

Bioconversion of different organic waste into fortified vermicompost with the help of earthworm: A comprehensive review

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Abstract

Purpose Solid waste management has become a serious global problem. There is a strong need to recycle them as these wastes are rich in plant nutrients and soil conditioners. The different organic wastes can be efficiently degraded into nutrient-rich vermicompost by using earthworms. In this review, an attempt has been made to highlight the vermicomposting of different organic wastes by using different earthworm species.

Method An extensive literature search was done on Science Direct, Pubmed Central, Google Scholar, Springerlink by using various search strings, and appropriate studies of vermicomposting of different organic waste were selected.

Results Any kind of organic waste can be converted into manure through vermicomposting. It was observed that for efficient vermicomposting, the waste should be mixed with another organic material. e.g., animal dung. It was observed that the vermireactors having 25 % to 30 % of waste mixed with about 70 % to 75 % of other organic rich material like cattle dung can be easily converted into a valuable product, but the high proportion of organic waste causes mortality in the earthworms.

Conclusion This study indicated that vermicomposting is an effective and a better option for the recycling of different types of organic solid waste but these wastes cannot be directly degraded with the help of earthworms. The vermicompost so produced can be used to promote the growth of wide range of crops in the fields. The farmers should also be educated regarding the harmful effects of chemical fertilizers and pesticides and also get motivated to use vermicompost in their fields.

Keywords Earthworms, Organic waste, Solid waste, Vermicomposting

Introduction

Vermes is the Latin word that is used for earthworms and vermicomposting. In recent years vermicomposting has received more attention all over the world, as it is

widely utilized for the management of the different types of organic wastes (Ghatnekar et al. 1998; Chauhan and Singh 2013; Bhat et al. 2018). Although all the organic matter will eventually decompose in nature, vermicomposting speeds up the process of decomposition (Benitez et al. 2005). The organic matter and productivity of soil can be well maintained by the use of organic manure and other agricultural wastes. Several types of animal excreta are produced worldwide and the appropriate use of these animal excreta through vermicomposting may improve soil physico-chemical properties and can also be used as plant supplements (Bhardwaj 1995; Chauhan and Singh 2015).

Vermicomposting is an effective technique to make a beneficial environmental impact by reducing the large amount of organic waste, if not managed can pollute

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rivers and groundwater by its runoff that contains a lot of nitrates, phosphates and ammonia (Krishna et al. 2017; Ramnarain et al. 2019). When the organic materials in the form of food ingested by the earthworms pass through their gut, the microbes of the earthworm gut start to breakdown the ingested material and convert the same into vermicast (Singh 2018). This vermicompost stimulates the plant growth by changing the physical,

chemical and biological properties of the soil (Fig. 1) (Datta et al. 2016). The physical properties of soil include soil structure, water holding capacity, etc.; chemical properties include nutrients such as macro and micronutrients for plant growth and biological properties include activation of microbial communities which diminish the attack of various pathogens (Hansen 2007; Datta et al. 2016; Bhat et al. 2018; Singh 2018).

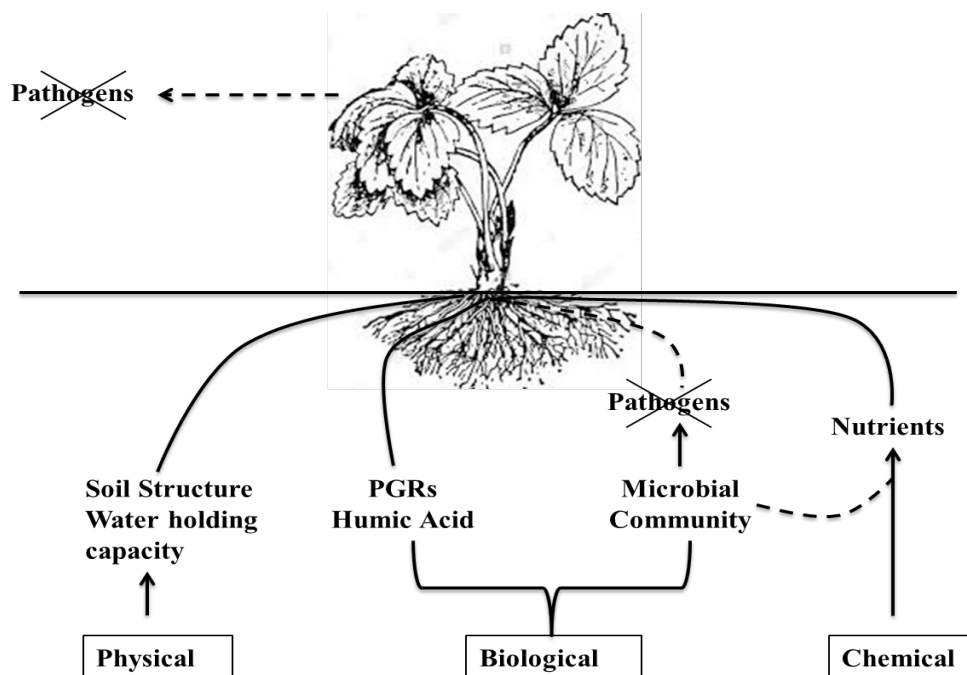


Fig. 1 Flow chart showing physical, biological and chemical properties of vermicompost

The cross on the pathogen showing the no attack of pathogens on the plant.

In this review, an attempt has been made to highlight the vermicomposting of different types of organic waste materials with the help of different earthworm species and also explain the changes in physico-chemical properties from initial to a final product of vermicomposting. We conducted a literature search in Science Direct (<https://www.sciencedirect.com>), Pubmed Central (<https://www.ncbi.nlm.nih.gov/pmc/advanced/>), Google Scholar (<https://scholar.google.co.in>), SpringerLink (<https://link.springer.com>) published from the year 1976 to 2020. The literature was searched by using various search strings like vermicomposting of different organic wastes such as agricultural waste (paddy straw, wheat straw, leaf waste), industrial sludges and wastes (beverage, leather, distillery, bakery), animal manure (cattle, goat,

sheep, horse, rabbit), etc., and appropriate studies of vermicomposting of different organic wastes with the help of earthworm were screened out.

Earthworm Category

Based on the type of feeding habitat and ecological nature, Bouche (1977) grouped earthworms in three categories, i.e., epigeic, anecic, and endogeic (Fig. 2). The earthworm species within epigeic ecological categories such as *Eisenia andrei* and *Eisenia fetida* are most widely used for vermicomposting (Dominguez 2018). The epigeic species are surface feeder and high bioconversion rate. They remain stable during unstable and unpredictable habitat and can tolerate various adverse environmental conditions like less

food availability, predatory pressure, etc. The epigeic species also have a high reproduction and feeding rate as compared to the anecic and endogeic ecological category of earthworms by which earthworm species can increase their number for vermiculture and also produce the vermicompost in a short time interval (Julka 2008; Dominguez 2018). Some studies also used endogeic earthworm species like *Metaphire posthuma* (Sahariah et al. 2015; Das et al. 2016) and anecic earthworm species such as *Lampito mauritii* (Tripathi and Bharadwaj 2004) for vermicomposting. The various characteristics of each category are given in Table 1.

Different substrates for vermicomposting

The vermicomposting is the common and cost-effective technology for the management of diverse types of organic wastes. Many researchers have studied the performance of different earthworm species on the different wastes and also reported the reproduction behavior of earthworms on the basis of hatchling and cocoon production at the end of each experiment. The basic process of vermicomposting from different organic wastes is shown in Fig. 3. Some studies also compared the results of pre and post vermicomposted waste on the basis of physico-chemical properties.

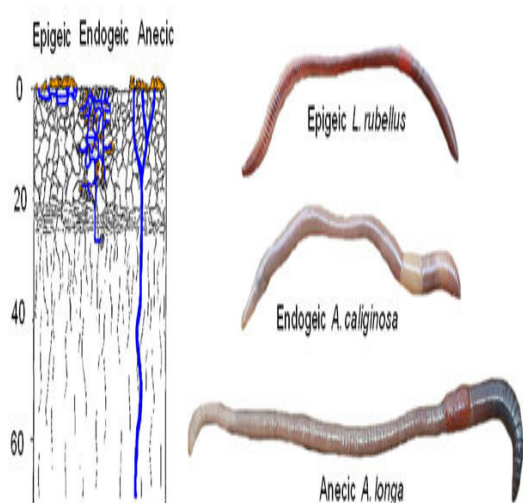


Fig. 2 Ecological category of earthworm along with their feeding habit and burrowing behavior

Table 1 Classification of earthworms on the basis of ecological category

Ecological Categories	Characteristics features	Examples
Epigeic	These earthworms live above the surface of the mineral soil. Their size is small and colour is uniform. Epigeics are phytophagous and have no effect on the surface of the soil as they cannot dig into the soil (Lee 1985; Ismail 1997). They are appropriate for vermicomposting as they can transform the residue of the leaf into manure.	<i>Eisenia fetida</i> , <i>Eisenia andrei</i> , <i>Eudrilus eugeniae</i> , <i>Drawida modesta</i> and <i>Perionyx excavatus</i> .
Anecic	These are the species living in burrows in layers of mineral soil, but coming to the surface to feed on dead leaves. As they display up & down movement, vertical tunnels were built which improve soil aeration. They ingest both plant matter and soil, that is, they are geo-phytophagous (Ismail 1997).	<i>Lampito mauritii</i> , <i>Lumbricus terrestris</i> , <i>Aporrectodea trapezoids</i> and <i>Aporrectodea longa</i> .
Endogeic	They live at a depth of 6 feet with in the soil; they push their waste to the soil's bottom surface. They feed more or less organically enriched in soil and create tunnels under the soil. This promotes aeration, water drainage, and sunlight accessibility to crop roots (Lee 1985; Ismail 1997).	<i>Octochaetona thurstoni</i> , <i>Allolobophora caliginosa</i> , <i>Allolobophora rosea</i> and <i>Drawida barwelli</i> .

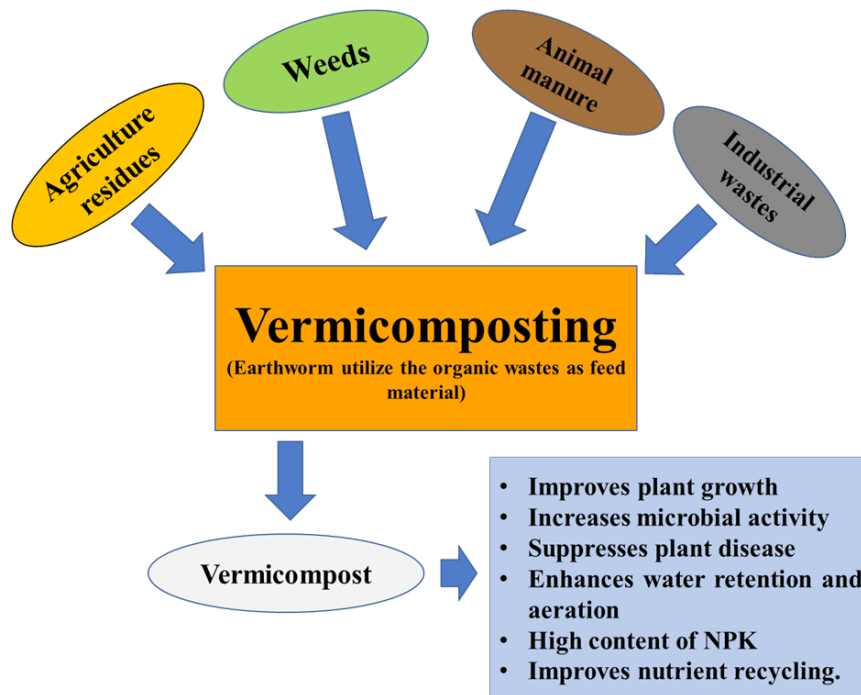


Fig. 3 The process of vermicomposting of different types of organic wastes

Agricultural residues

The decomposition of agricultural residues in the soil is directed by the interaction of these residues with bacteria and fungi. The earthworms also have the capability to degrade the agricultural waste into vermicompost. Tian et al. (1997) studied the importance of earthworms in the breakdown of mulches produced by mixing five plant residues viz. *Dactyladenia barteri*, *Gliricidia sepium*, *Leucaena leucocephala*, maize, and rice straw. They observed that *Leucaena* and *Gliricidia* mulches have a higher earthworm population (54 %) as compared to control. The decomposition of fresh and composted Mediterranean leaf litter of *Nicodrilus meridionalis* has been studied by Cortez and Bouche (2001) which concluded that the pre-composting of litter improved their palatability and increased the biomass of earthworms. In comparison, new litter feeding led to the loss of earthworm biomass. Manukovsky et al. (2001) evaluated the possibility of double-stage bioconversion of inedible biomass into biohumus by oyster mushroom followed by earthworms. They mixed the same with wheat straw (1:3 ratio) and then treated it with mushrooms followed by earthworms to turn potato waste into biohumus. This provided not only a good yield of mushrooms but also the biohumus for the plant growth. Singh and Sharma (2002) studied the technical viability of

wheat straw composting with bioinoculants (*Pleurotus sajor-caju*, *Trichoderma harzianum*, *Aspergillus niger*, and *Azotobacter chroococcum*) and subsequent vermicomposting to overcome the problem of lignocellulosic waste degradation. Their results indicated that the incorporation of lignocellulosic waste with bioinoculants and earthworms decreased the overall time for the production of nutrient-enriched vermicompost. The content of N, P and K were increased significantly during the experiment.

Chaudhuri and Bhattacharjee (2002) studied the reproduction and biomass of *Perionyx excavatus* on the different experimental diets, i.e., cow dung (control) and its combination with kitchen waste, leaf litter and straw bamboo (1:3 dry weight of control and each waste) in order to determine the appropriate diet requirement for vermiculture. They observed the highest rate of biomass and reproduction in the bamboo straw and leaf litter while the lowest rate of the same was reported in mixture with kitchen waste. The influence of tropical epigeic earthworms, i.e., *Eisenia fetida* (Savigny), *Perionyx excavatus* (Perrier) and *Dichogaster bolau* (Michaelsen) on the decomposition of forest litter *Tectona grandis*, *Madhuca indica*, and *Butea monosperma* were studied by Manna et al. (2003), and they reported that *Tectona grandis* litter may have been the most appropriate food material for earthworms because it contained

elevated reserves of mineral nutrients. They also reported a greater reproduction rate for *Eisenia fetida* as compared to *Perionyx excavatus* and *Dichogaster bolau* in the forest litter. Gajalakshmi and Abbasi (2004) studied the vermicomposting of neem leaves with earthworm (*Eudrilus eugeniae*) and found that earthworm fed voraciously on the neem leaves by converting up to 7 % of the food into vermicompost per day. They also observed that the vermicompost originated from neem leaves had a considerable positive impact on brinjal development and fruiting. The comparative studies of composting potential, biomass production, and biology of *Eisenia fetida* and *Lampito mauritii* were carried out by Tripathi and Bhardwaj (2004) using mixed bedding content from biogas slurry, cow dung, wheat straw, sawdust, and kitchen waste. They resulted that *Eisenia fetida* was a more productive breeder as compared to *Lampito mauritii* due to the high reproduction rate in *Eisenia fetida*. Gajalakshmi et al. (2005) successfully transformed the mango leaf litter into vermicompost through the action of the *Eudrilus eugeniae* by using two separate vermireactors with 62.5 earthworms and 75 individual earthworms per liter. They further observed that vermireactor having 62.5 individuals/l produced 13.6 g vermicast/l/day while vermireactor with 75 individuals/l produced 14.9 g vermicast/l/day. They also reported that the C/N ratio decreased at the end of the experiment as compared to initial which was due to the use of carbon by the bacterial metabolism in the earthworm's gut. They also noted that earthworm biomass increased by 103 % in the vermireactor. Garg et al. (2006) assessed the effectiveness of *Eisenia fetida* for the vermicomposting of various kinds of organic wastes including agriculture residues. They observed that the maximum decrease in total organic carbon (TOC) was in agriculture residue (3 times), followed by kitchen waste (2.2 times), institutional waste (1.7 times) and textile industrial waste (1.5 times) as compared to control.

Kurien and Ramasamy (2006) studied the potential of two earthworms, i.e., *Eisenia fetida* and *Eudrilus eugeniae* for the bioconversion of Taro (*Colocasia esculenta*) in different vermireactors. They observed that *Eudrilus eugeniae* was a more efficient producer of vermicasts than *Eisenia fetida*. Suthar (2007) studied the decomposition of various types of waste such as agricultural waste, farm manure and urban solid waste using *Perionyx sansibaricus* earthworm, which revealed

that substrates of vegetable waste and leaf litter have the highest production of biomass, growth rate (mg/day), mean number of cocoon and reproduction rate (cocoon/worm) as compared to other substrates. This study also reported that minimum population mortality in a mixture of vegetable market waste with leaf litter and the maximum in a mixture of household waste with cow dung, with a significant increase in total nitrogen (80.8-142.3 %), phosphorus (33.1-114.6 %) and potassium (26.3-125.2 %), while significant decrease in organic carbon (14-37 %) as well as C/N ratio (52.4-69.8 %). Suthar (2010a) made an effort to convert vegetable waste into nutrient-rich biofertilizers after mixing the same with wheat straw (WS), cow dung (CD) and biogas slurry (BGS) in different proportions by using earthworm *Eisenia fetida* and reported that waste minimization and humification rates were larger in the bedding which has easily digestible bulky agent, i.e., 40 % BGS with 60 % CD. The product has a significant decrease in organic carbon (4.8-12.7 %) and potassium (3.2-15.3 %) content, whereas an increase in total N (5.9-25.1 %) and available P (1.2-10.9 %), exchangeable Ca (2.3-10.9 %) and exchangeable Mg (4.5-14 %) contents.

Mainoo et al. (2009) studied the pilot-scale vermicomposting of pine-apple waste with *Eudrilus eugeniae* and reported rapid breakdown of pineapple waste. They also recommended vermicomposting as a viable and low-cost technology, which can be utilized for recycling organic waste into a nutrient-rich biofertilizer which has as much as 0.4 % total N, 0.4 % total P, and 0.9 % total K, and had a C/N ratio of 9-10. Ramnarain et al. (2019) studied the vermicomposting of paddy straw and grass with three different treatments, i.e., Paddy straw only, Paddy straw + grass, and Grass only. They reported that paddy straw + grass had the maximum rate of vermicompost production followed by grass only and paddy straw only. While on the other hand, Khwanchai and Kanokkorn (2018) studied the effect of different types of agricultural wastes, watermelon peel, soybean meal, coconut shell's hair, coffee ground, etc. on earthworm biomass (*Eudrilus eugeniae*) and vermicompost production. They reported that vermicompost produced with the help of *Eudrilus eugeniae* had 1.10 %, 0.66 % and 1.31 % higher N, P, and K contents, respectively as compare to initial waste while the biomass of earthworm individuals was increased by 28.33-104.67 % as compared to its initial weight.

Weeds

Weed handling is of excellent interest to the scientific community because of its adverse effect on various ecosystems such as a forest, farming, and city (Suthar and Sharma 2013). Weeds such as water hyacinth (*Eichhornia crassipes*) are one of the readily accessible organic products for vermicomposting in nature. Apart from working as a water purifier against water pollution, it is also a boon for different kinds of fish species that release the sticky eggs in the roots of water hyacinth. But the huge concentration of this weed is not good for the water bodies and can be utilized for vermicompost production (Saha et al. 2018). Gajalakshmi et al. (2002a) studied the sustainable vermiconversion of water hyacinth (WH) in different reactors by using *Eudrilus eugeniae* and found that vermireactor having a high population of earthworms produced 5-6 times more vermicompost as compare to vermireactor having low earthworm population. The vermicomposting of various types of WH, i.e., fresh plant, dried plants, chopped parts of fresh plants, spent weed taken from the reactor after extraction of volatile fatty acids, pre-composted fresh weeds and pre-composted spent weeds was studied by Gajalakshmi et al. (2002b) and revealed that pre-composted forms were most favored as a feed by the earthworms. They also observed that different forms of spent weed were most favored over the respective forms of new weeds and also blending of cow dung (14 % of feed mass) with distinct types of water hyacinth had a substantial beneficial effect on vermicast output relative to the respective unblended feed. Gupta et al. (2007) observed the potential of WH spiked with cow dung (CD) into vermicompost and reported that earthworms grew and reproduced favorably in 25 % WH and 75 % CD feed mixture. A larger proportion of WH in the feed mixture significantly affected the biomass gain, hatching amount, and cocoon production. Gajalakshmi et al. (2001a) observed the potential of two epigeic species *Eudrilus eugeniae* (Kinberg) and *Perionyx excavatus* (Perrier) and two anecic species *Lampito mauritii* (Kinberg) and *Drawida willsi* (Michaelsen) in terms of vermicomposting efficiency and sustainability of water hyacinth. They observed that *Eudrilus eugeniae* was the most efficient producer of vermicompost followed by *Perionyx excavatus*, *Lampito mauritii*, and *Drawida willsi*.

Singh and Kumar (2017) studied the vermicomposting of two terrestrial weeds *Lantana camara* L. and

Parthenium hysterophorus L. by using *Eisenia fetida*. They produced five distinct concentrations of weed with cattle dung, i.e., 0 %, 20 %, 40 %, 60 %, and 80 %, and also measured the physico-chemical properties of each concentration during the experimental period. They reported the decrease in the content of pH, EC, and organic carbon while the content of N, P and K in all the concentrations were increased which indicated that the aquatic weeds can be used as raw material for vermicomposting. Singh and Kalamdhad (2016) also reported the similar results for physico-chemical properties of vermicompost as compared to initial waste during vermicomposting of invasive green weed *Salvinia natas* by using earthworm *Eisenia fetida* and reported the increase in earthworm's biomass and growth in all the experimental trial. Gusain and Suthar (2020) also studied the various parameters like physico-chemical properties, microbial communities and enzyme activities during vermicomposting of *Ageratum conyzoids* with cow dung in 25 %, 50 % and 75 % (v/v) ratios. They observed that pH, organic carbon was decreased in vermicompost while the content of nitrogen, phosphorus, potassium and calcium was increased by 69.9 %, 148.7 %, 92.43 % and 55.3 %, respectively. They also reported a hike in both microbial communities and enzyme activities in vermicompost as compared to the initial feed mixture. Among the above said three concentrations, they concluded that 50 – 75 % waste of *Ageratum conyzoids* mixed with about 25-50 % of cattle dung can be efficiently vermicomposted.

Animal manure

Animal waste is a valuable resource that provides both macro and micronutrients for plant (Nasiru et al. 2013). Only a fraction of the nutrients excreted from animal waste are properly collected and used as manure but difficulties are encountered in disposing of animal excreta when large amounts of animal waste was originated. The unmanaged and overproduced animal waste resulted in overfertilization, soil contamination, pathogens dispersal, odor, water pollution and increased greenhouse gas emissions (Nasiru et al. 2013). Vermicomposting is the best technology to manage this kind of waste. The life cycle of *Dendrobaena veneta* was studied by Fayolle et al. (1997) to assess the potential of its breeding at distinct temperatures (10^o, 15^o, 20^o or 25^oC) on horse manure or on aerobic

paper sludge. They reported that *Dendrobaena veneta* life cycle can be influenced by the type of food and concluded that horse manure may not be the finest substratum for this species breeding. Dominguez et al. (2001) studied the biology and population dynamics of *Eudrilus eugeniae* in cattle waste in small containers kept at different temperatures, i.e., 15^o, 20^o, 25^o and 30 °C. They resulted that growth, maturation and biomass manufacturing were all considerably higher at 25 °C than 15^o, 20^o and 30 °C. Gunadi and Edwards (2003) studied the growth and mortality rate of *Eisenia fetida* in pre-composted and fresh livestock manure solids, fresh pig manure solids of different levels of maturity, fruits and vegetable waste. They resulted that *Eisenia fetida* was unable to survive in fresh cattle solids, fresh young pig solids, fruit and vegetable wastes, while the earthworm development was quicker in partially decomposed pig solids as compared to pre-composed cattle solids. Vermicomposting is commonly adopted for the treatment of livestock organic waste. Loh et al. (2005) compared the vermicomposting potential of goat manure and cattle dung by using *Eisenia fetida* and reported high biomass and reproductive rates of *Eisenia fetida* in cattle dung than goat manure, while cocoon and hatchling were not affected. Borges et al. (2017) also studied the rate of biodegradation with an increase in earthworm growth rate and biomass in a mixture of swine manure and cattle dung. They concluded that animal manure is an excellent waste for the vermicomposting process under controlled temperature and moisture conditions. Lv et al. (2016) evaluated the effects of vermicomposting on heavy metal speciation and mobility (Zn, Pb, Cr, and Cu) in cattle dung and pig manure and considered the vermicompost as a positive approach for stabilizing the heavy metals.

Industrial wastes

The industry sector in the world has been rising day by day to the modernization of the world. These industries produce a different type of product that is beneficial to society but also produces different types of effluent and sludge. The open dumping of this toxic sludge will not only pollute the soil areas and groundwater but a wealthy carbon resource will also be getting wasted (Singh et al. 2010). The environmental protection legislation, reducing landfill area, and government consciousness have attracted our attention to alternative methods for

recovering a wealthy pool of nutrients from wastes. The earthworms have the potentials to decompose and recycling of such types of organic waste materials into nutrients rich in organic manure and also help in minimizing the environmental pollution (Julka 2008; Bhat et al. 2018).

Paper-pulp industry waste

The paper manufacturing industries grew at a rate of 8.4 % while paper usage rose at a rate of 9 % in 2012 (Tripathi 2014). In the year 2009 alone, the US paper sector was the world's biggest record profit of 100 million USD (Kaur et al. 2010). These paper industries generate a huge amount of paper mill sludge which is very toxic. The quantity and structure of wastes rely on the raw ingredients, the methods used and the characteristics of the paper to be obtained. The two main limiting factors for the biodegradation process are the polysaccharides and low oxygen content, i.e., less than 0.5 % in the sludge of paper mill (Elvira et al. 1997). The paper mill sludge is rich in cellulose content but deficient in nitrogen. These issues can be resolved by mixing the paper mill sludge with cattle dung that acts as natural microbial populations inoculants followed by earthworm treatment (Butt 1993).

Gajalakshmi et al. (2001b) studied the vermicomposting of paper waste with variable proportions of cattle dung and resulted that rises in cow dung concentration in feed mixture from 14.3 % to 20 % had a slightly beneficial effect on earthworm health. Gupta and Garg (2009) studied the non-recyclable post-consumer paper waste with cattle dung to convert the same into vermicompost with *Eisenia fetida* and their study showed that paper waste could not influence the development and reproduction rate of earthworms when used up to a concentration of 30 % in a vermireactor. Mohan (2017) studied the biotransformation of sludge from paper mill industry into nutrient rich manure with the help of *Eisenia fetida* and observed the change in physico-chemical properties of paper mill sludge before and after the vermicomposting. It resulted that a 25 % mixture of paper mill sludge along with 75 % of cow dung can be efficiently converted into valuable manure. Amouei et al. (2017) also concluded that paper mill sludge waste can be degraded by earthworm much easily. Hence, vermicomposting is an efficient technology to solve the problems related to the disposal of paper mill waste.

Sugar industry waste

A sugar refinery is one of the important agro-based enterprises to generate sugar and ethanol. There are about 500 sugar manufacturing plants in India along with around 300 molasses-based liquor refineries (Tewari et al. 2007) which produce a huge amount of recyclable organic wastes during the crushing and processing of sugarcane like pressmud, bagasse, cane garbage, etc. As indicated by Yadav (1995), a 35 kg of pressmud is produced per ton of sugarcane being crushed. It has been estimated that about 3.6 to 3.9 million tons of pressmud has been produced in India annually (Rasappan et al. 2015; Karwal and Kaushik 2020). This pressmud is a good source of organic matter, organic carbon, protein, catalysts, macronutrients (N, P, and K), micronutrients (Zn, Fe, Cu, Mn) (Bhat et al. 2014). As specified by Sangwan et al. (2010), the pressmud has pH 7.1 with the content of organic carbon, nitrogen, phosphorus, potassium, and calcium was 313 g kg⁻¹, 24 g kg⁻¹, 3.6 g kg⁻¹, 0.86 g kg⁻¹ and 12.1 g kg⁻¹, respectively while the content of heavy metals Cu, Fe, Zn, and Mn was 870 mg kg⁻¹, 22,440 mg kg⁻¹, 1,392 mg kg⁻¹ and 2,008 mg kg⁻¹, respectively. Various studies emphatically recommended the use of pressmud in commercial scale vermicomposting.

Bhat et al. (2014) examined the physico-chemical changes and genotoxicity capability of pressmud waste before and after vermicomposting. They resulted that N, P, Na, EC, and pH content increased from an initial feed mixture to the end product. On the other hand, the content of organic carbon, K, and C/N ratio dropped from initial to final feed combination. They also concluded that percent aberration increased with the increase in the concentration of waste and vice-versa. On the other hand, the percentage of aberration has been decreased from an initial waste mixture to vermicompost. Khwairakpam and Bhargava (2009) have effectively utilized two exotic earthworm species (*Eisenia fetida* and *Eudrilus eugeniae*) and one regional earthworm species (*Perionyx excavatus*) in distinct (monocultures) and mixed culture (polycultures) to monitor the changes in pressmud. The consequences of their study showed that monoculture and polyculture worked similarly well, as well as the best result could be attained by utilizing earthworm polyculture. Similar results were also observed by Sangwan et al. (2010) that 50 % mixture of pressmud with cattle dung produced good quality vermicompost with enhanced

N, P and K content. Bhat et al. (2015a) also studied the vermicomposting of sugar beet mud and pulp with cattle dung and observed that development rate of earthworms was essentially influenced as the amount of the waste increased.

Shweta et al. (2010) studied the vermicomposting of different types of sugar refinery waste with a reduction in stabilization time and improvement in vermicompost quality. Their results suggested that pre-composting of wastes with microorganisms decreased the time for vermicomposting. Suthar (2010a and 2010b) measured the consistency of vermicomposting by mixing the pressmud, distillery sludge, cattle dung, biogas plant slurry and wheat straw in various proportions by utilizing earthworm *Eisenia fetida*. The mixtures of industrial sludge during the vermicomposting process supported both the growth and reproduction of *Eisenia fetida*. They observed that as the concentration of sludge in the feed mixture decreased, the rate of mineralization was increased and vice versa. Prakash and Karmegam (2010) reported that pressmud mixed with an equal amount of cow dung (1:1) can be transformed efficiently into vermicompost with *Perionyx ceylanensis*.

Textile industry waste

The solid waste generated by the textile sectors is regarded as one of the most polluting waste and their disposal in open dumps, agricultural areas, along street sides or railroad tracks can pollute soil and surface or groundwater that poses public health risks. Kaushik and Garg (2003, 2004) performed multiple experiments using *Eisenia fetida* to transform sludge from textile mills mixed with cattle dung into vermicompost. Their findings showed that up to 30 % of the mixture of textile mills sludge and cattle dung (on a dry weight basis) has good vermicompost quality; but if more textile mills sludge is applied to cattle dung, the growth and sexual maturity in the earthworm was delayed. Similarly, Garg and Kaushik (2005) effectively used the *Eisenia fetida* to vermistabilize textile mill sludge mixed with chicken droppings which resulted that earthworm grew and reproduced favorably in a feed mixture comprising of 70 % chicken droppings and 30 % textile mill sludge. They also suggested that the sludge waste used in vermicomposting be free of chemicals used in the textile industry; otherwise, sludge could be poisonous to worms.

Garg et al. (2009) conducted vermicomposting tests on textile mill sludge mixed with cattle dung and horse dung by using *Eisenia fetida*. Their findings showed that temperature differences had a significant impact on the development and fertility rate of *Eisenia fetida*. The vermicomposting led to a reduction in EC, pH, C/N ratio, and K while an increase in the content of P and N was occurred. Bhat et al. (2013) investigated the vermiremediation of dyeing sludge from textile mills by mixing with the cattle dung in various separate proportions. The N, Na, pH and phosphorus content increased in all the proportions while a decrease happened in the EC, C / N ratio, organic carbon and potassium.

Food industry waste

The solid waste produced by the food industry, particularly wastewater sludge, is a significant source of organic material. The major environmental contamination may arise due to the open disposal of the sludge of the food industry. Tajbakhsh et al. (2008) evaluated the potential of *Eisenia fetida* and *Eisenia andrei* for transforming consumed mushroom into vermicompost. They recorded a decrease in pH (from 7.23 to 6.69) and EC (40 % lower than initial waste) during the study period. On the other hand, they also resulted in an increase in nitrogen content (by 42–85 %) and phosphorus content (3 times higher) in vermicompost as compared to initial raw waste. Yadav and Garg (2009) also revealed that *Eisenia fetida* can also be efficiently used to recover the nutrients from wastewater treatment plant sludge from the food industry. Their research findings revealed the decline of pH, EC, organic carbon, organic matter, C/N ratio, N, P, and K during vermicomposting. The vermicomposting of wastewater treatment plant sludge of the food industry mixed with biogas plant slurry by using *Eisenia fetida* was also recorded by Yadav and Garg (2010). They found that *Eisenia fetida* was unable to survive in a 100 % concentration of sludge. On the other hand, the addition of sludge in the 20-30 % biogas plant slurry helps in vermicompost maturation. Finally, they concluded that vermicomposting of a mixture of industrial sludges with biogas plant slurry could be an alternative technology for managing the food industry sludge.

Garg et al. (2012) studied the use of *Eisenia fetida* for vermicomposting of food industry sludges mixed

with various organic wastes by preparing the different proportions of sludges with cattle dung. The N (60-214 %), P (35.8-69.6%), Na (39-95 %), and K (43.7-74.1 %) were increased significantly while pH (8.45-19.7 %), organic carbon (28.4-36.1 %) and C/N ratio (61.2-77.8 %) were decreased from initial feed mixtures. Thus, the different studies stated that if waste is mixed in adequate amounts with other organic waste, it could be transformed into excellent quality manure by vermicomposting.

Distillery industry waste

The distillery is a major sugarcane sector sub-unit. Like other sectors, distilleries also generate an enormous amount of sewage sludges, and the correct disposal of these sludge wastes is a key challenge for distillery companies. The distillery sludge includes substantial amounts of vital plant nutrients such as N, P, K, Ca, Zn, Cu, Mn, and Fe and hence can also act as a soil conditioner after processing via the suitable biological process. By using earthworm *Perionyx excavatus*, Suthar and Singh (2008) had evaluated the vermicomposting of distillery industrial sludge mixed with cattle dung in various proportions. Their results showed a substantial reduction in pH (10.5–19.5 %), organic carbon (12.8–27.2 %), Zn (15.1–39.6 %), Fe (5.2–29.8 %), Mn (2.6–36.5 %) and Cu (8.6–39.6 %) while substantial increase in N (128.8–151.9 %), P (19.5–78.3 %), K (95.4–182.5 %), Ca (45.9–115.6 %) and Mg (13.2–58.6 %). Suthar (2008) also studied the vermicomposting of distillery industrial sludge spiked with cattle dung by using *Eisenia fetida* in various proportions. The final product generated showed a significant reduction in pH (7.8–19.2 %), organic carbon (8.5–25.8 %) while significant increase in N (130.4–170.7 %), P (22.2–120.8 %), and K (104.9–159.5 %). They also observed that earthworm biomass and reproductive efficiency were increased in bedding having less proportion (up to 40 %) of distillery sludge which clearly suggesting that industrial sludge could delay earthworm potentials if applied to greater ratios. However, the treatment containing sludge from the 40 and 60 % distillery sludge showed a peak rise in content of nitrogen, phosphorus and potassium and a decline in pH and organic carbon content in the vermicomposted material. Hence, the previous studies showed that earthworms can degrade the distillery waste only after mixing the same with cattle dung in absolute proportions. As the quantity of the waste

increases in the feed mixture, the decomposition of waste has been decreased and vice versa. Singh et al. (2014) studied the vermiremediation of distillery sludge into vermicompost by using *Eisenia fetida*. They mixed the distillery industrial sludge waste with cattle dung in various distinct proportions, i.e., 0 %, 25 %, 50 %, 75 %, and 100 % and studied the rate of survival, growth rate, maturity, production of the cocoon and population build-up, which increased with a rise in cattle dung proportion.

Thermal power plants waste (fly ash)

Fly ash creates challenging disposal problems in various parts of the world, including India (Karwal and Kaushik 2020). There is a total of 150 million tons of fly ash generated in India annually, so there is a crucial need to create techniques for the use of tiny and large-scale fly ash (Gupta et al. 2005). Bhattacharya and Chattopadhyay (2006) revealed that significant amounts of insoluble plant nutrients (Fe, Mn, Cu, and Zn) and certain heavy metals (Pb, Cd, and Cr) from fly ash were converted into a more soluble form during vermicomposting of fly ash. They prepared different combinations of fly ash with cattle dung and treated with and without earthworms. The solubility of various trace elements has also been estimated periodically. Their findings showed that the incorporation of *Eisenia fetida* in various combinations of fly ash and cattle dung has transformed a significant quantity of micronutrients into bioavailable forms.

Gupta et al. (2005) studied vermicomposting of fly ash spiked with cattle dung in four distinct ratios, i.e., 20, 40, 60 and 80 %, and reported high vermicompost production with maximum amount of earthworm hatchlings in 40 % of fly ash mixture. Their work also concluded that *Eisenia fetida* has the potential to mitigate the metal toxicity and up to 60 % of fly ash-cattle dung mixtures can be effectively used for vermicomposting. Venkatesh and Eevera (2008) also reported vermicomposting of fly ash spiked with cattle dung in different combinations, i.e., 1:3, 1:1, and 3:1 proportion. In earthworm-treated fly ash and cattle dung combinations, both macro and micronutrient concentrations were increased as compared to fly ash alone. The overall availability of nutrients in the 1:3 ratio was significantly higher as compared to the other treatments. Singh et al. (2016) also studied the vermicomposting of fly ash from a thermal power plant with cow dung in different proportions (%), i.e.,

0:100, 25:75, 50:50, 75:25 and 100:0. They reported that pH, EC, TOC and C/N ratios were significantly decreased from initial to the final product while total K and P significantly increased. The heavy metal contents were also found to be lowest in the vermicompost thus earthworms gut has the microflora which has the capacity to neutralize the toxic effect of waste into neutral form.

Winery and Beverage industry waste

Winery and beverage industries generate huge amounts of waste, including grape marc, grape seeds, stalks, and skins left over after grape crushing, draining and pressing wine production phases. The beverage industry accounts for about \$22.2 billion and recorded a growth rate of 16.5-19 % in India in 2013, which is anticipated to expand tremendously over the next 20 years. This, in turn, will be followed by a rise in these industries' organic discard. Nogales et al. (2005) tested *Eisenia andrei* potential for the bioconversion of various winery waste through vermicomposting into a valuable product, i.e., vermicompost. They suggested that by the end of vermicomposting, a portion of the total organic carbon found in plant waste was lost as CO₂ (19 % and 31 %) and therefore, vermicomposting improved the agronomic value of winery industrial waste by reducing the C/N ratio and increasing the pH, humic materials and nutrient content. The vermicomposting of the beverage industry bio-sludge mixed with cattle dung was reported by Singh et al. (2010). The findings showed that the degradation or decomposition of 50:50 mixtures could be accomplished in 75 days when earthworms were inoculated at the rate of 25 g kg⁻¹ of feed mixture. From the various studies, it was observed that sludge from the beverage sector can be stabilized with vermicomposting, but it needs to be combined with animal dung as 100 % sludge is toxic to worms.

Change in physico-chemical properties from waste to vermicompost

The changes in physico-chemical properties of different organic wastes after vermicomposting is given in Table 2. The physico-chemical properties have been varied from waste to vermicompost and this variation is also dependent on the initial composition of the waste. The pH is one of the most important criteria for assessing vermicompost maturity (Esmaeili et al.

2020). The pH content has been decreased in animal manure (cattle, goat, rabbit, pigeon, horse), industrial waste (bagasse, fly ash, beverage, pressmud, coffee pulp, milk industry), agricultural waste (wheat bran, rice bran, vegetable waste, barley bran) and weeds (*Parthenium hysterophorus*; *Trapanatans*, *Lantana camara*). The decrease in pH of vermicompost may be attributed to organic acid production during the waste mineralization cycle (Nakasaki et al. 2005). On the other hand, some waste also showed an increase in the content of pH which might be due to the decomposition of organic acids and volatile fatty acids, as well as the mineralization of organic nitrogen to ammonium during the vermicomposting process (García-Sánchez et al. 2017). The EC content indicates the total soluble salts formed during vermicomposting process which is also used as an evaluation criterion to use vermicompost as a fertilizer (Gusain and Suthar 2020). The EC content has also been increased and decreased in different kinds of organic wastes. The increase in EC might be due to the increase in different types of soluble salts during the process of vermicomposting (Singh et al. 2019). On the other hand, a decrease in EC can be due to the use of certain essential salts by the microbial communities during the vermicomposting (Chauhan and Singh 2013; Sharma and Garg 2018). According to Wong et al. (2001), the EC content of vermicompost below 4 mS/cm is good to be used as fertilizers for plant growth.

The content of carbon has been decreased from the initial values in all types of organic wastes. This reduction of organic carbon content in vermicompost may be due to the mutual activity of both earthworms and microorganisms turning organic materials into carbon dioxide (Sharma and Garg 2018). The earthworm also consumed carbon for their growth which might be also the reason for less content of carbon in the vermicompost (Soobhany et al. 2017). The decrease in carbon also showed the efficient degradation of wastes by the earthworm (Ansari and Rajpersaud 2012). The content of nitrogen (N), phosphorus (P) and potassium (K) have been also increased from initial waste to final vermicompost. The content of N, P and K in vermicompost is dependent on the initial content of the same in waste. This increase in N, P, and K might be due to the accumulation of mucus, excretory substances and enzymes secreted by the earthworms in the vermicompost (Ganiger et al. 2020).

Advantage of vermicompost

The vermicompost prepared by recycling the above said different organic wastes can be used as an efficient organic manure. The vermicompost so produced can be used in agriculture land and the additional quantity of worms can be used for recovering vermiproteins. The use of vermicompost in fields boosts plant growth, suppresses plant disease, soil porosity, microbial activity, enhances water retention and aeration. The increase in the total nitrogen, phosphorus and potassium content in vermicompost makes it a good fertilizer. The vermicompost also reduces the need for chemical fertilizers and reduces the quantity of waste that goes to the environment. The other advantages of use of vermicompost is as follows:

1. Improves soil aeration.
2. Enriches soil with micro-organisms as microbial activity in vermicompost is 10 to 20 times higher than in the soil.
3. Improves water holding capacity.
4. The castings are rich in humic acids, which condition the soil and help to balance soil pH.
5. Improves nutrient recycling.
6. Enhances germination, plant growth, and crop yield.
7. Improves root growth and structure.
8. Enriches soil with micro-organisms.
9. Provides plants with essential nutrients and aids in the suppression of plant diseases.

Conclusion

This study indicated that vermicomposting can be a low cost, effective technology, and a better option for the management of different types of organic solid waste. The different organic waste cannot be directly degraded with the help of earthworms but it can be efficiently degraded by mixing the organic waste with other nutrients rich in organic material like cattle dung, leaf litter, etc. It is also concluded that up to 25 to 30 % of any organic waste mixed with 70 to 75 % of other organic material like cattle dung can be easily converted into vermicompost, but the high proportion or concentration of organic waste causes mortality in the earthworms. The farmers must be educated to adopt vermicomposting technology for the conversion of animal waste into nutrient rich vermicompost for field applications to decrease their investment in conventional

Table 2 Changes in physico-chemical properties from initial to final in different types of wastes

Category of waste	Type of waste	pH		EC (mS/cm)		C (g/Kg)		N (g/Kg)		P (g/Kg)		K (g/Kg)		References
		Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	
	Cattle manure	7.05	6.80	-	-	544.2	521.5	10.7	12.8	3.4	3.4	2.3	3.0	Loh et al. (2005)
	Goat manure	8.08	6.89	2.57	1.82	545.8	295.7	5.4	9.4	3.6	5.3	6.9	4.2	Venkatesh and Ramesh (2018)
Animal waste	Rabbit	8.4	7.8	1.70	1.95	468	373	27	25	-	-	-	-	Molina et al. (2013)
	Pigeon dropping	9.59	8.83	4.99	5.46	348.6	294.6	2.98	4.54	0.19	0.41	38.65	54.10	Singh et al. (2019)
	Horse dung	7.9	7.0	2.69	1.06	627.01	252.01	12.5	21.0	8.7	10.3	7.7	8.0	Nath et al. (2009)
	Human faeces	5.3	8.0	60	28.5	415	175	41.0	28.0	11.0	23.5	28.0	65.0	Yadav et al. (2010)
	Paper	7.21	8.30	3.13	1.83	271.6	150.4	13.03	21.8	4.71	6.68	10.02	7.13	Kaur et al. (2010)
	Bagasse	8.13	7.41	3.23	4.90	503	324.4	6.9	16.7	3.6	6.8	24.8	27.8	Bhat et al. (2015b)
	Textile sludge	7.44	7.89	3.13	1.73	278.4	197.2	12.6	18.1	8.8	11.1	74.4	48.7	Bhat et al. (2013)
	Tannery sludge	8.63	8.88	6.60	4.00	187	164	12.10	20.5	5.8	8.4	2.1	1.5	Vig et al. (2011)
	Distillery	7.63	8.29	3.50	3.20	236.2	185.6	14.01	18.03	6.53	6.98	10.03	6.01	Singh et al. (2014)
Industrial waste	Coal Fly ash	7.00	6.80	0.40	0.35	414	321	10.4	13.6	9.11	13.2	9.2	11.3	Jeyasinga and Vasudevan (2017)
	Beverage	7.4	5.07	4.8	24.64	405.5	279.02	14.8	15.97	4.8	6.57	29.2	40.75	Singh et al. (2010)
	Pressmud	7.0	8.3	2.9	3.2	303.3	218.9	27.7	35.5	23.1	28.2	6.1	4.0	Bhat et al. (2014)
	Pressmud	8.01	6.99	4.06	5.83	421	323.2	15.9	21.2	25.3	29.7	22.1	20.5	Bhat et al. (2016)
	Pressmud	8	7.3	-	-	383	359	17.4	22	-	-	4.1	1.42	Sangwan et al. (2010)
	Coffee pulp	7.60	7.33	-	-	535	167.8	10.3	18.6	1.3	5.1	1.2	7.8	Raphael and Velmourouane (2011)
	Milk processing industry	7.35	7.22	-	-	449.75	331.01	30.03	53.26	18.69	29.55	13.85	21.84	Suthar et al. (2012)
	Rice straw	6.56	7.89	1.44	1.25	364.3	158.7	12	19.9	41	64.5	57	254.0	Shak et al. (2014)
	Spent mushroom with paddy straw	-	-	-	-	317.44	168.73	6.07	15.23	2.181	10.63	2.078	17.45	Sailila et al. (2010)
Agricultural waste	Tomato fruit waste	8.3	9.7	5.0	5.3	460	338	22.8	20.4	4.9	9.7	23.6	28.8	Fernández-Gómez et al. (2010)
	Wheat Bran	8.4	7.3	2.63	1.10	681	303.20	12.8	25.0	7.7	9.8	6.9	7.6	Nath et al. (2009)
	Rice Bran	8.7	7.6	2.74	1.08	568.10	252.40	11.0	24.1	6.9	8.7	5.8	6.3	Nath et al. (2009)
	Vegetable Wastes	8.0	7.3	2.46	1.08	569.12	245.70	9.8	21.9	4.2	6.6	6.8	7.4	Nath et al. (2009)
	Barley Bran	8.3	7.2	2.80	1.16	482.14	216.40	10.4	24.6	4.9	7.4	5.9	6.4	Nath et al. (2009)
	<i>Azolla pinnata</i>	7.13	7.41	0.49	0.69	400	147.66	8.40	12.30	4.93	6.66	25.43	40.30	Najar and Khan (2013)
	<i>Ageratum conyzoids</i>	7.56	7.11	1.89	2.75	464	326.33	25.9	34.87	12.5	20.49	35.68	82.67	Gusain and Suthar (2020)
Weeds	<i>Parthenium hysterophorus</i>	8.0	6.7	1.50	2.64	498	275	6.68	19.1	5.8	9.1	4.3	6.83	Yadav and Garg (2011)
	Trapanatans	6.97	7.73	0.73	1.06	278.36	144	4.5	7.4	38.61	49.67	30.66	48.00	Najar and Khan (2013)
	<i>Ceratophyllum demersum</i>	6.90	7.60	0.70	1.10	428	115	4.80	6.40	4.90	5.74	26	52	Najar and Khan (2013)
	<i>Lantana camara</i>	8.46	5.86	1.16	3.970	632.0	544.0	24.0	31.7	8.46	5.84	4.86	7.94	Suthar and Sharma (2013)

farming. Therefore, by adopting this technology industry, municipal corporations, and farmers will not only save money but will also contribute to saving the environment.

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Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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