Bioremediation: A Sustainable Biological Tool for Food Waste Management

18

Isha Sai, Vatsala Sharma, Ashmita Singh, and Rukhsaar Sayeed

Abstract

In the past few years, there has been a tremendous increase in the generation of food waste due to rapid industrialization and urbanization. Food waste consists of high levels of sodium and moisture and is usually mixed with other types of waste during its collection. Food waste gathered to have a high level of contaminants which when combines with other components produces many toxic components and has deleterious effects. In order to cope with this food waste production at every level; advanced and effective waste management systems are to be adopted that can overcome the gap between production and management of waste disposal. the microorganisms play a pivotal role in the bioremediation of wastewater generated from various food industries as well. The chapter highlights the role of microbes as a biological tool for a sustainable food waste management system.

Keywords

Food waste · Microbes · Micro-remediation · Waste disposal

18.1 Introduction

Over the last few decades, the waste gathered in the environment is one of the major concerns globally. Food waste is gradually becoming one of the major concerns nowadays and recognized environmental issue globally. On one hand food security

I. Sai (✉)
Department of Biosciences, Sri Sathya Sai Institute of Higher Learning, Anantapur, India
e-mail: ishasai@sssihl.edu.in

V. Sharma · A. Singh · R. Sayeed
Amity Institute of Food Technology, Amity University Uttar Pradesh, Noida, India

M. Thakur et al. (eds.), *Sustainable Food Waste Management*,
https://doi.org/10.1007/978-981-15-8967-6_18

Table 18.1 Characteristics of food industry waste

S. No.	Various section of food industries	References
1.	*Fruit and vegetable processing industry* waste consist of hydrocarbons, proteins, fat, and wastewater have various dissolved solids, herbicides, pesticides, and chemicals used for cleaning purposes	Riggle (1989), Grobe (1994), and Punnagaiarasi et al. (2017)
2.	*Fermentation industries*—the brewing, distilling, and wine manufacture produces liquid waste (with high BODs and CODs) The wastewater has very high concentrations of tannins, phenols, and organic acids	Mayer (1991), Suzuki et al. (1997), and Punnagaiarasi et al. (2017)
3.	*Dairy industries* contain pollutants from the water resources, feed of cattle, and soil	Punnagaiarasi et al. (2017)
4.	*Meat and poultry industry*: Slaughterhouses are the major sources of environmental pollution as wastewater and solid waste	Cournoyer (1996) and Punnagaiarasi et al. (2017)
5.	*Wastewater from food industries*: The concentrations of pollutants (organic matters, fats, oil and grease—FOGS) in food wastewater is increased in wastewater	Punnagaiarasi et al. (2017)

is one of the major challenges, but the impact of food waste on the surrounding environment can no longer be overlooked. As the population is growing day by day and every piece of land is showing urbanization, on one hand, more and more food is being produced and on other side more food is being wasted also. Punnagaiarasi et al. (2017) observed that in urban sectors the food wasted affects environmental health and which in turn has a negative impact upon the environment and human health.

Zafar (2012) also claimed that food industries are the biggest source of the untapped energies, dumped almost in landfills and also releasing greenhouse gases into the atmosphere. Food waste is generally considered as biodegradable but, many times, it is very difficult to treat and recycle food waste due to its composition. The waste generated from the food products has very high levels of moisture and sodium content; which mixes with other types of waste and becomes very toxic. The characteristics of various food industry waste have been shown in Table 18.1.

Mavropoulos (2011) classifies the amount of waste generated into two different types:

- Consumers in the given area
- Consumption pattern of the consumers

Thus, in order to deal with this issue of the large production of food waste; a very effective waste management systems have to be analyzed and adopted so that the gap between production and management of waste disposal shall be fulfilled. A significant fraction of food waste is generally unavoidable, include peels and skins, bones and fats, oils and food mistakenly left to rot. The food waste is one of the major pollution problems which is plaguing the world today. We have to adopt various technologies and processing techniques, so that the same can be tackled at a very faster pace

18.2 Bioremediation

Bioremediation is a naturally occurring process where the microorganisms either immobilize or transform contaminants to the degradable forms in the environment (Thassitou and Arvanitoyannis 2001). NRC (1993) acclaimed the bioremediation process as one of the most widely accepted for the clean-up of the contaminated sited of the environment. Bioremediation is an environment friendly, cost-effective, and innovative approach that utilizes the metabolic potential of microorganisms to clean-up the environmental pollutants by complete mineralization into CO_2, H_2O, N_2, HCl, etc. (Asgher et al. 2008; Haritash and Kaushik 2009; Rhodes 2014).

Bioremediation is still an underutilized technology for food waste management and there is a definite need for these nondestructive types of solutions. Microorganism given encouragement can do most of the reclamation work for us in the environment. Bioremediation is the process by which microbes are used to eliminate contaminants by ingestion and degradation. The process of bioremediation mainly depends on microorganisms which enzymatically attacks the pollutants, but this can be effective only when the extrinsic growth factors are favorable and permit their growth and activity. These microbes are indigenous to the contaminated area and are non-pathogenic. Bacteria, Actinomycetes, fungi, and algae are all commonly used for bioremediation (Table 18.2; Fig. 18.1).

In the current scenario, the climatic conditions are also changing at a faster pace. These changes include a global rise in temperature and atmospheric pollution which adversely affects agricultural productivity. To mitigate the problems arising from the present climatic conditions and to ensure food security, sustainable agricultural practices and minimize the food waste are need of the hour. The pollution generated from the waste gathered in the environment has significant deleterious consequences on the sustainable food system. In the past few, the food waste management system is getting more and more complicated, causing more pollution and remediation of these pollutants again is a very challenging task.

Table 18.2 Biotic community used for bioremediation

Sr. No.	Microorganisms	Examples
1	Bacteria	*Pseudomonas veronii, Burkholderia spp., Kocuria flava, Bacillus cereus*, etc.
2	Fungi	*Aspergillus versicolor, A. fumigatus*, *Penicillium*, etc.
3	Algae	*Cladophora fascicularis, Spirogyra spp.*, *Spirullina spp*., etc.
4	Yeast	*Candida utilis*, *Saccharomyces cerevisiae*, etc.

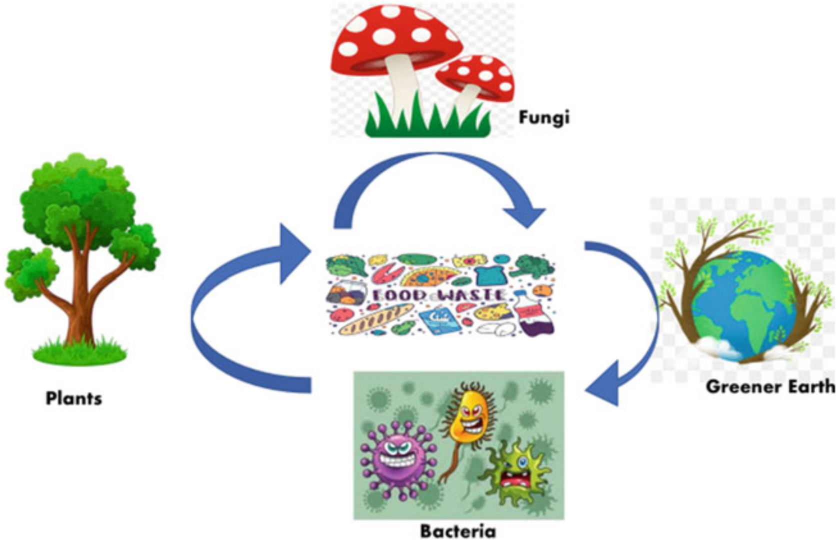

Fig. 18.1 Process of bioremediation of food waste

18.3 Microorganisms: Biological Tools for Sustainable Agriculture Food Waste Management

Microorganism (both bacteria and fungi) plays significant role as a significant role as a biological tool for the establishment of a sustainable agricultural system (Thakur 2014, 2019). Watanabe (2001) reported that naturally occurring microbial consortia including both bacteria and fungi have been utilized in a variety of bioremediation processes. Fungi are more widespread in the environment having rapid adaptability and diverse metabolic activities in agricultural systems. In the soil, the fungal cultures can sustain under diverse environmental conditions in the maintenance and functioning of the ecosystem because of their decomposing behavior. The beneficial fungi play an important role in improving plant growth, increasing plant yield, and involvement in biotic and abiotic stress tolerance, hazardous materials remediation, sustainable crop production, and food safety. Singh et al. (2019) also discussed the use of fungi in mycoremediation and mycocontrol.

Microorganisms also play an important role in attaining the sustainability of the ecosystem by involving itself in the following different ways:

- Fungi as a sustainable biological tool
- Microbial enzymes

18.3.1 Fungi as Sustainable Biological Tool

Finding sustainable solutions for the utilization of food and agricultural wastes is one of the greatest challenges in any ecosystem. Only fungi represent a wide variety of groups like wood-rot fungi, white-rot fungi, brown-rot fungi, leaf decomposing fungi, soil fungi, fungal mycorrhiza, endophytic fungi and aquatic fungi which in association with other microorganism has a greater potential to sustain the ecology of any ecosystem using mechanisms of mycoremediation and myco-control.

The key features of fungi which help in bioremediation are:

- Fungal species grow and symbiotic relationships with other species in the ecosystem and have various positive associations there.
- Fungal hyphae show indeterminate growth, therefore, no limitation of cell division in the hypha as long as resources are available (which they get from the food waste).
- Fungal mycelium form rhizomorphs that grow through vast distance with a robust system of adapting to highly restrictive environmental conditions.
- Fungi are more resistant to high concentrations of toxins in comparison to bacteria.

Mycoremediation is a fungal-based technology that uses the potential of fungi with their high growth rate and high activity of their extracellular enzymes in disintegrating the organic material from different food sources and converting them to simpler compounds (Thakur 2014; Purohit et al. 2018; Pozdnyakova et al. 2018; Thakur 2020). From the few past decades, many researchers have worked on mycoremediation and this technology has been used on oil spills, contaminated and polluted soil, industrial chemicals, contaminated water, and even agricultural farm waste (Alexander 1994; Bennet et al. 2001; Ashoka et al. 2002; Adenipekun and Lawal 2012).

Some specific examples of macro-fungi mycelium especially used for mycoremediation are as (Source: Thakur 2019):

- *Bjerkandera adusta*
- *Irpex lacteus*
- *Lentinus edodes; L. tigrinus; L. squarrosulus*
- *Phanerochaete chrysosporium*
- *Pleurotus ostreatus*, *P. tuber-regium, P. pulmonarius*
- *Trametes versicolor*

Mycorrhiza Fungi (MF)

Mycorrhiza, a heterogeneous group of fungi is primarily associated with plant roots. Mycorrhizal association assumes different kinds: ectomycorrhiza, endomycorrhiza (VAM or AM), ectendomycorrhiza, ericoid, arbotoid, orchidaceous, and monotropoid mycorrhiza. Fungal mycorrhiza is very helpful for sustainable agriculture and providing resistance to the plants against various pathogens. These associations are very helpful and the plant body gets protection from deadly pathogens, tolerance to drought, and higher pH. Their association helps the plant in improving the nutrient supply also (Basu et al. 2018). They also provide protection to plants against various water and metal toxicity stress by reducing metal translocation and therefore, helping plants to adapt and survive in these contaminated sites containing heavy metals.

18.3.2 Microbial Enzymes

Karigar and Rao (2011) studied the use of various enzymes from microorganisms like—bacteria, fungi, and with the presence of these enzymes, plants help on biodegradation of pollutants:

- Microbial Oxidoreductases
- Microbial Oxygenases
- Monooxygenases
- Microbial Dioxygenases
- Microbial Laccases
- Microbial Peroxidases (*Microbial Lignin Peroxidases*, *Microbial Manganese Peroxidases*, *Microbial Versatile Peroxidases*

18.4 Waste Water from Food Industries

The use of physico-chemical method for wastewater remediation has been replaced by microbial bioremediation method. Utilizing the potential of bacteria, fungi, and even yeasts for remediation purpose is eco-friendly. Microbes have been used for the reduction of wastewater pollutants to acceptable economy level. Microbes synthesize a lot of enzymes that are instrumental in degrading oil pollutants which are major constituent of food wastewater (Table 18.3). Microbes possess some distinctive advantages over other forms of organisms due to ease in handling, mass cultivation ability to withstand various environmental conditions, and high degradable capabilities. Their extremely small size and large surface area relative to their volume make them applicable in many areas of wastewater remediation (Xue et al. 2016). Therefore, the microorganisms play a pivotal role in the bioremediation of waste water generated from various food industries as well.

18.5 Advantages of Bioremediation

Bioremediation process has many advantages over other commercialized technologies available as:

- Natural and environment friendly

Table 18.3 Examples some isolated microorganism that have been identified for food waste water pollutants bioremediation

Sr. No.	Microorganisms	examples
1	Bacteria	*Acinetobacter junii, A. calcoaceticus, A. radioresistens, Achromobacter sp, Alcaligenes sp, Arthrobacter sp, Aeromonas sp, Bacillus subtilis, B. licheniformis, B.amyloliquefaciens, B. laterosporus, B. megatherium , B. cereus, B. Licheniformis , B. laterosporus ,Clostridium sp, Citromonas sp, Cryptococcus sp, Enterococcus sp, Erwinia sp, Enterobacter sp, Escherichia coli, Flavobacterium, Klebsiella sp, Lueconostoc lactis, Mycobacterium, Moraxella lacunata, Nitrosomonas sp. Nitrobacter sp, Pseudomonas aeruginosa, P. fluorescens, , Providences, Proteus vulgaris, Raoultella planticola , Stenotrophomonas sp, staphylococcus aureus, Streptococcus faecalis ,Serratia sp, Zoogloea sp*
2	Fungi	*Aspergillus versicolor, A. fumigatus, Absidia spp., Cunninghamella sp , Fusarium moniliforme, F. oxysporium, Penicillium spp., Rhizopus spp, Thermophilus spp. Alternaria sp, Trichoderma sp* and *Thermoactinomyces sp*
3	Algae	*Spirogyra, Cladophora,* and *Spirulina* species
4	Yeast	*Candida utilis* and *Saccharomyces cerevisiae*

- Safety, simple, and quiet
- Low maintenance and reusable end products
- Economically feasible with very less time consumed for clean-up
- Flexibility and fast
- Directly affects the target and not transferred across different medium
- Better acceptance by the mass

18.6 Limitation of Bioremediation

Some of the challenges faced during the bioremediation process as follows:

- Fungal species has the inability to compete with native microbes in soils. Bacteria could either inhibit the growth of fungi or in combination with fungi, enhance the degradation of pollutants available in the food waste also.
- Nutrient requirement of the microbe has to be completely understood so as to enable it to thrive at a contaminated site.
- Mushroom mycelium should not be used as a starter strain
- Legal issues involved in this process. There are several patents specifically granted for matching fungus against a toxin. This is a major hindrance in preventing wide-scale fungal clean-up of toxins from the food waste polluted site.
- Lack of experienced mushroom cultivators in outdoor trials is a problem in mycoremediation. This lacking has affected the success of several trials.

18.7 Future Scope

Recent advancements with the addition of potential microbial strains to the food waste and the enhancement of the indigenous microbial population have proven to be successful. Whether the fungal mycelium is native or newly introduced to the site, the process of destroying contaminants is important and critical for understanding. A lot of work is focused on the strategic development of the complete process to make it a full-fledged sustainable system. Further, the application of this technology in large scale projects will demand much more work to streamline the methodologies. The use of microorganisms for remediation would allow the commercial concern to offer inexpensive, safe products to their customers. If the underexploited potential of bacterial cultures and fungus mycelium is further exploited, it will go a long way and come as the most efficient biological tool in sustainable food waste management system.

18.8 Conclusion

Over the last few decades, food waste has become an increasingly recognized environmental issue globally. One side food security is one of the major challenges, but the environmental impacts because of food waste can no longer be overlooked. Although the researcher had found the variety of ways by which we can degrade the food waste, but bioremediation also making its leap to tackle the problem associated with different categories of waste with the help of microorganisms. The underexploited potential of bacterial cultures and fungus mycelium is slowly changing the way to tackle one of the most dangerous issues of food waste. More extensive research needs to be carried out on the potential of bacterial and fungal species for bioremediation managing food waste.

References

Adenipekun CO, Lawal R (2012) Uses of mushrooms in bioremediation: a review. Biotec Molecular Biology Rev 7:62–68

Alexander M (1994) Biodegradation and bioremediation, 2nd edn. Academic Press, San Diego

Asgher M, Bhatti HN, Ashraf M, Legge RL (2008) Recent developments in biodegradation of industrial pollutants by white-rot fungi and their enzyme system. Biodegradation 19:771–783

Ashoka G, Geetha MS, Sullia SB (2002) Bioleaching of composite textile dye effluent using bacterial consortia. Asian J Microb Biotech Environ Sci 4:65–68

Basu S, Rabara RC, Negi S (2018) AMF: the future prospect for sustainable agriculture. Physiol Mol Plant Pathol 102:36–45

Bennet JW, Connick WJ, Daigle D, Wunch K (2001) Formulation of fungi for in situ bioremediation. In: Gadd GM (ed) Fungi in bioremediation. Cambridge University Press, Cambridge, pp 97–108

Cournoyer MS (1996) Sanitation and stabilization of slaughterhouse sludges through composting. In: Proceedings of the Canadian meat research institute technology symposium, vol 1, Canadian Meat Research Institute, Ontario, Toronto, pp 1–7

Grobe K (1994) Composter links up with food processor. BioCycle 34(40):42–43
Haritash AK, Kaushik CP (2009) Biodegradation aspects of polycyclic aromatic hydrocarbons (PAHs): a review. J Hazard Mat 169:1–15
Karigar S, Rao SS (2011) Role of microbial enzymes in the bioremediation of pollutants: a review. Enz Res 11:11
Mavropoulos A (2011) Waste management world. http://www.waste-managementworld.com/index/display/article-display/8267238380/articles/waste-management-world/volume-11/issue2/features/wastemanagement_2030.html
Mayer ES (1991) Waste treatment experiments at the Gabriel Sedlmayr Spaten. FranziskanerBraeu K.-G.a.A. Brauwetl. (Ger.) 131:2346
NRC (National Research Council) (1993) In situ bioremediation: National Research Council Report, vol 1. National Academic Press, Washington, DC, pp 2–11
Pozdnyakova NN, Balandina SA, Dubrovskaya EV, Golubev CN, Turkovskaya OV (2018) Ligninolytic basidiomycetes as promising organisms for the mycoremediation of PAH-contaminated Environments. Earth Environ Sci 107:012071
Punnagaiarasi A, Elango A, Rajarajan G, Prakash S (2017) Application of bioremediation on food waste management for cleaner environment. In: Prashanthi M, Sundaram R, Jeyaseelan A, Kaliannan T (eds) Bioremediation and sustainable technologies for cleaner environment. Environmental science and engineering. Springer, Cham. https://doi.org/10.1007/978-3-319-48439-6_5
Purohit J, Chattopadhyay A, Biswas MK, Singh NK (2018) Mycoremediation of agricultural soil: bioprospection for sustainable development. In: Prasad R (ed) Mycoremediation and environmental sustainability. Fungal biology. Springer, Cham
Rhodes C (2014) Mycoremediation (bioremediation with fungi) – growing mushrooms to clean the earth. Chem SpecBioava 26(3):196–198
Riggle D (1989) Revival time for composting food industry wastes. BioCycle 29:35–37
Singh VP, Singh M, Singh SK, Kumar C, Kumar A (2019) Sustainable agricultural practices using beneficial fungi under changing climate scenario. In: Climate change and agricultural systems. Current challenge and adaptation. Woodhead Publishing, Sawston, UK, pp 25–42
Suzuki H, Yoneyama Y, Tanaka T (1997) Acidification during anaerobic treatment of brewery wastewaters. Water Sci Technol 35:265
Thakur M (2014) Mycoremediation – a potential tool to control soil pollution. Asian J Environ Sci 9 (1):24–31
Thakur M (2019) Mushrooms as a biological tool in mycoremediation of polluted soils. In: Emerging issues in ecology and environmental science (case studies from India). Springer, Cham, pp 27–42
Thakur M (2020) Fungi as a biological tool for sustainable agriculture. In: Yadav A, Mishra S, Kour D, Yadav N, Kumar A (eds) Agriculturally important fungi for sustainable agriculture. Fungal biology. Springer, Cham, pp 255–273
Thassitou P, Arvanitoyannis I (2001) Bioremediation: a novel approach to food waste management. Trends Food Sci Technol 12(5–6):185–196
Watanabe K (2001) Microorganisms relevant to bioremediation. Curr Opin Biotechnol 12:237–241
Xue L, Famous E, Jiang J, Shang H, Ma P (2016) Experimental survey on microbial bioremediation of food wastewaters. Intern J Sci Res 6:110–118
Zafar S (2012) BioEnergy consult. http://www.bioenergyconsult.com/trends-in-food-wastemanagement