida*- *Aeromonas hydrophila* [29].

Wormcasts contains abundant enzymes such as invertase, amylase, protease, cellulase, peroxidase, phosphatase, urease, and dehydrogenase. Enzyme dehydrogenase is

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involved in oxidative phosphorylation. It is also a measure of the functions of microbes in the soil [3]. Vermicompost prepared from biodegradable wastes has more total microbial count and enzyme activity than traditional compost [11]. Organic matter decomposers present in the gizzard of earthworms and worm casts are *Azoarcus, Pseudomonas, Burkholderia, Paenibacillus, Acidobacterium, Acaligenes and Spiroplasm* [46]. Other microorganisms isolated from vermicompost are *Bacillus cereus, B. subtilis, B. megaterium, B. licheniformis, B. pumilus, B. benzoevorans, B. macrolides* and *Firmicutes*; *Proteobacteria- Pseudomonas* spp., *P. libaniensis, Sphingomonas* spp., *Kocuria palustries*; Actinobacteria- *Microbacterium* spp., *M. oxydans, Cellulosimicrobium cellulans* [13]. The alimentary canal of earthworms also contains bacteria from following families- *Comamonadeceae, Actinobacteria, Enterobacteriaceae, Flavobacteriaceae, Moraxellaceae, Pseudomonadaceae, Sphigobacteriaceae, Aeromonadaceae* [20]. The alimentary canal of earthworms and casts contain microflora which help in the digestion of several humus containing materials and polycarbohydrates such as sugars, cellulose, starch, lignin, polylactide acids and chitin [9].

Some species of earthworms like *Aporrectodea caliginosa* and *L. terrestris* contain bacteria such as *Bacteriodetes*, *α-proteobacteria*, *β-proteobacteria* and some belonging to class *Sphingobacteria*, *Flavobacteria* and *Pseudomonas* spp., were found in their worm casts and some unclassified *Sphingomonadaceae* and *Alcaligenes* spp., were also present [10].

Table 2: Types of vermicompost bacteria and their functions

Species of Earthworms	Types of Bacteria	Functions
Eisenia foetida	*Bacillus* spp., *B. megaterium, B. pumilus, B. subtilis*	Antimicrobial activity against *Enterococcus faecalis, Staphylococcus aureus*.
Eisenia foetida	*Actinobacteria, Bacteriodetes, Firmicutes, Proteobacteria*	Antifungal activity against *Collectotrichum coccodes, R. solani, P. capsica, P. ultimum*.
Pheretima spp.	*Pseudomonas oxalaticus*	Oxalate degradation.
Eudrilus spp.	*Azospirillum, Azotobacter*, Autotrophic *Nitrosomonas, Nitrobacter*, Ammonifying bacteria, Phosphate solubilizers	Plant growth promotion by nitrification, phosphate solubilization and plant disease suppression.
Lumbricus rubellus	*R. japonicum, R. putida*	Plant growth promotion.
L. terrestris	*Bradyrhizobium japonicum*, Filamentous *Actinomycetes*, Fluorescent *pseudomonads*	Improved distribution of nodules, antifungal activities.
Apporectodea trapezoids, A. rosea	*P. corrugota*	Disease suppression in wheat.
A. trapezoids, Microscolex dubius	*R. meliloti*	Increased root nodulation and nitrogen fixation in legumes.
Unspecified	*Rhizobium trifolii*	Nitrogen fixation and growth of leguminous plants.

2.14 Vermicompost and Crop Production

Vermicompost when applied as biofertilizer, they rapidly increase the amount of available nutrients and enhance the function of microorganisms. Vermicompost created from natural materials like kitchen garbage, pig dung, cattle dung, etc., can be used as media supplements. They enhance sprouting and maturation of seedlings and improves the productivity of the crops [33]. Vermicompost, when used in plant media improves growth, germination, fruiting, flowering of several plants [2]. This shows that growth factors have a great impact on sprouting of seeds and crop yield. Evidences shows that microorganisms are the manufacturers of several plant hormones and plant-growth regulating substances (PGPRs) like gibberellins, auxins, cytokinins, abscisic acid and ethylene [36].

Some species of bacteria like *Arthrobacter* spp., and *Bacillus* produce cytokinins in soils, which increases the vigor of seedlings. Gibberellins produced by microbes help in the development and maturation of plants. Auxins obtained from *Azospirillum brasilense* influences plant growth of the plants of *Paoceae* family [47]. According to some researchers, humic substances have important functions that stimulates growth of plants. Humic substances in plant tissue culture, induce formation of root and shoot. Vermicompost prepared from kitchen waste, animal waste, paper mill waste and sewage have large amounts of humus content [20]. Minerals which are not soluble in organic biomass are dissolved by fulvic and humic acid present in the humus, which are directly taken up by plants. They also reduce stress and triggers plant growth [2].

Earthworms aid in the formation and maximizes the number of regulators of plant growth. Earthworms enhance the function of microorganisms. They also increase the production of plant growth regulators [36]. Some substances which trigger crop yield were obtained from *L. terrestris*, *Dendrobaena rubidus* and *Aporrectodea longa*. Other substances such as substances like indole from the tissues of *E. foetida*, *A. caliginosa* and *L. rubellus* [20]. *A. trapezoids* helps in the proper distribution of *Rhizobium* in top soil, thereby, enhancing formation of roots and nodulation in leguminous plants. Earthworm casts have a major impact on plant propagation, improves root initiation. It also enhances colonization of roots and amount of biomass. Earthworm casts have a hormone-like effect on the development, maturation, and metabolism, which causes shrinking, formation of roots, elongation of internodes and precoiousness of flowering by the metabolites released by the microbes in the soil [5]. Earthworm casts triggers the development of carpophore in button mushroom (*Agaricus bisporus*) which is used in cultivation of mushrooms [5]. Some important growth hormones were present in the liquid concentrates of vermicompost such as gibberellins, cytokinins, and auxins on *Begonia*, *Petunia* and *Coleus* shows that vermicompost is an enriched medium of plant growth regulating substances [36].

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According to studies conducted on the impacts of urea solution and vermi-wash on sprouting of seeds, length of shoot and root in cluster beans (*Cyamopsis* tertagonoloba) shows that vermi-wash contains hormones like cytokinins, indole-acetic-acid (IAA), and gibberellins [47].

There are a range of microorganisms that are present in the gizzard of earthworms that enriches vermicompost with hormones that are soluble in water and sensitive to light, which are present in vermicompost, thereby, making it highly stable and persistent for staying longer on the mud and therefore, influences plant growth [36]. Vermicompost is an enriched source of organic matter, plant growth regulators and essential nutrients, which is an excellent natural biofertilizer (vermicompost) that improves growth, germination, fruiting, and flowering in several crops [20]. Vermicompost significantly reduces the incidences of disorders such as albinism, defects in fruits and grey mold. It also decreases diseases related to nutrients and other plant diseases, therefore, increases the production and superior marketable fruits [34]. Plants, especially fruits which are harvested from vermicompost were firmer, has more amount of vitamin C contents, dissolved solids, and attractive colors [33]. Rise in crop yield is dependent on processed waste, which improves physiochemical characteristics and nutrients. It is easily taken up by the crops. Some bacteria help in reducing plant diseases and promote plant growth [34].

2.15 Vermicompost and Pest Control

2.15.1 Arthropod pest control

Organic fertilizers aids in the reduction of several pests like corn borer, aphids, brinjal shoot, fruit borers, etc. [23]. According to some studies, vermicompost decreases the attack of *leaf miner (Apoaerema modicella), Spodoptera litura, Helicoverpa armigera, aphids* (*Aphis craccivora*), spider mites and jassids (*Empoasea kerri*). Vermicompost controls pests in field conditions and reduces the destruction by aphid (*Myzus persicae*), mealy bug (*Pseudomonas* spp.,) and 2 spotted spider mites (*Tetranychus* spp.,) under green-house conditions [23].

Some studies shows that application of liquid concentrates of vermicompost decreases infestation of pests and their reproduction rates in infected plants. The utilization of vermicompost teas with higher doses stimulates mortality of pests [23].

Addition of inorganic fertilizers in farming increases pest attack compared to organic fertilizers. Addition of inorganic nitrogen fertilization enhances nutritional quality of host plants, inhibits the rise in the levels of secondary metabolites, enhances insect's diet, speeds up oviposition and maturation rates of pests [34]. Organic fertilizers improve nutritional composition, nutrients are released at reduced rates, thus, plants which are grown in organic fertilizers, decreases nitrogen levels. It also increases the number of phenols and makes plants resistant to the attack of insects. Vermicompost shows gradual, controlled distribution of nutrients, mainly in the release of available potassium, calcium, nitrogen, phosphorus, and magnesium [34].

Vermicompost contains nourishing source of phenols and humic acid. Phenolic compounds help in controlling the pest attacks, if utilized as feeding deterrents. Earthworms in soil contains polychlorinated phenols and their metabolites. *L. rubellus* contains an endogenous phenoloxidase, which bioactivates substances and produces toxic phenols such as p-nitrophenol [23]. The gizzard of earthworms contains humic acids which can absorb monomeric phenols. Vermicompost consists phenols, that are easily absorbed by tissues in plants, making them unpalatable. This, affects the reproduction rates and pest survival [23], [34].

2.15.2 Parasitic nematode control

The utilization of biofertilizers decreases the number of parasitic nematodes in plants. The utilization of vermicompost in field suppresses parasitic nematodes in plants [35]. Vermicompost can suppress the incidents of insects such as *Meloidogyne javanica* and *Meloidogyne incognita* [35].

These processes are used for the reduction of parasitic nematodes in plants by using vermicompost and includes many factors such as biotic and abiotic factors [34]. Incorporation of organic biomass into the soil increases the number of microorganisms- bacterial and fungi, which have an antagonistic action on the nematodes (e. g- *Pasteuria penetrans, Pseudomonas* spp., and *Chitinolytic* bacteria, *Trichoderma* spp.,). Some nematode predators such as nematophagus mites such as *Hypoaspis calcuttaenis, Collembola* and other arthropods feed on these parasitic nematodes in plants [34].

The utilization of vermicompost stimulates fungi which kill the nematodes and destroy nematode cysts. They also aid in the multiplication of plant growth-promoting rhizobacteria, thereby, producing some enzymes which are toxic to parasitic nematodes in plants [34]. Some abiotic factors such as nematicidal compounds like ammonia, nitrates, hydrogen sulfides, organic acids produced during vermicomposting, and reduced ratios of carbon or nitrogen in compost has major impact. But, changes in soil's chemical and physical properties such as density, water retention capacity, permeability, pH, EC, CEC, and nutrition has indirect impact on parasitic nematodes in plants [23].

2.16 Vermicompost and Treatment of Clinical Waste

Hazardous garbage like biosolids, sewage sludge and clinical wastes are dangerous to the surroundings and must be decontaminated before releasing into the surroundings. So, it is important to manage waste by safe, cheap, and easy methods. Biosolids contain a great variety of pathogenic microorganisms. Bio-composting of wastes can biologically transform humus content and reduce the threat of pathogens [41]. Thermophilic phase is not included in vermicomposting but reduces pathogenic microorganisms like *Salmonella* spp., enteric virus, helminth ova and fecal coliforms from biosolids [17]. Vermicomposting of wastewater with *L. mauritti* completely removes *Salmonella* spp., *Escherichia* spp...,. The earthworm's activities on the

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sludge decreases the levels of pathogens, reduces the foul smell of decomposition, and speeds up sludge stabilization [17]. Vermicomposting eliminates of enteric microorganisms, which is based on the diet of earthworms, which includes microorganisms [48].

Generally, earthworms are utilized for the treatment of domestic waste and used in treatment of sewage water. Multiplication of beneficial decomposing bacteria in wastewater are done by earthworms. They also function as crushers, grinders, biological stimulators, aerators, and chemical degraders [39]. Earthworms aid in the granulation of clay particles, maximize air circulation, grind the slit, and sand particles, expand the surface area, and therefore, accelerates inorganic and organic mass adsorption in wastewater [45]. The body of earthworms is a 'biofilter' which eliminates total dissolved solids (TTDS), total suspended solids (TSS), chemical oxygen demand (COD), biological oxygen demand (BOD) from wastewater by 90-92%, 90-95%, 80-90% and 90% by ingestion. Degradation of solids, domestic wastes and heavy metals from wastewater and absorption by body walls [41].

Vermicomposting transforms infectious bio-hazardous waste having several infectious microorganisms such as *Escherichia coli*, *Pseudomonas pyocyaneae*, *Staphylococcus aureus* and *Proteus vulgaris* into a non-pathogenic waste having *Citrobacter freundii* and spore forming microorganisms found in top soil and gizzard of earthworms [45]. Vermicomposting helps in the treatment of bio-hazardous and municipal wastes from sewage treatment plants. It also helps in the transformation of wastes into manure free from enteric bacteria [39]. Earthworms used in vermicomposting reduces the levels of infectious microorganisms such as *Escherichia coli*, viruses, helminth ova, *Salmonella enteriditis* and fecal coliforms in various wastes [18]. Decrease in microbial numbers by gut passage is by gastric enzymes and mechanical grinding, these are direct methods. Other methods of elimination of pathogens are providing aerobic environment that helps in minimizing of the number of coliforms [45].

3. Conclusion

In the recent times, a major hazard is observed in agriculture, where poisonous chemicals and synthetic fertilizers are in constant use for improving soil fertility. Organic farming can be a great replacement for the traditional agricultural methods. Vermicompost is the best-known alternative to chemical fertilizers. Earthworms are ecosystem engineers in natural soil habitats; detritivores which serve the purpose of converting biodegradable organic residues into compost by their feeding. Earthworms are biological indicators of soil health like levels of contaminants like chemicals, heavy metals, toxic substances, and industrial effluents.

Vermicomposting is an economical and environment-friendly method of management of garbage with the help of microorganisms and earthworms. Vermicomposting is an excellent method compared to conventional thermophilic composting. Vermicompost is a good source of natural biofertilizers. They also enhance the chemical, biological and physical characteristics of soil. Vermicomposting increases the distribution and concentration of beneficial microorganisms.

According to some studies, a few pathogenic microbes like *Fusarium* and *Pythium* are eliminated by earthworms. Vermicomposting increases activities such as disease suppression and maximizes bacteria promoting crop yield by reducing the harmful effects.

Finally, vermicomposting is a great tool to use instead of synthetic fertilizers since the microorganisms found in vermicompost can kill pathogenic microorganisms.

4. Future Scope

Vermicompost is a method, which has been extensively studied over the years. It is an important topic. Many studies have been done in the field of vermicomposting and has helped in providing information on the role of vermicompost [57]. There are many facts, which needs to be explored like the potential of vermicompost, composition of bacterial communities, amount of vermicompost, organic waste selection, role of vermicompost on heavy metal contents [57]. In this paper, the knowledge gaps mentioned and explained in this review, are the most important and provides future research opportunities in vermicomposting [57].

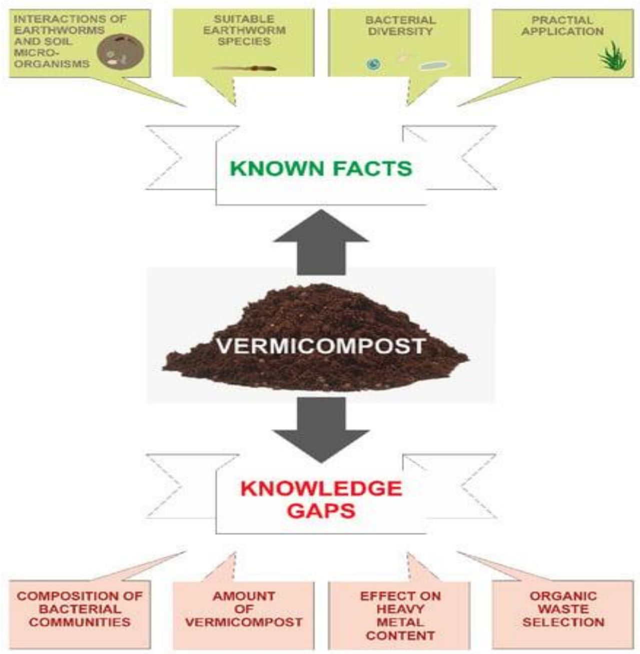

Figure 2: Many facts about vermicompost are known, some unknown facts which has to be investigated to maximize potential of vermicompost

4.1 Role in heavy metal content reduction

Future research can be based on the potential of vermicomposting in reduction of heavy metals. More studies need to be done to understand the effect of vermicomposting on heavy metals. Positive effects must be available and can be used for heavy metal remediation [51]. Future research

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depends on how vermicomposting effects heavy metals content, their mobility and bioavailability. This opens new questions and new potential roles of vermicomposting [51]. Vermicomposting might have a major role in biofortification. Heavy metals like Zn are important for all living organisms. Some soils might be lacking Zn, which is related to deficiency of Zn in humans, thereby, causing serious health issues. Research on the potential of vermicompost through Zn and Fe enrichment in soil as well as in the grain. In this topic, the aim is to enrich the soil with Zn to increase its accumulation in crops, in turn, can help in meeting the needs of humans [51].

4.2 Composition of bacterial population

An additional information on the specific functions and composition of bacterial population is required. Even though, there is existing information but, there are research opportunities on bacterial interactions related to earthworm species used in vermicomposting [51]. More intensive research is required on the microorganisms in soil, in earthworm's gut and in vermicompost and their role in the process of decomposition of organic matter are important. Finally, in-depth research on the bacterial populations participating in the active phase of vermicomposting is required. Another important and interesting topic is the anti-susceptibility and anti-microbial properties of the bacterial community in vermicomposting and antibiotic resistance in bacterial community in vermicomposting needs to be investigated [51].

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