Biotransformation of Industrial Wastes for Nutrient Rich Vermicompost—A Review of the Bioconversion Process by Earthworms

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1 Introduction

Industrial solid waste management has been a rising concern with the growth of industrial sector and economy buildup of developing countries like India where standards of living are getting better each day resulting in destruction of green space and major demand for urbanization and adequate infrastructure leading to expanding industrialization. According to Central Statistics Office, Ministry of Statistics and Programme Implementation, Government of India, total 371, 336 polluting industries were in operation in India (*Sugar; Pulp & Paper; Pharmaceutical; Pesticides; Iron & Steel; Fertilizer; Distillery; Soap & Detergent; Cement; Aluminium; Copper; Zinc*), out of which 40,095 were large-scale and 331,241 were small-scale industries [1]. About 30% of 960 million tons solid waste generated in India comes from the industrial sector [2]. Different industries produce different levels of hydrocarbons, phenols, heavy metals, organic chemicals, and other effluents in different forms which pollute the overall environment through its unsafe disposal. Hazardous industrial wastes are destructive in all manners while non-hazardous industrial wastes are non-toxic by-products generated by commercial and industrial activities and are safe for recycling and other waste-to-energy processes. All the *agro-based industries, pulp & paper industry, tanneries, food processing industries & textile industries*, thus become a major source of raw materials as their by-products can be reused again.

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H. Singh et al. (eds.), *Sustainable Development Through Engineering Innovations*, Lecture Notes in Civil Engineering 113,
https://doi.org/10.1007/978-981-15-9554-7_23

In the current scenario of sustainable development where the population is increasing at an enormous rate and the natural resources are decreasing in an uncontrollable manner, the environment is facing the adverse effects of the overall human activities. The management of solid wastes is a major concern in the path of achieving sustainable needs that can be solved only by providing access to engineering innovations. The current methods available for solid waste management include landfilling, incineration, recycling, source reduction, and reuse [3]. The operation of incineration is least-preferred considering the toxic emissions, high capital costs, and Global Warming Potential. Landfilling has been the most dominant technique of disposing waste due to cheaper costs among all operations [4]. The problem of water & land contamination through leachate and greenhouse gas emissions arises in landfilling and is, therefore, not the best solution for managing waste [5, 6]. Recycling is slow and informal in developing countries like India which lacks in providing basic recycling facilities [7, 8]. As a result, reuse is the most feasible option for industrial waste management. Reuse can be done by both composting and vermicomposting. The cost-benefit analysis of reusing is much attractive as compared to other management technologies [7]. Therefore, the need of the hour is to adopt vermicomposting as a sustainable waste management strategy in bio-transforming industrial wastes into fertilizers.

Vermicompost is the bio-oxidized and stabilized product formed by the combined action of earthworms and micro-organisms. Vermicomposting process is an eco-friendly process that is best suited for industrial waste bioconversion [9]. The earthworm species *E. foetida* is extensively used in vermistabilization process because of its high potential for bioconversion of organic wastes into vermin casts [10].

The cocoon production, the increase in biomass, and the low mortality rate of earthworms in the vermistabilization of paper mill wastewater sludge is an indication of the suitability of *E. fetida* in industrial waste stabilization [11]. Higher heavy metal concentration levels occur in different industrial waste by-products due to the involvement of chemicals in different processes. In the final vermicompost samples, the heavy metals content decreased as compared to the initial *sewage sludge* while that in the earthworms increased due to the bioaccumulation factor (BAF) [12]. This clearly depicts the efficiency of vermiconversion process in effectively removing the heavy metals content. An increase of 6.6 times the initial value of Total Nitrogen Content occurred in the finally stabilized *tea coal factory ash* vermicompost sample which clearly shows its high nutrient value [13]. The macronutrients and micronutrients are readily available to plants in vermicompost [14]. Therefore, in these adulteration times, the excessive use of inorganic fertilizers should be countered while the demand for organic fertilizers such as vermicompost should be given preference in agriculture. The existing resources should be used adequately and industrial wastes need to be utilized in a manner such that sustainability could be achieved. The main objective of this review is to focus on the potential of stabilization of industrial wastes by using earthworms and implementing this technology on a large-scale for sustainable agricultural development.

2 Vermicomposting

In the process of waste conversion, the waste material to be stabilized passes through the gut of the earthworms, where it gets transformed and is excreted out in the form of worm manure. These castings are not only helpful in regulating the growth of plants but also act as pest repellents thereby enriching microbial activity. This process of valorization of waste material is known by different names such as vermicomposting/vermitechnology/vermiconverion/vermistabilization. This process can work within a mesophilic temperature range of 10–32 °C and both microbes and earthworms survive and work effectively in this range [15]. Vermicomposting is a closed-loop renewable technology for amendment of waste materials into rich nutrients source for soil fertility and also enhances the water retention capacity of soil. It also results in compositional change of waste, decrease in C:N ratio due to decrease in organic content, and gain in nutrient content by the earthworm activity [16]. The earthworms not only aerate the substrate but also decompose it thereby increasing their biomass and overall microbial activity of the process [17]. The agro-industrial organic residues need to be transformed for use in food production by the addition of vermistabilized humus to soil instead of expensive disposal of such wastes [18]. The researchers have been managing the industrial wastes using earthworms extensively [19–21].

Industrial wastes cannot be directly fed to earthworms due to containment of hazardous chemicals as it can drastically affect the vermicomposting process. Amendments are bound to be added to the industrial wastes for successful working conditions. Cow dung was used as a bulking agent to stabilize *bakery industrial sludge* in vermicomposting trials [22]. Three bulking agents cow dung (CD), biogas plant slurry (BGS) and wheat straw (WS) were added to stabilize *agro-industrial sludge* procured from *sugar mill* [23]. *Tea waste* was stabilized in a short period of 28 days with the condition that it should be mixed with cow dung [24]. 50:50 combination of sludge obtained from *beverage industry* and cow dung was ideally suggested as nutrient-rich end product in terms of its earthworm growth and nutrient content [25]. Therefore, it is evident that a bulky material is necessary for the degradation of industrial wastes if they are mixed in suitable ratios.

Many researchers have also reported a decrease in toxicity levels of the industrial waste in the vermicomposting process on the basis of heavy metal bioaccumulation in the gut of earthworms. Vermicompost made from 1:1 combination of *textile mill wastewater sludge* and cow dung was reported ideal due to reduced bioavailability of toxic heavy metals after vermistabilizing it using two epigeic earthworm species *Eudrilus eugeinae* and *Perionyx excavates* [26]. The earthworm also contains a protein called metallothionein which is known to bind heavy metals such as Cu^{2+}, Zn^{2+}, and Mn^{2+} [27]. Detoxification of industrial wastes is done by chloragocyte cells and gut microbes available in earthworms [28]. A considerable increase in heavy metal content was also noticed [29, 30]. It is, therefore, crucial to study the behavior of heavy metals and their bioaccumulation in the vermistabilization process. The industrial waste should be properly utilized by using earthworms in order to obtain end product that can sustainably be used as a crop nutrient and reduce the use of inorganic fertilizers [31].

3 Biotransformation of Different Industrial Wastes

Non-hazardous industrial wastes that are otherwise disposed of unhygienically by the industries, have been successfully used by researchers in biotransformation for the preparation of vermicompost using earthworms of different species. Vermicomposting process depends on a variety of factors such as type of substrate material to be degraded, its physicochemical properties, species and number of earthworms added, temperature, moisture content, amendment material, mixing ratio of different added materials, aeration process in the material. Bioconversion by red earthworm *Eisenia fetida* on *brewers's spent grain (BGS)* showed a decrease in C/N ratio whereas earthworm population increased at the end [32]. Increase in dehydrogenase activity also depicts the release of extra-cellular enzymes in the manure castings and the degrading ability of active microbial population [33]. Detoxification and recycling of *brick kiln coal ash* increased the nitrogen and phosphorus contents, thus decreasing the heavy metal content which resulted in less polluted vermicompost [34]. The vermiconversion process also involved the use of green plants such as *Tephrosea purpurea* (TEP) and *Gliricidia sepium* (GLS) that were utilized to stabilize *paper industry sludge.* PMS + CD + TEP/GLS (2:1:1) combination being ideal for sustainable agriculture [35]. The waste material maturity can also be indicated by dehydrogenase, urease, and phosphatases activities. The problem of *leachates* in landfills was also countered when *Eisenia fetida* were added to it which led accumulation of toxins in the tissues of earthworms enhancing their reproductive ability and detoxified the municipal leachate [36]. Potential of earthworms *Eisenia fetida* was also checked after transformation of *citronella bagasse* and *paper mill sludge* mixture (3:2) leading to nutrient content increase and bacterial population growth. Increase in ash content and decrease in humification index are indicative of better maturity of compost [37]. By-products of agricultural industry can be effectively converted into useful resource just like transformation of 2:1:1 ratio of *pressmud* of sugar industry with cow dung and green plants (*Gliricidia sepium* and *Leucaena leucocephala*) produced nutrient-rich manure [38]. Similarly, 60:40 combination of *distillery sludge waste* (DSW) and *tea leaf residues* (TLR) acquired favorable results in terms of casting activity of earthworms and depicted the preference of earthworms for less DSW content and more TLR content consumption when compared with 80:20 ratio [39]. S*ewage sludge derived biochar (SSDB)* was applied as an amendment in *sewage sludge* (SS) which increased the cocoon production with addition of SSDB and high bioaccumulation of heavy metals. The decrease in C/N ratio showed positive trends in good vermicompost transformation [40]. In a separate study, mushrooms were cultivated using *tea factory waste* (TFW), and the obtained product (mycotea waste) was completely transformed into vermicompost. The 1:1 mixture showed maximum cellulose reduction. High C/N ratio is said to be an outcome of high cow dung content [41].

Similarly, other industrial wastes that have successfully been used by various researchers include *milk industry sludge*; *apple pomace waste*; *soft drink industry sludge; herbal pharmaceutical industry waste*; *paper mill sludge, tannery sludge and distillery waste* each in combination with municipal solid waste [42–46]. Residues from *palm oil mill*; biomass of an oil yielding plant named *java citronella*; *biosludge from beverage industry* are some other by-products of industrial processes that were vermicomposted and proved to be beneficial for environment instead of harming when disposed of in a rendered manner [47–49]. The industrial wastes are stabilized and detoxified after bioconversion by earthworms and the end product brings nutrient value with it that adds to the effective yield of crops and soil conditioning. The vermitechnology is an environment-friendly technique of converting industrial wastes into resourceful manure and covers the ecological, social and economic dimensions of sustainable development.

4 Role of Earthworms in Bioconversion Process

Aristotle, the Greek philosopher, called earthworms "*intestines of the earth*". Earthworms were also denoted as "*ecosystem engineers*" [50]. Earthworm castings are soil aggregates that help in the organic matter decomposition in the soil and also create soil porosity by humus formation [51, 52]. Many exogenic and endogenic enzymes are available in the gut of the earthworms for conversion of organic minerals into exchangeable forms for growth of plants and soil structural development [53].

The addition of organic fertilizer into the soil is advantageous for C and N mineralization and biomass of earthworm along with the availability and assimilation of nutrients such as Mg, K and P [54]. Poly-aromatic hydrocarbons (PAHs) are bioaccumulated to a great extent by earthworms [55]. The microbial and biochemical soil activities are facilitated by earthworms on the substrate and the environmental risks are also reduced by partial degradation of excretions of earthworms [56]. The ingestion of organic wastes in the gut of earthworms occurs including microflora present in it which is expelled out in the form of vermin castings (faecal matter) [57]. High bioaccumulation of heavy metals in earthworms can be observed due to worm activity whereas it may not be seen in substrates in which earthworms are absent [58, 59]. Earthworm castings are humus-like substances, enriched with certain hormones, enzymes, microbes and other complexes that are transferred to the soil through the gut of earthworm [60]. The feeding regime of the earthworm is also dependent on the selection of substrate for the nutrient pool soil [61].

The growth of earthworms and complete decomposition of organic matter is depicted by high levels of humic acid present in vermicomposts thereby indicating "hormone inducing activity" [62]. 25% increase was seen in the yield of crops when the earthworms are present in the agricultural-based ecosystem [63]. Aerobic conditions are maintained by earthworms through continuous mixing of soil, eliminating contaminants present in it. Both earthworms and their vermicast play a vital role in sustainable agriculture and food production by increasing the nutritional quality of the harvested crop. Therefore, the cheapest and permanent solution to make modern-day agriculture more sustainable and productive is vermitechnology.

5 Conclusions

- The researches of almost all authors have indicated to comply with vermicomposting as a sustainable method to transform a variety of industrial wastes/sludges into useful end product. This reduces their toxicity and adds to the existing resources thus maintaining ecological balance.
- Adequate recycling of by-products of industries by the most effective vermitechnology should be implemented on a larger scale to decrease the load on the environment and control the existing resources from depletion.
- The investment cost of setting up a vermicompost system is lower as compared to other waste treatment methods. Additionally, it is considered clean and sustainable technology because waste is reused to produce organic fertilizer which could be applied to agricultural lands.
- Biotransformation leads to zero waste production without the misuse or burning of organic wastes. As a result, the concept of circular economy is better achieved by less exploitation of virgin resources. It also aims at increasing the efficiency of materials, energy use, recycling and reuse, accompanied by low waste generation.
- Vermicomposting is a sustainable method that works on the same principle of Waste-to-Energy (WTE) processes and is an energy-efficient process for waste to biomass conversion using engineering innovations.

Acknowledgements The authors acknowledge Dr. Puneet Pal Singh Cheema, Assistant Professor, Department of Civil Engineering, Guru Nanak Dev Engineering College, Ludhiana for his guidance and the necessary research facilities provided in the Environment Engineering Laboratory.

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