Chapter

Role of Decomposers in Agricultural Waste Management

Nusrat Iqbal, Amrish Agrawal, Saurabh Dubey and Jitender Kumar

Abstract

In this chapter, agricultural waste residue management by bio-organisms is discussed along with different types of decomposition processes. Tons of agricultural wastes are produced every year. These agricultural wastes create major environmental problems without effective means of management methods. There are many technologies being used for the decomposition, which mainly include anaerobic decomposition, compositing, fermentation, etc. All these decomposition processes depend upon the different soil-inhabiting microbes. These microbes are the key components of agri-residue decomposition process. Every step of decomposition requires different microbes. Various sets of catalytical enzymes are involved for the catabolic procedures of organic matter. By successive catabolic reactions, all the organic matters are mineralized into soil essential constituents, which will be the most effective sources of macro- and micronutrients for the soil fertility. Working efficiency of these microbes depends upon different parameters like moisture, temperature, pH, etc. The vitality and efficiency of microbes can be enhanced by using various inert carriers. If the efficiency of these soil microbes enhances by various factors, then the rate of decomposition could be enhanced to handle this ever-increasing problem of agriculture residue in near future.

Keywords: agri-waste, pollution, decomposition, mineralization, microbes

1. Introduction

Agricultural waste is produced by various agricultural operations, and it contains sugarcane baggage, paddy and wheat straw and husk, waste of vegetables, food products, jute fibers, crop stalks, etc. About 998 million tons of agri-residue waste is produced every year [1]. The abundance of agricultural waste production causes a lot of environmental pollution and generates many environmental contamination problems. During certain periods of time, characteristics of waste materials have changed and cause harmful and toxic effects toward human beings. Approximately, 2 tons per day agri-waste is produced in rural areas. Besides this, cow houses and sugar industry produced an average 20 million tons of waste, which is a rich source of nutrients and manures. Conventionally, farmers burnt up or left the agricultural waste in the field, but this causes lots of air pollution and soil pollution. Various techniques have been utilized for agri-residue disposal.

Agricultural waste mainly consists of crop residues which have lots of organic carbon content and a supply of plant nutrients. Crop residues' retention after harvesting reduces soil erosion [2]. Combine harvester machines contributes 75% residue after harvesting but due to high silica content animals are not likely to feed these residues. Then farmers start to burn the residues, but burning emits 8.77 Mt. of CO, 141.15 Mt. CO2, 0.23 Mt. of NO, and 0.12 Mt. of NH3 [3], which causes air pollution and loss of organic content of approximately 80–90% N, 25% of P, 20% of K, and 50% of Singh et al. [4]. So, the rice straw management is a challenging task in rice-producing regions. So, there is a need for an effective waste disposal technology for converting this waste into some valuable form. Physical, chemical, and biological decompositions break the lingo-cellulose bonds in crop residues and result in the enhancing of the nutrient content of soil [5]. Biological decomposition is the main and efficient decomposition method in which bacterial and fungal spores speed up the decomposition of waste under aerobic and anaerobic conditions. Microbial decomposition enhances nutrient content by nitrogen fixing, phosposorous solublization, and cellulose decomposition of decomposed final product [6]. There are a variety of bio-decomposers such as bacteria, fungi, protozoa, etc. and they are capable to degrade cellulose by depolymerizing cellulases which hydrolyze ligno-celluloses. Most commonly known bio-decomposers are fungi which include *Humicola*, *Trichoderma*, and *Penicillium aspergillus* [7]. The market sale value of soil microbes are increasing nowadays [8]. Indian government is working for food self-sufficiency and environmental sustainability. Due to the high market value, the production of soil microbial-based decomposer product would be expected to increase in coming years. Researchers have been able to identify and isolate multiple types of bio-decomposers, but still no formulation is available for the efficient use of these microbes. Researchers are working to improve the efficiency and storage of multiple types of microbes in an effective formulation product in one package which would have a high commercial value.

2. Production of agricultural waste internationally

About 998 million tons of agri-residue waste are produced every year [1]. Eighty percent of organic waste can be converted into organic manure with the rate of 5.27 kg/day/1000 kg wt basis [9]. Development of agricultural waste management methods for sustainable and eco-friendly approach is required for effective disposal of agri-waste [10]. Agro-waste may cause several health and environments issues if not disposed properly so, it requires a very safe method for disposal [11]. Many studies and research work have been focused on development of agro-waste based bio-fertilizers. Bio-fertilizers basically contain living organisms and enrich the soil with different soil nutrient and minerals which is very essential for the growth and development of plant [12]. Microbial inoculants in industries were being used in Malasiya in late 1940s [13].

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Many studies and research works have been focused on development of agro-waste based bio-fertilizers. The bio-fertilizer obtained from the natural resources is a sustainable source of fertility inducer for the small farmers [14]. Bio-fertilizers basically contain living organisms and enrich the soil with different soil nutrients and minerals which are very essential for the growth and development of plant [12].

Bio-fertilizers are derivatives of agricultural residues such as straw, corn stalks, etc. that are decomposed by bio-decomposers and are also known as recycled

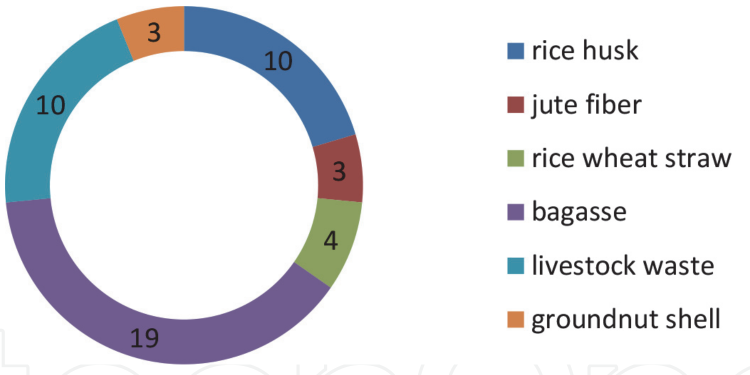


Figure 1.
Agriculture waste percentage from different sources.

products. The leafy vegetables, fruits, and cereal crops residues are an efficient source of basic nutrients such as nitrogen, phosphorus, and potassium as well as secondary and micronutrients such as calcium, boron, magnesium, and manganese. The bio-decomposer enhances the soil fertility and soil texture (**Figure 1**).

3. Types of agricultural waste

There are three major types of agricultural waste (**Figure 2**):

1. **Livestock manure**: The agricultural land is generally devoted to three farm animals: cattle, pig, and poultry, and lands used for the farms are about 15.3, 0.10, and 1.3 million hectares, respectively [15]. Around 120 million tons of manure are produced from these livestock sectors per year.

2. **Postharvest agricultural waste:** These wastes are in the category of primary agricultural residue. It mainly includes straw, husk, and stalks of planted crop, which are left after harvest. These can be used in fodder and rest is decomposed by different waste decomposers or burnt. These residues are rich in cellulosic fibers [16].

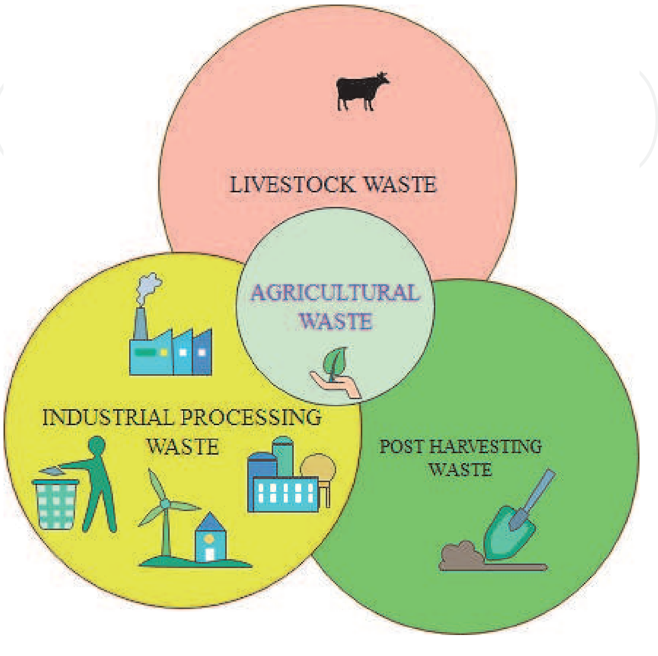


Figure 2.
Types of agricultural waste.

3. **Agro-industrial residues**: These are in the category of secondary agricultural residuals produced after processing of agricultural crop into various bio-product forms. These include husk, molasses, bagasse, peels, hulls, husk, etc.

4. Waste management processes

There are different methods of solid waste management which are well known. Among the various methods, bio-process-based are the most suitable for managing the waste in a safe way and they generate the nontoxic degraded foams.

1. **Landfills:** Landfill is the most primitive and commonly used waste disposal method (**Figure 3**). In this method, waste organic materials are simply collected and thrown in depth or pits. There are two main processes involved in an efficient landfilling method: 1. Collection of waste in a very small and confine place. 2. Compaction of collected waste by compactors or bulldozers.

There are five phases involved in this method:

i. Phase I: Adjustment of waste with O_2 supply

The waste compacted in this phase with void spacing for oxygen exchange (O_2). Initially, O_2 level is high due to activity of microbes for aerobic decomposition process but O_2 level gradually decreased due to high microbial density.

ii. Phase II: Transition from aerobic to anaerobic

Due to high microbial density, O_2 level decreases and CO_2 level increases. The anaerobic condition occurs in the layers and primary electron acceptors are sulfates and nitrates instead of O_2.

iii. Phase III: Generation of organic acids by acidification

This phase is also known as acidification phase, and in this, volatile fatty acids (VFA) are decomposed to acetic acid (CH3COOH), CO2, and H2. The H2 formation phase occurred in the last and activates the H2 oxidizing bacteria. The acidogenic bacteria increase the decomposition rate of waste.

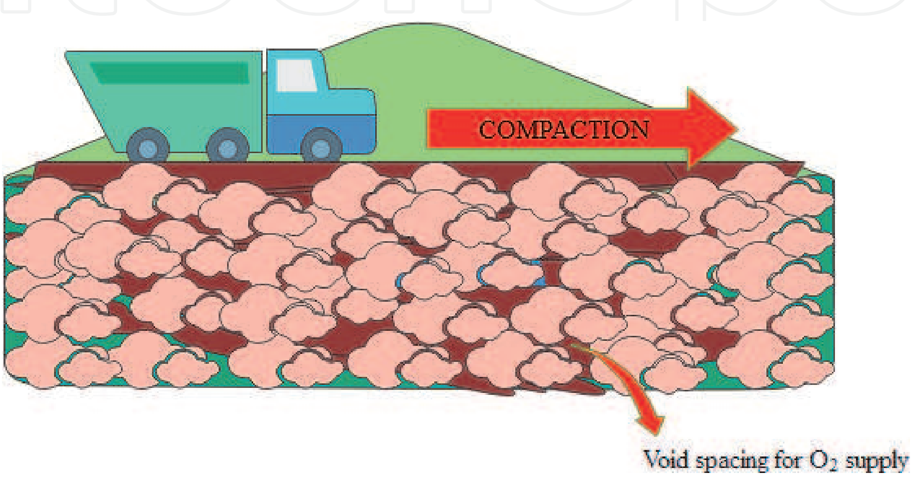


Figure 3.
Landfill mechanism of waste decomposition.

iv. Phase IV: Methonogenesis

The organic acids products, viz., acetic, propionic, and butyric acids are converted into CH4 and CO2 as intermediate products by methoanogenic microorganisms. In this phase, pH changes from acidic to neutral. This phase is the longest phase of decomposition.

v. Phase V: Humification

All the microbial activity slows down in this phase and CH4 production also completely disappears. All the remaining organic materials are converted into gas phase by the oxidative processes and converted into humic acid compounds.

2. **Anaerobic decomposition:** Anaerobic decomposition is gaining attention in various energy sources to fulfill the demand of increasing population in a safer and economical way [17]. There are around 267 plants that have been distributed all over the world. In anaerobic decomposition, microorganisms decompose the solid waste into biodegradable and nontoxic forms in the absence of oxygen (1). There are two types of bacteria which play a significant role in anaerobic decomposition reactions, which include hydrolytic bacteria and the acidogenic bacteria. These two bacteria belong to two kingdoms, the archea and the bacteria [18].

There are four successive stages of anaerobic decomposition which are: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. These four stages are carrying out by the interaction of various microbes [19].

a. Hydrolysis

The decomposition pathways start with the hydrolysis of the waste agricultural biomass, which is rich in complex polymeric constituents. The hydrolytical cleavage broke the polymeric interconnecting bonds by the hydrolysis process. Agricultural waste is rich in organic polymers such as cellulose, hemicelluloses, lignin, etc. [20]. Hydrolysis breakdown is an electrochemical process driven by the hydrolytic bacteria by cellulolytic enzymes, lipase enzymes, etc. Hydrolysis cleavage converts these insoluble long chain polymers into soluble simpler derivatives like ammonium and other organic constituents [21].

Kinetically, hydrolysis reactions are the first-order reactions in which complex biodegradable waste material is hydrolyzed at constant temperature and pH [22].

$$\mathrm{(C6H10O5)n + n\ H2O \rightarrow n\ C6H12O6 + n\ H2}$$

$$\frac{\mathrm{dXdegr}}{\mathrm{dt}} = -Kh.\mathrm{Xdegr} \tag{1}$$

where Xdegr = Amt. of Decomposed material (kg/m^3)

t = time interval (days)

kh = hydrolysis constant in first order reaction.

Hydrolysis reactions in anaerobic decomposition can be considered as rate-determining steps, which depend upon the ration of hydrolytic product to microorganisms, pH 5–7, and 30–35°C [23]. The hydrolysis reactions make the agricultural postharvesting biodegradable waste residue into e simpler forms and make it accessible for acidogenic bacteria for further breakup.

b. Acidogenesis

The hydrolysis soluble products of biodegradable material are easily diffused in to the cell membranes of acidogenic microorganisms. Acidogenic reactions are associated with obligate and facultative microbes, viz., *Micrococcus*, *Peptococcus*, *Streptococcus*, *Desulfomonas*, and ***Escherichia coli***. The acidogenic microorganisms further convert the hydrolytic products into CO_2, H_2, and various organic acids which are known as volatile fatty acids (VFA) like acetates, propionate and butyrate along with this small amount of ethanol and lactate [24, 25]. The rate of reaction of VFA production is more in lower pH conditions, that is, pH 5 and ethanol production occurs in pH 4 [26]. The final acidic product can be used as a liquid and dry fertilizer [27]. VFA also creates the precursors for the final stage of methanogenesis. Chemical reactions that occur in acidogenesis are:

$$C6H12O6 \leftrightarrow 2\ CH3CH2OH + 2\ CO2$$

$$C6H12O6 + 2\ H2 \leftrightarrow 2\ CH3CH2COOH + 2\ H2O$$

$$C6H12O6 \rightarrow 3\ CH3COOH$$

c. Acetogenesis

The acidogenesis products like acetates and other organic acids further convert into hydrogen gas by dehydrogenation reactions. The hydrogen produced in this stage is the main substrate for methanogenic microorganisms. The reactions involved in this stage are [28, 29]:

$$CH3CH2COO - +3\ H2O \leftrightarrow CH3COO - +H + HCO3 - +3\ H2$$

$$C6H12O6 + 2\ H2O \leftrightarrow 2\ CH3COOH + 2\ CO2 + 4\ H2$$

$$CH3CH2OH + 2\ H2O \leftrightarrow CH3COO - +3\ H2 + H+$$

The hydrogen produced in this step causes an inhibitory effect toward acetogenic microorganisms and the produced hydrogen is available for the consumption of methanogens. So, microorganisms of acetogenisis and methanogenisis work symbiotically in association.

d. Methanogenesis

In the final stage of anaerobic digestion, all the intermediates convert into H2, CH4, CO2, and CH3COOH [30]. The microbial species mainly include *Methanobrevibacter ruminantium*, *M. bryantic* and *M. thermoautotrophicum*, *Methanogenium cariaci and M. marinsnigri*, etc. [31]. Methane-producing bacteria can be divided into two groups, namely, acetophilic and hydrogenophilic.

The reaction equations in the methanogenic stage are as follows [32]:

$$CH3COOH \rightarrow CH4 + CO2$$

$$CO2 + 4\ H2 \rightarrow CH4 + 2\ H2O$$

$$2\ CH3CH2OH + CO2 \rightarrow CH4 + 2\ CH3COOH$$

3. **Compositing:** Compositing is defined as the process of decomposition of complex waste organic matter into the simpler molecular chains. These smaller molecular compounds further decompose and form soil humus [33].

Compositing process is also mediated by different microorganisms in aerobic environment so it is also known as aerobic decomposition. The most common microorganisms are: bacteria, fungi, algae, and protozoans [34].

Compositing process can be explained by this equation:

$$\text{Organic matter} + O_2 \rightarrow \text{Compost} + CO_2 + H_2O + NO_3^{-} + SO_4^{2-} + \text{Heat}$$

Compositing process occurs in two phases which include: 1. degradation and 2. maturation.

1. Degradation: In this phase simpler organic matter are degraded by aerobic microorganisms. This phase is for several weeks to few months and occurs with high speed. This step needs temperature with full aeration for cooling the support also termed as thermophillic phase. Various phytotoxins also release as decomposition proceeds [35]. After degradation of simpler organic matter then decomposition of complex organic matter starts. At the end of this phase, most of the microorganisms die due to nonavailability of sufficient food. In addition to this, thermophillic condition changed to mesophillic and temperature drops from 50-55C to 25 C. According to several authors [33, 34, 36], this stage occurred for longer period of time.

2. Maturation: During the mesophillic phase or maturation phase, actinomyces appear and start degrading compost material of first phase into finer particles. Lots of invertebrates like earthworms, ticks, and centipedes further disintegrate by chemical and biological transformations (**Figure 4**). These transformations are termed as humification which is endorsed by the oxidative polymerization of phenolic compounds acquired by degradation of organic matter in the first phase.

3. Solid-state fermentation (SSF) process is another bioprocess for solid waste disposal in absence of free water [37]. Microbial growth is very important for

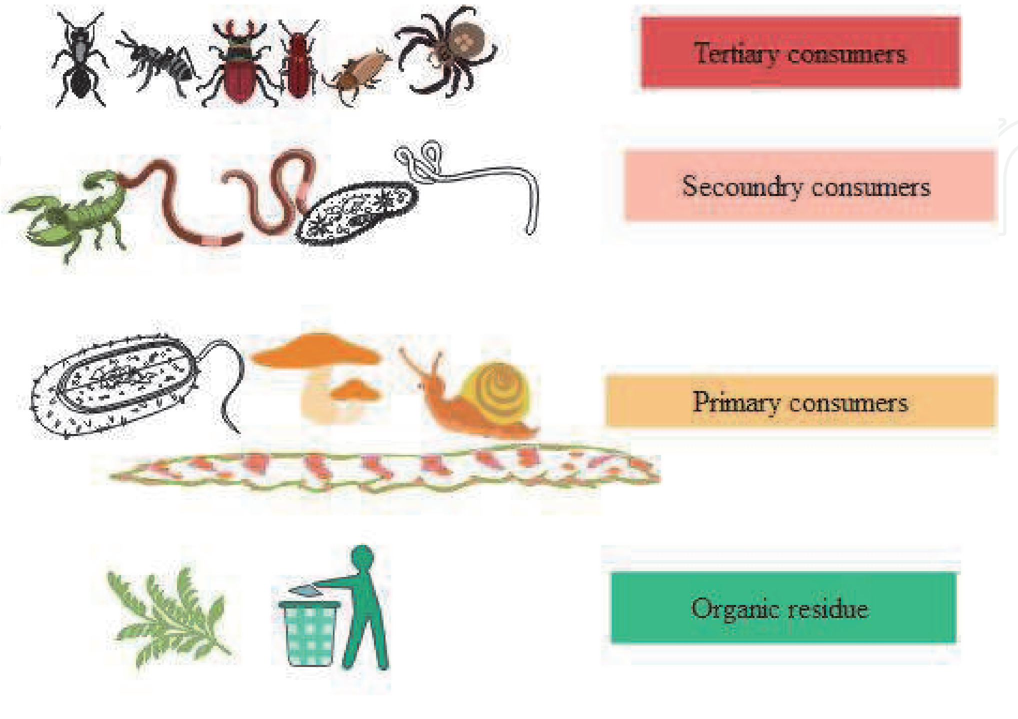


Figure 4.
Hierarchy of bio-decomposers in compositing process.

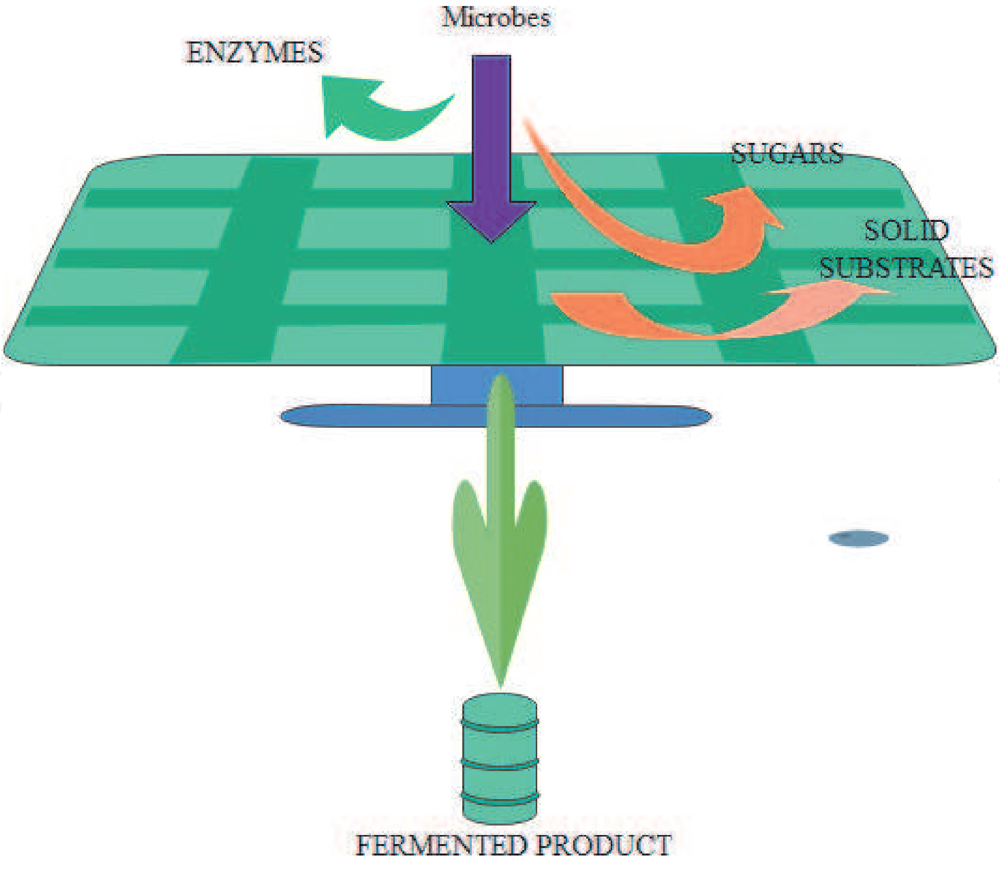


Figure 5.
Solid fermented product.

SSF which are very much affected by various environmental factors like moisture content, temperature, Ph, etc. [38]. Moisture is very crucial factor in hindrance of microbial enzymatic activity. The main bio-products of SSF are antibiotics, are organic acids, aromas, biopesticides, bio-fuel, biosurfactants, and bioplastics (**Figure 5**).

5. Classification of decomposer biota

There are three main biota involved in agricultural waste management, which include:

1. Microbes involved in soil organic matter formation.

2. Microbes involved in mineralization process.

3. Microbes involved in channelization of energy involved in decomposition process.

There are vast variety of decomposers like bacteria, protozaons, and some larger vertebrates. These are classified on the basis of size as (**Figures 6, 7**):

1. Microflora and fauna: Bacteria, fungi, actinomycetes, and protozoans.

2. Mesofauna: Acarina, collembola, etc.

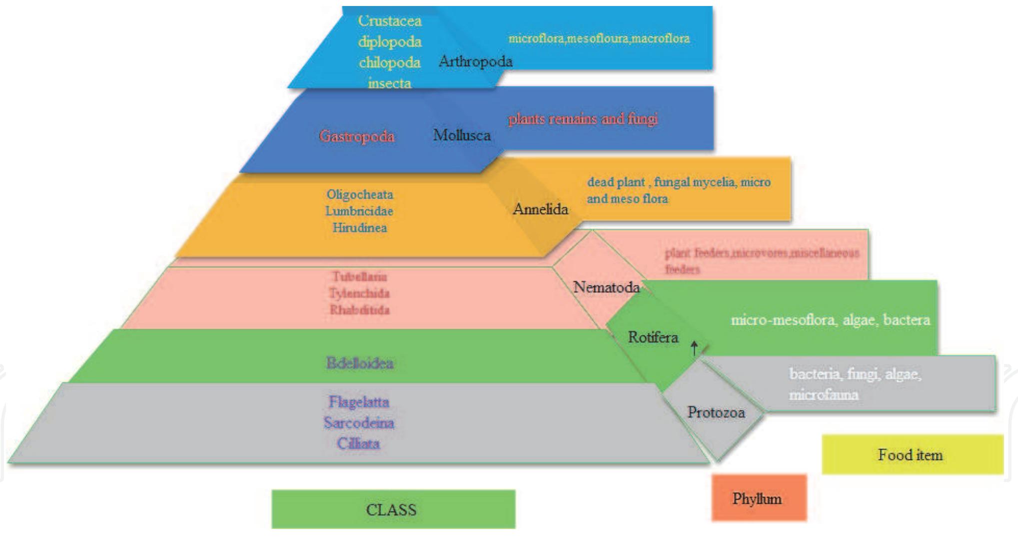


Figure 6.
Taxonomical biodeversity of waste decomposers.

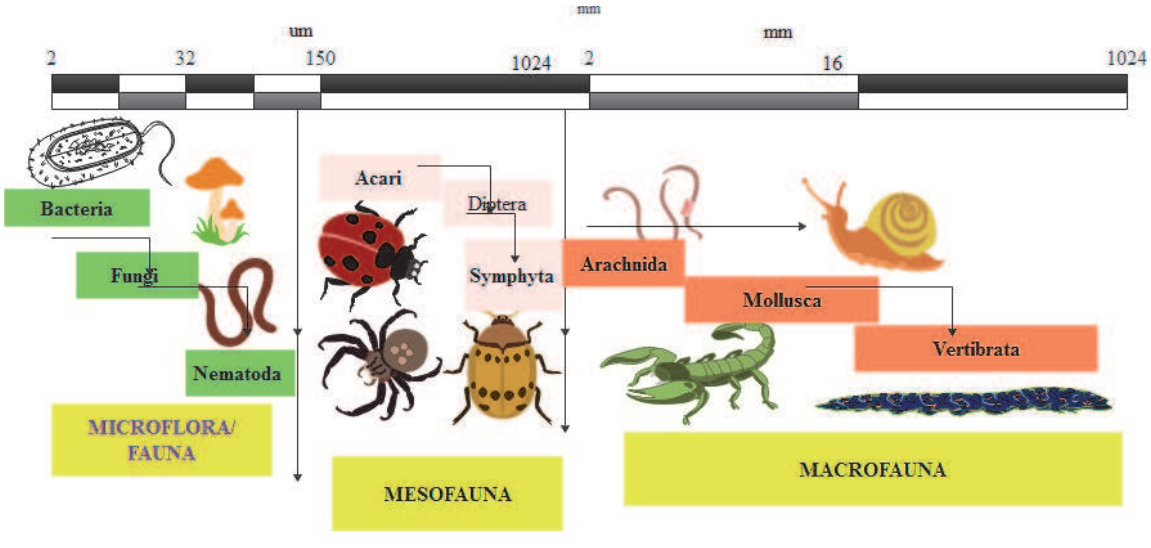


Figure 7.
Classification of bio-decomposers on the basis of size.

3. Macrofauna, including lumbricids, enchytraeids, millipedes, gastropods, and arthropods.

These decomposers further classified on the bases of role in decomposition process primary and secondary (**Figure 4**).

1. **Primary decomposers:** These microbes have the potential to decompose the compounds present in organic matter. These microbes have the requisite enzymes like pectinase, ligase, cellulose, etc. to break the complex agricultural residues complex components like cellulose, hemicelluloses, lignin, etc.

2. **Secondary decomposers**: These decomposers play a significant role in the fragmentation and comminution of decomposing agricultural waste. These microbes do not require enzymes for decomposition. These decomposers constituted earthworms, collembola, mites, enchytraeids, etc. and the rate of decomposition gets slower without secondary decomposers [39, 40].

Major decomposers of soil are bacteria, fungi, nematodes, micro-arthropods, and earthworms [41, 42].

1. **Bacteria**: Bacteria are the most effective decomposers due to their high degree of versatility. On the basis of mobility, there are two types of bacteria: mobile and immobile, due to the presence of whip-like structure flagella. They are further classified by the number of flagella; uniflagillated or multiflagillated. The average size of bacteria is in the range of 2 mm. The bio-decomposer bacterial species are the most important and initiator of decomposition process. There are about 5000 bacteria of estimated 109 bacterial cells present in one gram of organic soil. The cellulose-producing bacteria are the potent bacterial cell lines in hydrolytical cleavage of agricultural residue in decomposition process which includes *bacillus* spp., *pseudomonas*, *cellulomonas*, etc.

2. **Fungi:** Fungi constitute a very large decomposer biomass [43]. The organic matter decomposition is mainly regulated by fungi [44, 45]. The mobility of fungus is prompted by the mycelia. There are approximately 100–120 fungal species present in natural soil without any contamination. Among all the species, mycorrhizal fungi is the most destructive bio-decomposer of any types of agri-residue. The degradation rate is very high by these fungal species. These fungal species mainly include Aspergillus, sclerotium, white-rot fungi, Trichoderma, etc. These fungal species produce enzymes for the degradation of cellulose and lignin during decomposition process [46].

3. **Nematodes:** Nematodes are the free living organisms. These work in a dual way, decomposition as well as recycling of nutrients in soil. Nematodes do not feed directly the soil organic matter but feed bacteria, fungi, protozaons, etc. On the basis of feeding habits, nematodes are categorized in four types-bacterivores (feed bacteria), fungivores (feed fungus), predators (protoazoans, rotifers, etc.) and omnivores (bacteria, fungi, algae, protozoans, etc.). Decomposition process is accelerated in the presence of nematodes. The minerals and other nutrients return back to the soil by the nematodes' feeding cycle and are easily absorbed by the plants.

4. **Micro-arthropods:** Micro-arthropods play significant role in decomposition of litter standing crop. Mineralization of N, P, and K from the litter is enhanced by 23% due the feeding activities of micro-arthropods [47]. The soil micro-arthropods include chelicerates (spiders, mites, and pseudoscorpions), crustaceans (small aquatic forms), myriapods (millipedes, centipedes), springtails, and other insects.

5. **Mechanism of decomposition:** In organic matter decomposition two main process are cellulolytic and lignocellulolytic process, which is governed by the several bio-organisms [48]. These microorganisms mainly decompose organic waste by enzymatic reactions which involves breakdown of cellulose, hemicelluloses, pectin and poly aromatic inputs such as lignin, humus and phenolic acids [45]. These microflora accelerate the decomposition in composting process by the action of cellulolytic and lignocellulolytic enzymatic activity [49]. The cellulolytic microbes include mesophillic bacterial species that degraded proteins, amino acids, peptide bonds, etc. Fungi and bacteria are the main microbes which play significant role in release of hydrolytic and oxidative enzymes. These cellulolytic and lignocellulolytic activities transform the organic waste to humus substances [50, 51]. Therefore, many studies have revealed that these enzymatic activities results into high quality of composts.

6. Different phases of decomposition process along with enzymatic activity

6.1 PHASE I: Hydrolysis

Polysaccharides/lipids/proteins ⟶ Mono-sacharides/glycerol and fatty acid/amino acid.

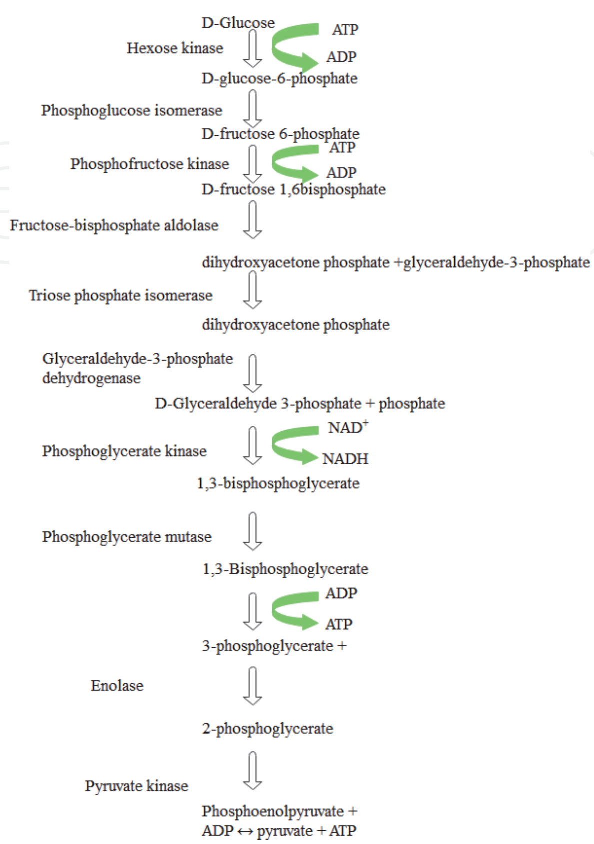
Hydrolytic enzymes

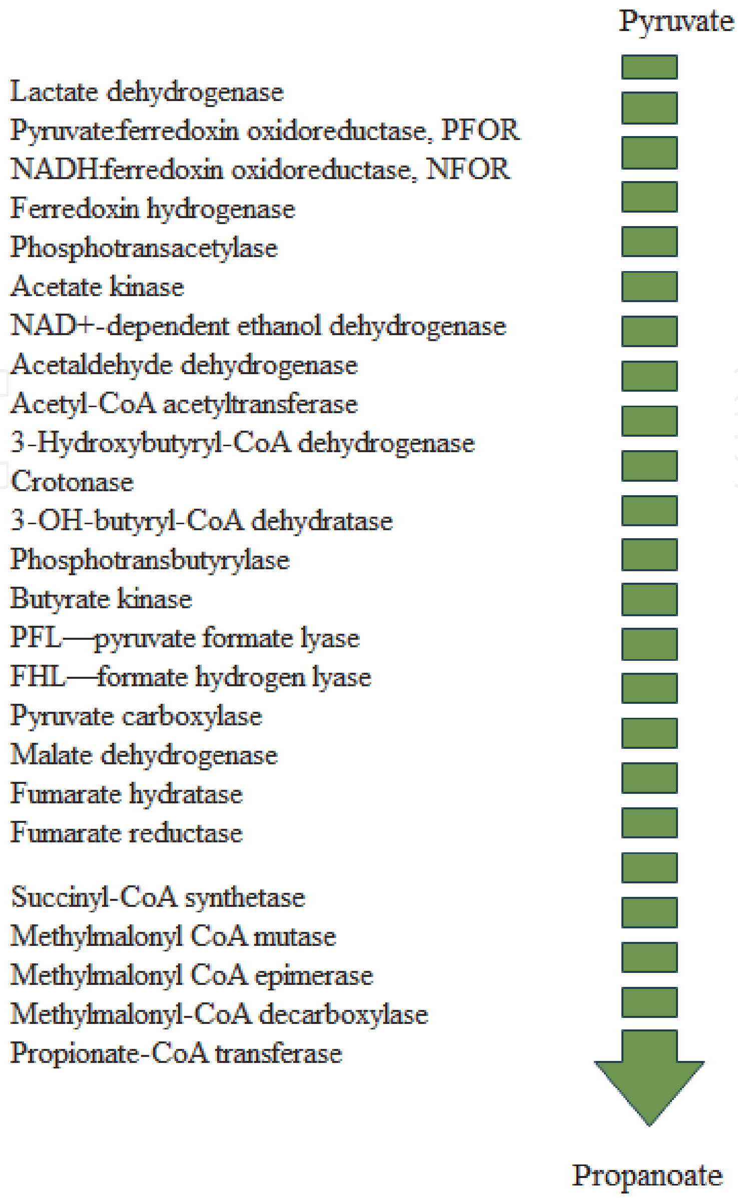
Name of enzymes	Hydrolytic product
Cellulase; endo-1,4-beta-d-glucanase	Cellulose, lichenin, and cereal beta-d-glucans
Cellulose 1,4-beta-cellobiosidase (nonreducing end)	Cellulose and cellotetraose
Beta-glucosidase	Nonreducing beta-d-glucosyl residues
Endo-1,4-beta-xylanase	Xylans
Xylan 1,4-beta-xylosidase	D-xylose
Mannan endo-1,4-beta-mannosidase	Mannans, galactomannans, and glucomannans
Beta-mannosidase	Terminal, nonreducing beta-d-mannose residues in beta-d-mannosides
Alpha-galactosidase	Hydrolysis of terminal galactose oligosaccharides, galactomannans, and galactolipids
Alpha-glucuronidase	Alpha-d-glucuronoside
Peptidases	Acting on peptide bonds

6.2 Phase II: Acidogenic

$$\text{Sugars/amino acids/peptides} \xrightarrow{\text{Fermentation}} \text{Propionate, butyrate}$$

Enzymes involved in acidogenic pathways

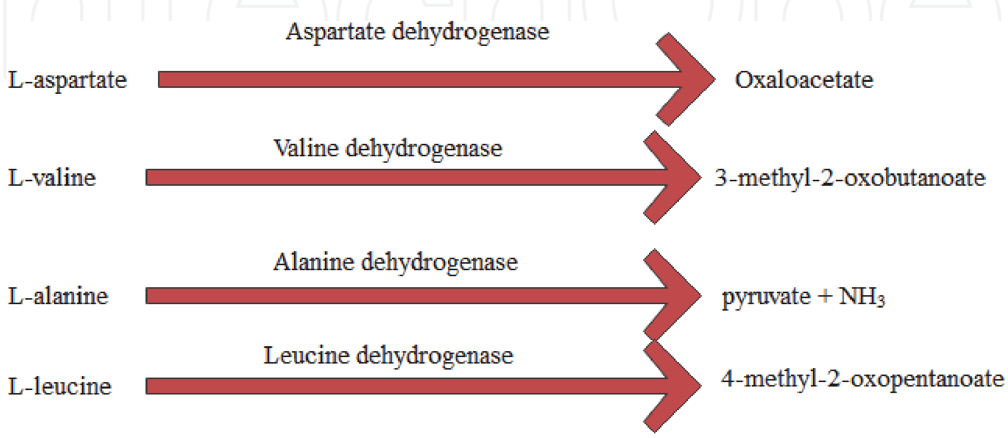




Amino acids fermentations

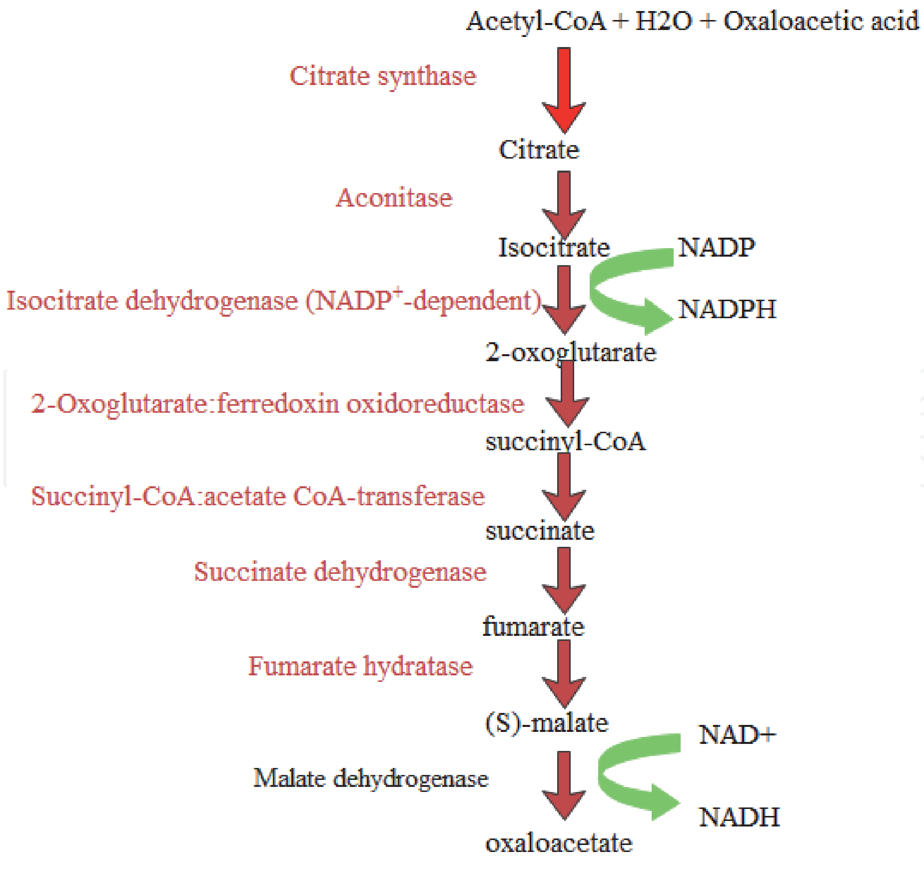
$$RCH(NH_4^+)COO^- + H_2O \rightarrow RCOCOO^- + NH_4^+ + H_2$$

$$RCOCOO^- + H_2O \xrightarrow{\text{Oxidative Decarboxylation}} RCOO^- + CO_2 + H_2$$



6.3 Phase III-Acetogenesis

Enzymes involved in acetogenesis reaction pathways
Citric acid cycle



7. Process for improving the vitality of bio-decomposer microbes

In 1998, Kale's finding was that if solid by-products of agricultural waste are dumped as landfilling, a traditional disposal method of agricultural waste disposal, it results in the contamination of groundwater, soil, as well as food resource materials [52, 53]. The contamination is due to the presence of fibrous substances in agri-residues which have very high BOD and COD for decomposition or oxidation process.

7.1 Addition of inert materials to enhance the performance of bio-organisms

Various scientists offered some safe inert ingredients for managing this agro waste along with microorganisms which is environmentally friendly, economical and accepted by the farmers [56]. A compositing technology is then come into application in which waste is processed to remove bio-toxic compounds by anaerobic decomposition method. Previous studies revealed that vermin-compositing was an appropriate technology for converting agri-waste into a valuable product [54]. In vermin-compositing, earthworms and associated micro-flora convert waste into soil nutrients which boost up the soil fertility [55]. For decomposition of hazardous substance like pesticides, fertilizers, etc., mix with some bulky inert ingredients like saw dust and cow dung in 1:1 ratio for vermin-compositing trails for maximum decomposition by earthworms [56]. Textile sludge mixing with biogas plant slurry in combination of 2:3 ratio further increases decomposition [57]. Vermin-compositing of waste by beverage industry in combination with cow dung enhances the nutrient end product and earthworm performance in 1:1 ratio [58]. So, all these studies revealed that vermin-compositing performance is enhanced in presence of some bulky inert materials in suitable proportion.

7.2 Addition of some moisture-absorbing inert materials

Moisture is very crucial factor in hindrance of microbial enzymatic activity in solid-state fermentation decomposition method. So, some moisture-absorbing inert ingredient is very important for maintaining the decomposition activity.

7.3 Methods to increase the rate of survival of microorganisms

The success rate of microorganisms depends upon the survival of bio-decomposers in soil [59]. Formulation of bio-inoculants extends the period of storage and maximizes the decomposition rate in field and produce high quality of inoculants [60]. US Patent no. 7097830 reveals synergistic bio-inoculant *Trichoderma harzianum* with Bacillus strains in combinations with carrier which results into promotion of plant growth. In formulated product, various types of bio-inoculants can be combined which will provide economical and effective crop growing systems. Along with this formulated product would have longer shelf life while maintaining the easy usability and handling of agriculturally important microbial bio-inoculant [61].

As waste decomposer is very valuable for the Indian farmers and the value can be further increases if it is formulated into formulations like wettable powder and suspension concentrate. In formulated products their viability, shelf life and efficiency would be further enhanced by adding carriers, stabilizers, wetting and dispersing agents.

8. Challenges of agricultural waste decomposition process

1. **Nonuniform compositing:** Incomplete or immature composts cause many deleterious effects to soil, which in turn affects plant growth and ecosystem function [50]. Similar study also explained that application of immature compost for nitrogen fixation will release the toxic gases or compete for o2 in rhizosphere and results hindered growth of plant [62]. Mulec et al. also reported that immature compost cause phyto-toxicity due to presence of heavy metals and ammonia. Immature compost causes competition for oxygen between plant and microbes and results into toxic gases NO2 and H2S [50].

2. **Emission of gases:** Many studies have reviewed the gas emission problem. The rate of gas emission during compositing is the qualitative parameter of final compost. High emissions of these gases cause environmental pollution and other deleterious effect in ecosystem [63]. Most common odorous gaseous by-products are N2O, NH3, CH4, etc. [64].

3. **Leaching of compost:** Compost is rich in organic carbon content, which is very beneficial to plant growth. In addition to this beneficial aspect, leachate generated from compost is problematic to environment and causes groundwater contamination [65, 66]. Therefore, the compost cannot be stored in a same place for longer period of time [67, 68].

9. Future prospective of agricultural waste management

1. **Farmer-friendly**: Integrated approach of farm production along with compost formation by using agricultural waste will be beneficial for the farm

productivity and soil health. By following this approach, farmers need not depend on costly fertilizers and manure.

2. **Technological advancement for quick composting:** Compositing process is a time-consuming process, but due to some technological advancement, the compositing process's duration could be shortened. According to Lim et al. [69], addition of polyethylene glycol and jaggery speeds up the compositing process and results in a superior quality compost. These additives are cost-effective. More research studies should be done in these additives for finding more cost-effective and efficient additives.

3. **Use of genetically modified stains of innoculum:** Genetically modified stains of microbial inoculums will be used to accelerate the bioconversion of organic matter. These modified stains are more efficient than the natural innoculum. These innoculum will produce uniform compositing in an efficient way.

4. **Government agencies support:** Government supports the compositing process by providing loans and grants for compositing facilities for farmers. These steps of government will ensure sustainability and create job opportunities and uplift the rural areas. By this approach, government encourages organic farming by use of composts as soil conditioner and soil fertilizers [70].

5. **Installation of bioreactors to reduce the toxic gas emissions:** Bioreactors can be used to reduce the emission of toxic volatile organic constitutes. This strategy would manage the toxic gases emissions and save the environment [71, 72].

6. **Utilization of heat release in other energy sources:** Heat released during the compost formation can be utilized as a reliable energy source [73]. The energy generated by these heat harvests would be a sustainable and renewable source of energy in near future. In coming years, compost formation will not only decompose the residues but will also be a source of many other transformations.

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