Journal of Entomology and Zoology Studies

Available online at www.entomoljournal.com

E-ISSN: 2320-7078
P-ISSN: 2349-6800
www.entomoljournal.com
JEZS 2020; 8(6): 2022-2025

Received: 25-09-2020
Accepted: 29-10-2020

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Entomoremediation: An ecofriendly approach for waste management: A review

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DOI: https://doi.org/10.22271/j.ento.2020.v8.i6aa.9171

Abstract
The long-term sustainability of organism groups depends critically on their ability to survive in contaminated habitats. Decontamination and excretion can be useful mechanisms to prevent the detrimental physiological impacts of pollutants building up in organisms. Insects are a great source of natural fertilizer, since they can eat organic byproducts and absorb their nutrients into their bodies, reducing the material levels in the environment. This process plays a critical role in the recycling of organic matter in nature. Furthermore, insects and larvae can also be used to reduce plastic debris and remediate heavy metal toxins in soil, helping to lessen environmental pollution. From this point forward, various study findings may suggest that meal worms, black soldier flies, and ground beetles can be used to clean up an extremely polluted environment. But at present different optimisation strategies that would lower the number of insects employed while preserving process efficiency require more study. To lower the price of entomoremediation for higher quantities of wastes produced by human activity, such optimization should be performed.

Keywords: Entomoremediation, recycling of plastics, black soldier fly, meal worms, ground beetles

Introduction

Soil is an incredibly delicate ecosystem. It can be polluted by a range of factors, such as chemicals (Like hydrocarbons from petroleum products), pesticides, heavy metals, as well as human activities that alter the nature of the soil. Contaminated sites can be hazardous not only to human health, but to the surrounding ecosystems as well. To combat this, there are a variety of methods emerging for remediation of soil on-site. (Gimsing *et al*., 2004) [1]. This review paper suggests that entomoremediation be used as an in situ soil decontamination technique, in addition to the in situ and ex-situ soil remediation techniques already being practiced around the world. Entomoremediation, a term derived from Greek "entomon" (meaning 'insect') and in the Latin "remedy" (Meaning 'to clean or restore'), can be defined as the use of specialized insects and associated microorganisms to utilize, extract, sequester and detoxify soil, sediment or biomass contaminants.

In Bioremediation has recently seen the emergence of Entomoremediation as a sub-domain, made possible by the use of saprophytic insect larvae with their remarkable resilience to tough environmental conditions. These larvae not only help reduce sludge-related nuisances, but they also take in heavy metals, helping to reduce the contamination levels.

Insects have a lot of benefits compared to bacteria and fungi when it comes to dealing with multiple waste streams. Their intricate digestive systems, including the ability to crush, allow them to break down a variety of useful waste materials, including household trash (Diener *et al*., 2011) [2] and also animal manure (Parodi *et al*., 2020) [3]. Raw waste can be fed directly to insects without needing to undergo any pretreatment, processing, or sterilization that's usually required for microbial fermentation. (Meyer *et al*., 2016; Dahman *et al*., 2019) [4-5]. Certain species of insects, like black soldier flies (*Hermetia illucens*), are already being utilized for waste treatment, and they have a high tolerance for bacteria and fungi (Joosten *et al*., 2020) [6] and are easily separated from organic waste for further processing (Dortmans *et al*., 2017) [7].

Insect biotechnology is highly viable for mass production because the setup and infrastructure needed are relatively inexpensive, and the land requirements are minimal (Kim *et al*., 2021) [8] Furthermore, the use of butterfly larvae for the production of recombinant proteins has been a long-standing practice. The silk moth Bombyx mori, for example, has been used to express and produce human α-interferon. This is a significant development, as the production of recombinant proteins using insects can be a more cost-effective and efficient process than traditional methods (Maeda *et al*., 1985) [9]. Using transient baculovirus systems to infect larvae is a common method for producing proteins, but it is not always practical for large-scale or long-lived proteins. This is because the system is only effective for a short period of time and is not sustainable for long-term protein production. To address this issue, researchers are exploring multi-generational approaches that allow for more sustained and efficient protein production over an extended period of time. By utilizing these innovative techniques, scientists are able to create more stable and effective protein products that can be used for a wide range of applications.

1. Biodegradation of plastics by Insects

Nowadays, different plastics are recycled using different methods. This includes recycling plastic using mechanical, chemical, and biological methods like bacteria and fungi. But which entails plasticizing and reintroducing waste plastic into the production cycle. Because they can change shape at high temperatures, thermoplastics like polyethylene (PE), polypropylene (PP), and polystyrene (PS) are all appropriate for this technique.

This method's drawback is that plastics must be meticulously processed before recycling. Recycled plastics must generally be kept out of touch with food since the food industry employs packaging that must adhere to strict standards. Typically, recycled materials are used to create lower-value products (Down cycling), such rubbish bags and traffic cones. (Achilias, 2017) [10]. Yet, a more sophisticated phenomenon known as biodegradation potential has also been observed more frequently in insects. *Tenebrio molitor*, a meal worm, can eat polyurethane (PU), polylactic acid (PLA), polyvinyl chloride (PVC), polyethylene (PE), polystyrene (PS), polypropylene (PP), and even tyre fragments and vulcanised butadiene-styrene elastomer (SBR) rubber (Billen, 2020) [11]. (Aboelkheir, 2019) [12]. The beetle *Tribolium confusum* larvae exhibit PE and PS biodegradability as well. (Abdulhay, 2020) [13] and the super worm *Zophobas atratus* (Yang, 2020) [14]. *Galleria mellonella*, a wax moth, which is more capable of degradation of polyethylene (PE) (Lou, 2020) [15].

According to studies, an insect's ability to biodegrade plastics is typically reliant on the microorganisms in its intestine. For instance, the wax moth mentioned earlier experienced PE breakdown due to the fungus Aspergillus flavus (Zhang, 2020) [16]. However, research on the larvae of the Corcyra cephalonica rice moth has shown that they can still break down low density polyethylene (LDPE) even after receiving antibiotic treatment, proving that biodegradation is not reliant on the presence of intestinal microflora enzymes (Kesti, 2019) [17]. Hence, the processes described above constitute a new subtype of bioremediation used in the environmental remediation of plastics.

2. Remediation of metal contamination by insects

Heavy metals pollution poses a major threat to organisms due to direct and/or indirect contact with the contaminated environment (Ciadamidaro, 2017) [18]. Based on this, monitoring the fate of pollutants in ecosystems is very important during environmental risk studies. Metal accumulation was widely investigated and found to be varied by ground beetle species, while the accumulation potential of a certain species was also assessed inconsistently in previous publications (Heikens *et al*., 2001) [19]. Found that the general metal concentration in ground beetles was significantly lower than that in spiders. As a possible reason, Kramarz (1999) [20] attributed the relatively low metal concentration in ground beetles to the efficient decontamination and excretion mechanism of the digestive system. Ground beetles as insects with generally low metal accumulation potential. Several studies have investigated major differences in metal accumulation between *Carabus* and *Pterostichus* species bioremediation of soil metal pollution.

Many researchers have studied ground beetles as bio indicators, as they are sensitive to environmental changes and can provide valuable information about the health of ecosystems. Ground beetles are abundant in many different habitats, including forests, grasslands, and agricultural fields, and can be easily collected and studied. Overall, ground beetles are a highly valuable organism for studying ecological processes and environmental health. Their abundance in many different habitats and diverse food preferences make them a valuable species for researchers studying the impacts of environmental changes on ecosystems (Kulkarni *et al*., 2017) [22]. Beetles are a diverse group of insects that have been extensively studied for their ecological and economic importance. However, when it comes to assessing their metal accumulation, the results are often contradictory. This can be attributed to various factors, including experimental designs and methods used in individual publications. In addition, the results on metal accumulation in beetles are further influenced by several other factors, such as feeding preference, breeding type, developmental stage, physiology, and sex.

Factors Affecting Metal Uptake in Beetles

1. Feeding Preference

Beetles have a wide range of feeding preferences, including carnivorous, herbivorous, and omnivorous. The type of food they consume can significantly affect their metal uptake. For instance, herbivorous beetles that feed on plants may accumulate higher levels of metals than carnivorous beetles that feed on other insects.

2. Breeding Type

The breeding type of beetles can also influence their metal uptake. Some beetles breed in the spring, while others breed in the autumn. Studies have shown that spring-breeding beetles tend to accumulate more metals than autumn-breeding beetles. This may be due to differences in the availability of food and environmental conditions during the breeding season.

3. Developmental Stage

The developmental stage of beetles can also affect their metal uptake. Beetles go through several stages of development, including egg, larva, pupa, and adult. Studies have shown that larvae and pupae tend to accumulate higher levels of metals than adults. This may be due to differences in the feeding habits and physiology of different developmental stages.

4. Physiology

The physiology of beetles can also influence their metal uptake. Some studies have shown that beetles with a higher metabolic rate tend to accumulate more metals than those with a lower metabolic rate. This may be due to differences in the ability of beetles to metabolize and excrete metals from their bodies.

5. Sex

The sex of beetles can also affect their metal uptake. Studies have shown that male beetles tend to accumulate higher levels of metals than female beetles. This may be due to differences in the feeding habits and physiology of males and females. (Simon *et al*., 2016) [23]. Furthermore, seasonal changes can also affect beetles' body metal concentrations (Butovsky, 2011) [21].

3. Insect used as composting agent (Entomocomposting)

Insects like black soldier fly (*Hermertia illucens* L.) and meal worm (*Tenebrio molitor*) are revolutionizing the way we recycle organic waste into high-quality organic fertilizer. Thanks to research by the International Centre of Insect Physiology and Ecology (ICIPE), we now know that BSF larvae can produce mature organic fertilizer in just 5 weeks, compared to the 12-24 weeks it takes for conventional composting. Not only that, but the resulting fertilizer is superior in nutrients to commercial organic fertilizers. This breakthrough has enormous potential to benefit farmers looking to improve soil health and crop production in a shorter time frame. By embracing insect-based fertilizer production, we can create a more sustainable and efficient agriculture system while reducing waste.

The use of insect composted organic fertilizers (ICOF) has shown promising results in improving soil health and crop productivity when compared to conventional fertilizers. By utilizing insect frass fertilizer, it is possible to reduce reliance on synthetic pesticides and expensive mineral fertilizers, which can have a negative impact on soil and environmental health. While there are only a few studies with preliminary results testing the ability of black soldier fly frass (BSFF) as an organic fertilizer, the potential benefits are significant in the long term. By adopting sustainable practices like ICOF, farmers can improve soil health and crop yields while reducing their environmental impact. The first experiments were done with basil and sorghum, the subsequent experiments were with asparagus bean (Anggraeni, 2010) [25], corn (Alattar *et al*., 2016) [27], onion (Zahn, 2017) [27], lettuce and ryegrass (Kebli and Sinaj, 2017) [28], although inconclusive in terms of consistency as far as concerns the positive effect that isintended with the use of these type of entomocompost as organic fertilizer.

The BSFF's composition varies depending on the substrate used, and it's important to understand how it affects crop yield. Insect composted organic fertilizers (ICOF) are better for soil health and crop productivity when compared to conventional fertilizers. It is expected that the sustainable use of insect frass fertilizer will reduce the need for synthetic pesticides and expensive mineral fertilizers in the long run, which can be harmful to soil and the environment. However, exploring the full potential of ICOF more research to:

To fully unleash the potential of ICOF, it is crucial to conduct further research in four key areas.

Firstly, quality standards must be established to regulate the production and marketing of ICOF. This will ensure that farmers receive reliable and consistent products that meet their crop nutrient requirements. The development of such standards will require collaboration between industry experts, scientists, and policymakers.

Secondly, there is a need to develop more ICOF products that are suitable for current production requirements. This may involve researching and testing different combinations of organic materials to create more effective and versatile fertilizers. It may also involve exploring innovative production methods to increase the efficiency and sustainability of ICOF production.

Thirdly, stakeholders involved in ICOF production, marketing, and quality control must be provided with adequate training and capacity building. This will enable them to effectively assess and monitor product quality, as well as communicate the benefits of ICOF to farmers and other stakeholders.

Finally, public-private partnerships must be established to develop a policy and legal framework for integrating ICOF into existing fertilizer markets and farming practices. This will require engagement with governments, international organizations, and private sector actors to create an enabling environment for the adoption and scaling up of ICOF.

Overall, further research in these areas will be critical to unlocking the full potential of ICOF and realizing its potential to improve soil health, increase crop yields, and promote sustainable agriculture.

Conclusion

Still present research on entomoremediation should focus more on exploration of different insects and different optimization strategies that would lower the number of insects employed while preserving process efficiency and require more study on these aspects. To lower the price of entomoremediation for higher quantities of wastes produced by human activity, such optimization should be performed.

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