Review on Entomoremediation: a new waste management strategy

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Abstract

With the advent of modern technology waste material is increasing day by day. If they are not properly recycled, they will possess very harmful impact in our environment. With increase urbanization it becomes a challenge to manage such huge waste in a cost-effective manner and in a sustainable way. Entomoremidiation is a new and less explored field of waste management strategy where insect adults and larvae are used to break down the waste materials and also to convert them into organic nutrient rich material that can further used either in fields as a manure or as feed for aquaculture, poultry or in cattle farms or to obtain valuable biproducts like biofuels, dyes, lubricants or in pharmaceuticals. Not only insects do ecological services by helping in degradation of biological waste but they are also good bio accumulator of heavy metals. They can be used effectively to detoxify heavy metal contamination. Some insects can accumulate more heavy metals in their body than the environment like Loccobius spp. Some insects accumulate those metals in their pauperum like Black solder fly Hermetia illucens. Some crickets like Teleogryllus testaceus produces enzymes in their body which breakdown large heavy metal compounds into small less harmful compounds. So, through introducing those insects' heavy metal contaminants as well as other waste materials can be removed from the environments in a very effective and cost-effective way.

Keywords: Bio remediation, Entomoremidiation, Heavy metal, Waste Management

Introduction

Excessive production of waste materials caused scarcity of drinking water, reduction of the fertility of soiland spreading of harmful disease-causing pathogens (Kamaludeen *et al.*, 2003). Bioremediation is a method by which different biological agents are used to reduce the pollutants and contamination (Donlon and Bauder, 1980). Lots of research and interest have been generated to develop strategies for remediation of environmental contaminants (Gerhadt *et al.*, 2008). There are so many advantages of in-situ bio remediation technique (Donlon and Bauder, 1980) as well as of ex-situ decontamination technique (Pavel and Gavrileseu, 2008). Entomoremidiation (Greek word entomon – insect, Latin remedium – to clean) can be defined as the use of insects and their associated microorganisms to detoxify pollutants from soil, sediments or from organic biomass. Entomoextraction, a term which, analogously to

phytoextraction describes the idea of Gao *et al.* (2017). Beetles, Collembolans, termites and ants, these four groups of insects are termed as ecosystem engineers (Folgrait, 1998). But not only have these 4 groups played important roles in waste management practice. As the class insecta is very diverse group there are many potential species which can be used as waste management agent. Some of them already discovered and used effectively in many countries and many of them yet to be discovered. Soil that is contaminated with heavy metals can be decontaminated using insects (Hester, 2012). The soil invertebrates like collembolans ants etc sequester the heavy metal in their body, and as a result of which they can no longer possess harmful effect in the environment Just like plants do (Marscher, 1995). Those insects use their midgut epithelium for the storage purpose of heavy metals .When this insects undergo nothing this stored heavy metals excreted out with old cuticle .Some insects store heavy metals in their pauperum that also cast off during molting process.

Culture and mass rearing of insects

The rearing of the insects can be done in field cages or in the laboratory condition, after investigating biological indices or ecotoxicity (Knoepp *et al.* 2000, Gestel, 2012). The black solder fly (*Hermetia illucens*) larvae are extensively reared for the bioremediation as well as bioconversion purposes. It is proposed that the rearing of the larva of black solder fly has so much significance, as these larvae convert the waste materials into a fat and protein rich material, that can be used as feed of domestic animals and also for other purposes like chitin or biodiesel production, discussed later (Van Huis *et al*., 2013; Li *et al*., 2011, Diener *et al*., 2011). Dung beetles are mass reared and introduced in the site and it shows potential role (McKay, 1976; Hayakawa and Yamashita, 1990). African giant termites were mass reared in the laboratory and released and also proved potential for degradation of bio waste (Leuthold *et al*., 2004). *Anuridagranuria* is a collembolan species and cosmopolitan in distribution and safe for incorporation and not endangered or threatened (Lynch, 2001). They also prove promising role in waste management practice. The rearing process is easy and just require essential environmental condition, after that they can be introduced to the garbage site. Careful attention should be given as many pathogenic organisms spread widely within the colony. *Entomophthora muscae* is an entomopathogenic fungi that causes high mortality *in Musca domestica* and and *Sarcophaga argyrostroma.* Proper cleaning can reduce the pathogen outbreak (Schneider, 2009)

Egg production

The first and foremost important part of establishing a mass rearing plant is the efficient egg production. The adult colony must lay enough number of eggs to process huge amount of waste and to produce good quantity of larval biomass. So, to maintain a large production of egg is very important. A clear understanding about the biology of these insects is essential, and the knowledge from various types

of literature about their detail biology is implemented in this mass rearing process (Schneider, 2009).The critical parameters for egg production and lying by the females are environmental temperature, moisture, quality as well as quantity of adult and larval diet, successful mating, density of adult population, age and the substrate for oviposition. Genetic factors as well as photoperiod also play important role. The temperature, humidity, and photoperiod can be controlled to optimum level in production plants (Zverev and Zhemchuzhina, 1988).

Substrate for oviposition

Generally female flies are very specialist for oviposition to provide better survivality of the larvae (Ward *et al*, 1999). So before designing oviposition devices and substrates it is very vital to know the species behavior (Hogsette and Washington, 1995).Various observations were made about the process to build the oviposition site much more attractive to the females. It was concluded that the substrate should be covered and equipped with supported structure. Ammonia is considered as an oviposition attractant for various types of dipteran flies including *H. illucens*. fish, meat (pork or beef), blood or liver are considered oviposition attractant for the flies belonging to the family Calliphoridae and Sarcophagidae. As these flies need animal protein for ovarian development and maturation of egg and the larva also depend on such diet. The oviposition of hoverfly can be stimulated by pollen. 5% honey solution in water when given to *H. illucens* the egg production increased (Rachmawati *et al*., 2010).

Adult population density

Several authors reported adult population density to be an important parameter. The adult cages should fill with adequate number of pupae to obtain enough adult population. It is observed that when the adult density is less (192 dm^3/fly) the egg production rate is high (Gobbi *et al.*, 2013).

Choosing right strain is also a valuable parameter as some strains are better than other in egg production, survivality and for cultural condition, as described for some species of house fly (Beard and Sands, 1973). In case of Blow fly (*Lucilia sericata*) differences can be seen between British and Spanish strain in case of development time and egg production ability (Martinez-Sanchez *et al*., 2007).

Heavy metal sequestration using insect

With the advancement of industrialization, urbanization and extensive uses of different chemicals heavy metal pollution becomes very prominent (Waseem *et al*., 2014; Islam and Ahmed *et al*., 2015). Insects can be used as bioindicator for heavy metal contamination (Spehar *et al.*, 1978). Insects play a crucial role in bio accumulation of heavy metals. In recent studies it has been found that water strider (*Gerris sp.)* are more in numbers in the location of stream with high cadmium concentration. Same positive correlation is also found with the high Zn, Cd or Cu concentration and the population density of

ant lions (Nuorteva, 1995). Dragon fly larvae are aquatic and they also can tolerate as well as store heavy metals in their body and the concentration of heavy metal sequestration depends on particular species (Meyer *et al*., 1986). Aquatic insects also can accumulate heavy metals from contaminated waterbody and sediments. Coleopteran insects of the family Hydrophilidae are major example of this category (Pourang, 1996). *Loccobius spp*. A beetle of the family Hydrophilidae accumulate high amount of heavy metals from their environment and play crucial role for the transportation of elements from environment (Aydogan *et al*., 2018). Black solder fly can also accumulate heavy metals like leads in its puparium, (Gao *et al*, 2017). Entomoextraction is a new term which defines the extraction of heavy metals from the body of the insects (Gao *et al*, 2017). Insects with its associated symbiotic microorganisms in its body degrade the complex toxic mineral compounds into less toxic compounds and also accumulate inits body and that can be extracted further. *H. illucens*or the black solder fly larvae are successfully use to reduce biomass contaminated by heavy metals like cadmium, mercury or zinc.it is observed that when black solder fly larvae grow in a diet rich in Zn no statistically significant increase in puparia occurs but when Cd was added to the larval diet the biomass of puparia significantly increases (by 19.6%) (Diener *et al.*, 2015).

Plastic degrading insects

Plastic is one of the biproduct of industrialization which already giving threat to the whole world. As a result, plastic pollution gets worldwide attention. Improper dumping and management causing major issues like soil pollution, blockage in drainage system and major threat to the aquatic organisms even in ocean. Comparing to the marine and freshwater pollution issue by plastic the soil pollution is neglected though many organisms including human being directly or indirectly depend on soil. For proper agriculture practice it is necessary to maintain a healthy soil environment. Plastics are synthetic polymer made from petroleum. The total plastic production comprises of polyethene and polypropylene (Chae and An., 2018). Polyethylene is mainly used for packaging and about 40% of the total plastic production. More than a trillion plastic produced each year in the world. In last 50 years plastic production has increased enormously and as a result plastic pollution has increased. Plastic degradation by microbes is reported in many research articles previously (Bonhomme *et al*., 2003) But in recent years one insect larvae has proved potential role in degrading this polyethene types of plastic that is wax warm larva *(Galleria melonella),* and producing ethylene glycol (Bombelli, 2017). This insect is found in the beehive and eats honey and wax from the hive. When scientists keep them is polythene bag, they eat out the bag making holes. Further research proved that these insects can consume polythene bags and water bottles 1400 times faster than other organisms (Jordan, 2015).

Bioconversion using insects

Insect based bioconversion means conversion of biological waste from agriculture or from food procession industries into frass and valuable organic biproducts like animal feed (as supplement animal food), food for human or secondary industrial biproducts like biodiesels, lubricants, chitin-based compound, or pharmaceuticals or dyes (Fowles, 2020). The benefits of these processes are that they are environment friendly, cost effective, profitable and one of the effective solutions of food waste management. These processes yield higher feed conversion ratio comparing to the conventional methods for the live stocks (Li *et al.* 2011, Van Huis *et al* 2013). In recent years the insect mediated biproduct production and waste management becomes a major business and a growing industry (Dossey *et al*., 2016). Presently only a few insect species is used as the bio converting agent but many have the potentials that yet to be discovered. Black solder fly (*Hermetiaillucens*) is the widely used and a potential species. The larvae convert the waste materials into an aminoacid rich fatty organic compound that can be used as feed of cattle in fisheries and in poultry farms (Wang and Shelomi, 2017). Commercialization and the marketing of bio-converted by products shows a good shift and it provide alternative and sustainable solution for reduction of food waste (Nyakeri *et al*., 2017; Wang and Shelomi, 2017). The converted waste material by the insects are good source of biofuel like methane which is a sustainable source of energy (Bulak, 2018). When these waste meterials are kept in ambient condition in fermentation chamber without oxygen they produce significant amount of bio gas like methane. That proved to be a profitable source from the insect converted bio waste materials. Another important bi product is the biodiesel. It is one of the sustainable sources of fuel and a promising alternative. It is found that when preexisting fats were removed from the waste by preprocessing and then introduced to the larvae fordegradation the yield is increase any fold (Yang *et al*., 2012).

Advantages of entomoremidiation

There are various types of potential benefits if this whole process. Asthe waste materials are degraded by the insects the chance of environmental pollution gets reduced. The garbage and the waste if not properly recycled that caused various types of diseases. Not only the insects help to degrade the waste products but also, they convert the bio waste into animal feed containing nutrients. The black solder fly converts the waste material in such a way that can also be used in fisheries as fish food. This material is rich in amino acids, anti-microbial peptides and natural chitins (Rindhe *et al*., 2019)

Dung beetles play very important role as a decomposer of the waste organic materials and also take part in the process of nutrient cycling (Maldonado et. al., 2019). All these process coasts less amount of money and also environment friendly with a lot of benefits. The biproducts have high values in the markets (Zheng, Li, *et al.* 2012). The property of insect frass both physically and chemically is somewhat identical to commercial manure and it also has the potential to compete with them (Salomone *et al.* 2017). It was tested for the growth of cabbage and found that it was potentially identical to the commercial

fertilizers (Choi *et al.* 2009). One study also made to see the growth of onion with black solder fly frass and surprisingly found that it was similar to compost amendments (Zahn, 2017). One more benefit of using insect frass is that it is less susceptible to infected by pathogenic microbes and need less pesticides (Lalander *et al*., 2016).

Current problems with entomoremediation

Though the process of bioremediation using insect is cost effective and with so many opportunities but it also has some limitations. About 61 industries were set up between 2014 and 2015, who produce or sell insect products (Dossey *et al*., 2016). But the main obstacle for wide scale use of this process is the technical aspects and the large-scale production. For large scale production and laboratory rearing deep knowledge about the fly biology is necessary (Eby and Dendy,1978; Diener *et al*., 2011). Some of the main problems while using insects for Entomoremidiation process are the following

Technical challenge for conversion of huge waste

Generally, the fly larvae cannot burrow very deep into the waste substrate. They hardly can survive more than 10 cm depth into the substrate. Various types of biotic and abiotic factors play important role here, so large number of shallow trey is necessary for that purpose. Second obstacle is that to operate such huge number of trey is not an easy task also. Several approaches were made for increasing the depth of the substrate medium for larvae like forced delivery of oxygen through pipe and pumping of air into the substrate (Eby and Dendy, 1978). But the main problem for this process is that during pupation the larvae enters the pipes and crawl along the length of the pipe. Another alternative to facilitate the oxygenation process is to use mesh wall for the container (Ivanov *et al*., 1980).

Proper management and designing

Proper designing of the whole system is very important as all the processing systems are interlinked. The bioconversion process produce large amount of volatile by products and gases. The temperature difference between the larval substrate and the environment becomes as high as 12.5-degree Celsius (Zvereva., 1984). Eggs are very sensitive to temperature, so the egg production and biodegradation chamber should be separated and the eggs should transferred to the egg chamber soon after oviposition.

Quality control

Many abiotic as well as biotic factors play important role in the successful rearing process. Quality control is another important factor which should maintain strictly to get uninterrupted results. Regulating correct strain very important and contamination with other not desirable strain should also be

checked. The flies should also be out crossed otherwise viability will lose as a result of inbreeding depression (Day *et al*., 2003).

Safety and legal issue

Commercialization of the byproducts from insects need to pass safety issues.it require proper investigation as many contaminants can enter in the food and feed. According to European Food Standard Agency (EFSA) this type of food and feed should not possess more threat than the food already presentin the market (EFSA, 2015). Furthermore, this agency also emphasizes on microbial contaminants, allergic potential or any environmental impacts of these products. Positive results come from the European Commission and World Health Organization regarding chemical safety issues as these insect bi products contains below the maximum limit of toxic heavy metals so can be used as feed and manure (Charlton *et al*., 2015). And those which accumulate high content of heavy metals in its body like Black solder fly or, blowfly (*Calliphora sp.)* Or house fly can be used as heavy metal remediation process solely. the mass rearing of insects is considered as the "farmed animals", that are used as feeding purpose (Smith and Pryor., 2013). So that the wastes produced by insects when used for animal feed in farms are limited by the regulations 1069/2009 of category 3 materials. Under regulation (EC) 1069/2009 the use of insect-based waste form manure or organic fertilizers is permitted. To produce insect base bio converted materials the existing legislations should be relaxed in Europe. Some other aspects should be considered like animal welfare while the technology increases (Smith and Pryor, 2013). European Food Standards Agency (EFSA) has emphasized on the need for extensive research in chemical, microbial, and other hazards like allergies, toxicity and also the hazards in storage, processing and to the environment (EFSA 2015).

Future aspects

Entomoremidiation process meets the vast need for sustainable waste management practice. Insects proved to be a potential alternative for this regard. In future with the increase in the technical aspects the process and large-scale conversion will also increase and also the production cost will decrease. More research should take place to know all the toxicological consequences. Microbial safety is another big issue. Now only some of the insects like black solder flies and house flies are extensively used but there are other species which can be used as very potential for this purpose. The flightless strains should give much priority as it decreases the chance of introducing invasive fly species into the environment (Beard and Sands., 1973). Genetically modified flies also can be used in near future to enhance their ability for bio degradation process.

Conclusion

So, from all these aspects it can be concluded that Entomoremidiation can be a promising way in reduction of the waste in future. Though at present time this is practiced only a few countries of the world but it can be said that it will be popularize globally. As this practice need much space and technical support initially it becomes problematic to provide all the set up. From plastics to heavy metals, from food waste to municipality waste, insects are potent agents to solve the waste problems. Further study and research are necessary for elucidating more potential of insects as bioremediatory and ultimately all these processes will lead to maintaining our healthy environment.

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