

## Advances in Bioremediation: A Prospective Approach for Green Food Waste Management

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### Abstract

Fruit and vegetable industries' wastes consist of various by-products with an acidic pH, sodium, and a moisture content of 80–90%. These attributes of food waste lead to the destruction of soil and help in the generation of greenhouse gases. Different waste management techniques are used for food waste management such as slurry phase decomposition, extraction, thermal treatment, and bioremediation. Among these bioremediations is the most effective technique owing to low expenditure, minimal operational costs and almost no harmful environmental effects. It converts toxic contaminants emerging from various food industries into useful components. A complete bioremediation protocol reduces, degrades, detoxifies, mineralizes or may convert more hazardous pollutants into less harmful pollutants. In this review, a general outlook on bioremediation will be discussed followed by its applications in the management of various food industries. A comprehensive discussion of the advantages and limitations of the techniques will also be covered.

**Keywords:** Bioremediation, food waste, waste management, environment

### 1. Introduction

The food we consume begins its life cycle in the fields where it is cultivated and harvested, or in the sea, lakes and rivers where it is caught. It continues through the steps of storage and handling, as well as, in certain cases, processing, before being distributed and consumed. At farms, processing factories, storage houses, distribution centers, supermarkets, households and restaurants losses and wastage occur throughout the food cycle (Lipschutz & Stabinsky, 2018).

Both within the chain of food and geographically, the terms food, food loss, inedible food, and food waste must be contextualized. Any substance that is intended for human consumption, whether it is processed, semi-processed or raw, as well as the "inedible sections" of that substance that are not meant for human consumption, is referred to as food (Gustafsson, O'Connell, Draper, & Tonner, 2019). As Pomegranate is a food with inedible skin. Food that has spoiled is described as food in which deterioration has occurred in quality or quantity through mistake because of infrastructure restrictions at different stages in the life cycle of food like manufacturing, storage, processing, and distribution, such as spills, spoilage, bruising, wilting, or other similar damage. Food waste is defined as a reduction in the amount or quality of food as a result of retailers, food service providers, and customer decisions and behaviours ("Food Loss and Food Waste,"). Because of their nutrients and health-promoting components, vegetables and fruits play an important part in human life and our diet. They are ingested raw, slightly processed, and completely processed. As a result of the rising global population and changing dietary preferences, demand for such vital food commodities has grown dramatically (Sagar, Pareek, Sharma, Yahia, & Lobo, 2018).

According to the United Nations (UN) Food and Agriculture Organization, global fruit production surpassed one billion tons in 2017, resulting in huge volumes of waste and by-products depending on consumption, geographical locations, and growing traditions. Only Europe creates about 100 Mt of trash and by-products each year, with the beverages sector (26%) and fruit and vegetable industries accounting for the majority of this (14.8 percent) (Fierascu, Sieniawska, Ortan, Fierascu, & Xiao, 2020).

Fruit and vegetable waste (FVW) is a broader term which refers to inedible sections of fruits and vegetables that are wasted owing to a lack of suitable handling procedures and infrastructure at various stages such as handling, collection, processing and shipping. As per the aforementioned definition, FVW is defined as the loss of fruit and vegetable rather than their waste. FVW can be formed at many stages throughout the food supply chain, from farmers to consumers, both at pre- and post-consumer stages (H. Kumar et al., 2020). Fruits and vegetables make a loss because they are perishable and have a short shelf life. Due to the high concentration of nutritious ingredients in this food category, its waste and byproducts have an impact on the environment, economy, and social sectors. Regarding the environment, many of these biomaterials are not used and ultimately end up in dump sites, where leachate generation and microbial decomposition contribute significantly to environmental issues. To get rid of parasites and fungi, the leftovers are occasionally burned. The negative economic impact is due to the expenditures associated with the disposal of solid waste in landfills (Torres-León et al., 2018).

The impact factors on producing fruits and vegetables for retail sales in Northern America and Europe are 1.5 tonnes CO<sub>2</sub> equivalent/tons, 242.3 m<sup>3</sup>/tons blue water use, and 0.1 ha/tons land impact factors (Tedesco, Scarioni, Tava, Panseri, & Zuurro, 2021). As food products move through the supply chain, GHG (greenhouse gas) emissions rise. This means that a unit of food lost or wasted at the wholesale level has a higher environmental impact than a unit lost or wasted on a farm (Tedesco et al., 2021).

In certain European Union (EU) member nations, studies regarding the creation of household food waste have been conducted. According to recent British research, British homes create 1.8 million tons of food waste each year. The estimated global warming potential (GWP) of this non-eating food comes from its manufacture, production, and distribution is 4.6 million tons of CO<sub>2</sub> equivalent. Swedish families create approximately 100–116 Newton of food waste per capita per year. According to the same study, a substantial portion of the created home food waste might be prevented. However, in order to use the inherent energy and nutrients in food waste, resource-efficient technologies and user-friendly for separate collection may be important (Bernstad & la Cour Jansen, 2012).

Due to the manufacturing, preparation and consumption of food, the food processing industry produces enormous amounts of solid and liquid waste. These wastes are posing a rising number of disposal and possible environmental issues, as well as a loss of important nutrients and biomass. Vegetables and fruit, meat and poultry, alcoholic fisheries, plantation, grain processing, beverages, and other consumer product groups such as cocoa products, confectionery, chocolates, soya-based products, milk and milk products, mineral water, high protein foods, and other consumer product groups are all covered by the food processing sector (Khedkar & Singh, 2018). Food waste (FW) disposal that is both efficient and safe is of global concern. By 2025, it is expected that more than 2.2 billion tons of FW would have been produced worldwide (B. Wang et al., 2021).

Food waste costs to the world economy are almost USD 2.6 trillion per year in terms of economic, environmental, and social losses (*FAO Food wastage footprint – Full-cost accounting*, (2014)) which is clear from Table 1.

**Table 1.** Food Waste's Global Cost

Cost (US Dollar)	Aspect
700 billion	Environmental
900 billion	Social
1 trillion	Economic
2.6 trillion	Total

Source: *FAO (2014) Food wastage footprint (2014)*

FW accounts for 4.4 giga-tons (Gt) of CO<sub>2</sub> eq. per year, which represents 8% of global anthropogenic GHG emissions (" Food Wastage Footprint & Climate Change," 2015). China, the United States, and India, respectively, emit 12.45, 6.34, and 3.00 Gt CO<sub>2</sub> equivalent per year (The World Bank Data Bank based on European Commission & Research (EDGAR)). In conclusion, food water causes a lot of problems such as GHG emissions (Al-Rumaihi, McKay, Mackey, & Al-Ansari, 2020) and water footprint (Lins, Puppini Zandonadi, Raposo, & Ginani, 2021a) climate change (Jeswani, Figueroa-Torres, & Azapagic, 2021); - nutrient loss (C. Chen, Chaudhary, & Mathys, 2020); economic impacts (Philippidis, Sartori, Ferrari, & M'Barek, 2019) Sanitation (Lins, Puppini Zandonadi, Raposo, & Ginani, 2021b). In terms of FW management, developing countries face bigger hurdles than developed countries. FW is currently a problem for the environment since it is not effectively separated from Municipal Solid Waste (MSW), resulting in increased greenhouse gas (GHG) emissions in landfills (Thi, Kumar, & Lin, 2015).

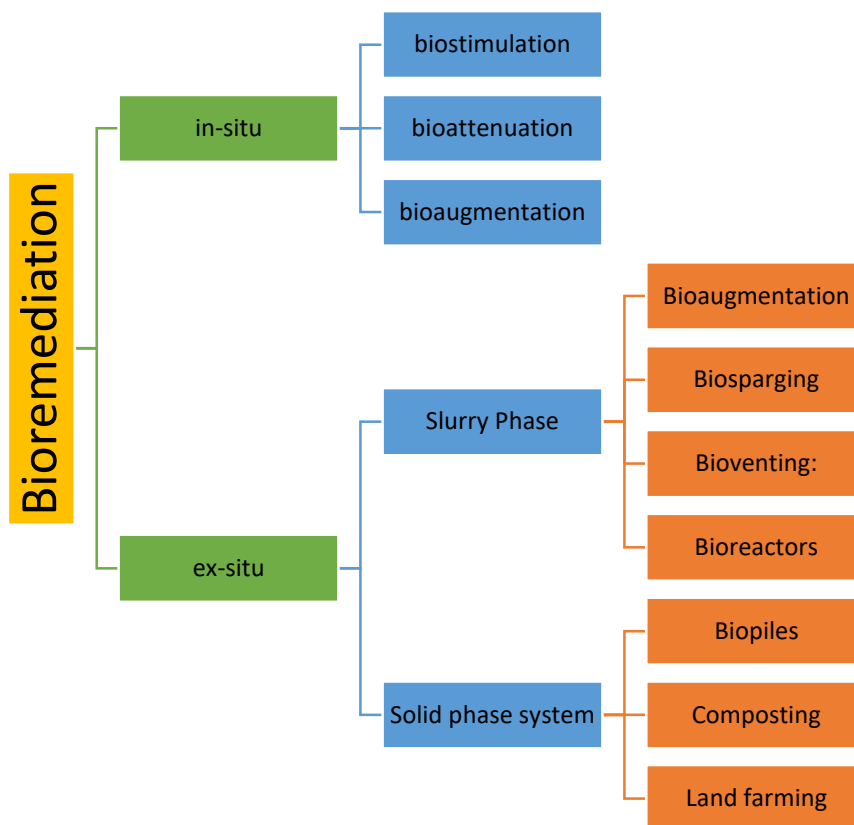
Waste management has received worldwide attention because of rising pollution, health-related concerns, and economic losses on the part of governments and the general population. Trash management is the collection, separation, handling, and disposal of waste in an environmentally friendly manner (Aziz., (2018)). Biological wastes can be ranged from complete, useless (rejected) materials to combinations and fractions created by biochemical, physical, thermal and chemical processing of the initial raw material. Fruit and Vegetable trimmings, as well as cereal remnants like bran and barley grain that have been extracted, as also pulps and residues left over after juice, sugar, oil and starch extraction are examples of wastes of plants. Blood, bone, and nerve tissues, as well as dairy processing wastes, are some examples of animal-derived processing wastes. Furthermore, a lot of wastewater is generated. In the manufacture of ready meals that contain material from both plants and animals, more complicated mixed wastes are frequently generated. Food processing wastes have a diversified composition as a result of the impact of various processing processes on the complicated raw materials. In the manufacture of ready meals that contain material from both plants and animals, more complicated mixed waste is frequently generated (Waldron, 2007).

Food waste must be appropriately managed to limit the quantity of waste that ends up in landfills and the environmental impact that food waste can have. Choosing the most effective waste management system might be difficult.

Different waste management techniques are used for food waste management such as slurry phase decomposition (Yun, Park, Suh, & Park, 2000), thermal treatment (Lee, Kim, Kwon, & Lee, 2020), extraction (Sagar et al., 2018) and bioremediation (Punnagaiarasi, Elango, Rajarajan, & Prakash, 2017). Among these bioremediations is most effective technique owing to low expenditure, minimal operational costs and almost no harmful environmental effects. According to the definition of bioremediation, it is the process of biologically reducing organic wastes to a safe level or to a level below the appropriate concentration limits established by the governing bodies under controlled conditions (Zouboulis, Moussas,

& Psaltou, 2019). Bioremediation is a broad term that refers to all the processes and actions that occur to bio-transform an environment that has previously been contaminated back to its natural state. Although the methods used to achieve the intended results differ, they generally follow the same principles: the use of microbes or their enzymes that are either native and enhanced by adding nutrients or optimizing conditions or those that are implanted into the soil. Implementing such techniques has a number of benefits, the most important of which is that they do not disrupt the ecosystem's ecology (Thassitou & Arvanitoyannis, 2001).

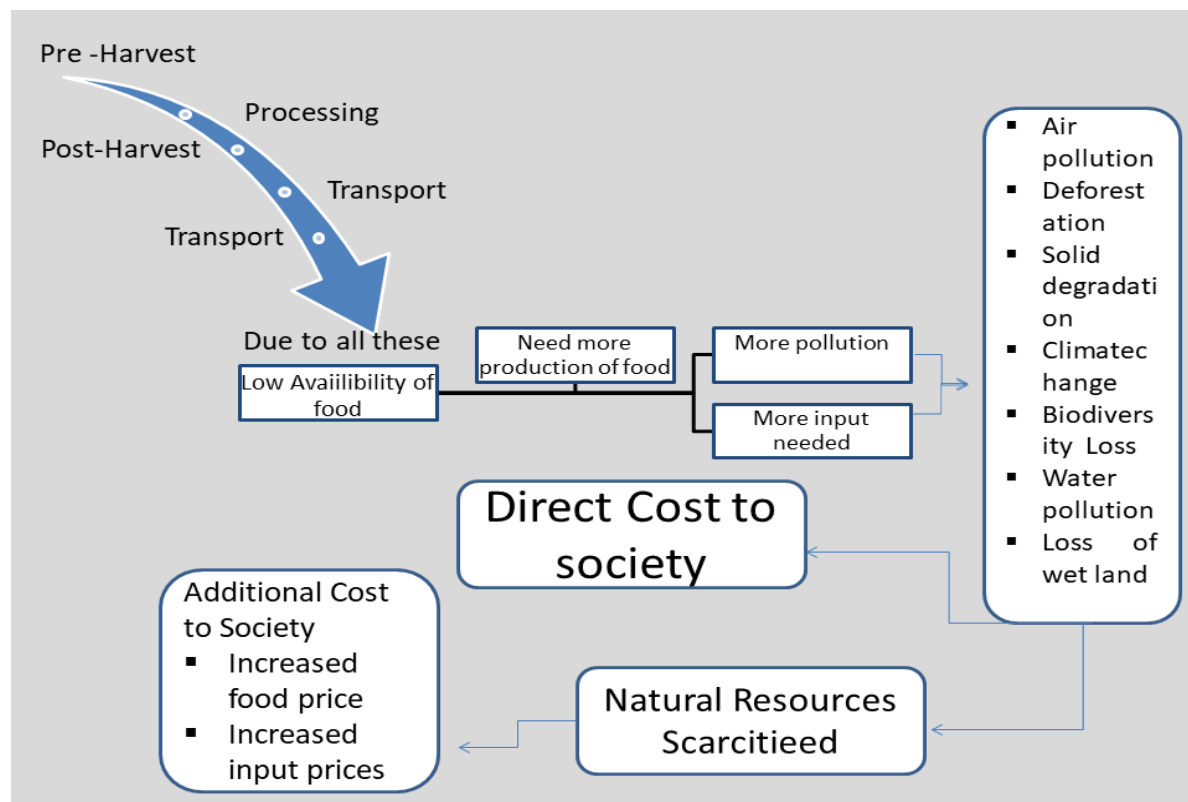
Using live organisms for waste management, decomposition or recycling is a cost-effective strategy that is frequently combined with other physical or chemical procedures. This technology can be used in a variety of materials, but it is most suited to the management of household, agricultural and municipal wastes (Aziz., (2018)). Both *in situ* and *ex-situ* bioremediation are possibilities, which means the contaminated material stays in its original place later which means the contaminating material is removed from its original place for treatment, permanent disposal or long-term storage (Fennell, Du, Liu, Häggblom, & Liu, 2011). Bioremediation approaches *ex-situ* (Raja & Kalyanasundaram, 2014) and *in-situ* (Megharaj, Ramakrishnan, Venkateswarlu, Sethunathan, & Naidu, 2011) for organic pollutants can be represented in the following Figure 1.



**Figure 1.** Bioremediation approaches

When choosing a bioremediation technique, it is important to take into account the type of pollutant, environment, level and depth of contamination, location, environmental policies, and cost. Besides of selection criteria, performance measures (temperature, nutrient concentrations, oxygen, pH, and other abiotic parameters) that influence the efficacy of the bioremediation processes are also taken into account

prior to the start of a project (Azubuiké, Chikere, & Okpokwasili, 2016). Wastage of food and its impact on food supply chain are represented in Figure 2.



**Figure 2.** Wastage of food and its impact on food supply chain

Many studies have shown how effectively bacteria may degrade such harmful organic pollutants. According to (Roets-Dlamini, Moonsamy, Lalloo, & Ramchuran, 2022), *Bacillus cereus* variants have demonstrated good bioremediation potential when used for the degradation of fats, oils, greases, and the reduction of odors.

From the work of (Warmootá et al., 2021) it was clear that *Paenibacillus* sp. AD can be used for the development of a process for the infield degradation of sea food waste.

According to (Almansoorý, Hasan, Idris, Abdullah, & Anuar, 2015), the addition of a biosurfactant produced by *Serratia marcescens* and the planting of *Ludwigia octovalvis* resulted in 93.5% of the total petroleum hydrocarbons (TPH) being removed from gasoline-contaminated soil.

## 2. Food Waste and Bioremediation

When food is deposited in landfills which may be \$172 billion in amount, that is inappropriate for human consumption and left over after meals, can have negative socioeconomic effects, nutrient leakage into aquatic bodies, greenhouse gas emissions

Food waste is frequently collected with other waste forms and has a high salt content. Food waste has a significant concentration of contaminants, which, when mixed with other substances, creates different dangerous substances and has severe effects. (Sai, Sharma, Singh, & Sayeed, 2020). Waste from foods has significant economic, environmental and social, consequences, and its significance has grown in recent

years, with the United Nations including it among the 17 Sustainable Development Goals (SDGs) in 2015 (Amicarelli & Bux, 2021).

Bioremediation was first utilized on a significant basis in 1972, when it was used to clean up a Sun Oil pipeline accident in Ambler, Pennsylvania. A range of practices known collectively as "bioremediation" use biological systems to clear away or restore contaminated environments. For bioremediation, the microbial species are consistently reported. The majority of naturally occurring bacteria may successfully restore the environment by oxidizing, changing, or immobilizing contaminants. It aims to reduce pollutant concentrations to levels that are safe, undetectable or acceptable. (i.e., within regulatory agency limits) levels (Vishwakarma, Bhattacharjee, Gohil, & Singh, 2020). Bioremediation techniques are still being used regularly and growing exponentially in popularity today. Bioremediation of polluted areas has shown to be reliable and efficient due to its ecologically beneficial features. In the past two decades, new developments in bioremediation methods have taken place with the ultimate aim of successfully repairing damaged areas in an affordable and environmentally friendly way (Sharma, 2021).

This method is based on how plants and microorganisms may perform numerous energy-dependent processes on the components of the sample present in contaminants, such as oxidation, accumulation, reduction, and precipitation. Bioremediation takes place in both aerobic and anaerobic environments, and the process takes a long time to complete. The bioavailability of pollutants is an important factor to consider that all bioremediation operators must keep in mind (Varjani, Gnansounou, Gurunathan, Pant, & Zakaria, 2018).

Now a days bioremediation is one of the best techniques for food waste management.

## **2.1 Domestic Food Waste and Bioremediation**

Domestic food waste is leftover food from meal preparation or food that is left uneaten after the meal, as well as food that is thrown away after being unused or only partially consumed rather than being given to pets, composted, or used for other beneficial uses. Around 40% of all edible food is thrown away, costing households around \$28–33 per month (Tucker & Farrelly, 2015). Purchasing far too much owing to poor planning and bad storage due to a not having understanding, throwing out edible pieces of food such as apple peels or bread crusts and discarding leftovers and portions which are of larger sizes are only a few of the key reasons for domestic food waste (Geffen, van Herpen, & Trijp, 2020).

One challenge to avoiding food waste and loss is insufficient information at the international and national levels. To address this issue, the FAO created the Food Loss Index, which estimates of the amount of food wasted during the manufacturing or supply - chain management before it reaches to retail outlet. According to the FAO, 14% of food is being lost in the supply chain before the product reaches consumer. Consumers i.e., households or/and retailers waste a significant amount of food, although little is known about this. As a result of the scarcity of data, hardly any reliable studies of the links between food waste, consumer, environmental effects, health and food security have been conducted (Lopez Barrera & Hertel, 2021). Food waste in families is influenced by a variety of factors, including habits and emotions. Taking into account emotions as non-cognitive causes of behavior and habits as relatively stable behavioral patterns, through social awareness and social values, it is essential to identify and respond in recurring bad behaviors, unsustainable and recurrent and underestimated errors waste attitudes (Amicarelli, Tricase, Spada, & Bux, 2021). Household food waste is a big challenge in developed countries, and it is primarily caused by bad food-related behavior. Because of the significance and scope of the problem, the United Nations has set a global goal of reducing food loss and waste by 2030 (Principato, Mattia, Di Leo, & Pratesi, 2021).

Despite several attempts to lower it through changing behavior, raising awareness related to food waste and encouragement using incentive and intrinsic motivation, household food waste remains largely uncontrolled. Researchers looked at a refrigerator that alerts users about expiration dates of product, sends shopping lists via SMS or email, suggests recipes, and posts messages to households. Food waste is harmful to the environment because it contributes to greenhouse gas emissions and wastes resources that would otherwise be utilized to market, produce, process, refrigerate and transport food. Despite attempts, food waste makes about 40–60% of the average consumer's annual domestic waste, contributing about 20% to landfills (Farr-Wharton, Foth, & Choi, 2014). The emphasis on in-home settings, including food purchases, is seen as essential since consumers have more authority to affect food waste reduction at the household level than they have with out-of-home food consumption. Not only policymakers, but also researchers and agri-food chain operators, need to know and comprehend the current impediments to adopting food waste prevention practices (Scalvedi & Rossi, 2021). Each person wastes an average of 180 kg per year-over 290 kg per year, with considerable differences between EU nations and significant financial and environmental consequences (Amicarelli et al., 2021).

According to estimates, more than half of the 37 percent of domestic food waste occurs as a result of food waste in Europe (Kummu et al., 2012), and in the United States, up to 60% of all food waste at 38 different stages (Griffin, Sobal, & Lyson, 2009). According to studies conducted in the UK, about 22% (330 kg for 40 households per year) of all food and drink purchased for households end up being wasted (WRAP. Banbury, 2009). Variations in amounts could also be attributable to differences in the methodologies and criteria used to estimate and define food waste.

Domestic food waste has numerous negative health and environmental consequences. When food is wasted, land, energy, water, human labor, and capital are all wasted, and the waste contributes to environmental damage and greenhouse gas emissions (Tucker & Farrelly, 2015). A huge quantity of household waste of food have a significant negative consequences on the environment, in addition to financial and social consequences. First, food waste is associated with high greenhouse gas emissions and inefficient resource usage, including crops, water, fossil fuels and fertilizers. Second, in the years ahead, an increase in global population is expected, putting more pressure on the availability of food. Reducing food waste has been seen as a means to increase the amount of food available to feed the world's increasing population (Stancu, Haugaard, & Lähteenmäki, 2016).

There are a variety of approaches for treating food waste with biological organisms. a) aerobic digestion, b) composting, c) liquefaction and d) Mechanical Biological Treatment (MBT) are a few of them. From which Anaerobic digestion (AD) is a series of processes involving the breakdown of organic matter by microbes in the absence of oxygen (Gopal, Sivaram, & Barik, 2019). Lipid wastes (e.g. fats, greases and oils), complex carbohydrate wastes (e.g. Municipal solid trash organic portion and fruits and vegetables waste (MSW), simple carbohydrate wastes (e.g. bakery waste, sugar based solutions and brewery waste ), protein waste (e.g. wastes from slaughterhouses and dairy production plants) as well as waste from industrial and commercial areas may be included in urban waste for AD ("Food Waste to Energy: How Six Water Resource Recovery Facilities are Boosting Biogas Production and the Bottom Line," 2014). One of the most important advantages of AD is that it produces renewable energy (T. Chen et al., 2017). Another method for household treatment except of AD is Composting which is a natural process that occurs because of microbial succession, which results in the degradation and stabilization of organic material in waste. The utilization of microbial additives during composting is thought to be very effective, as it increases the production of various enzymes, resulting in a faster rate of decomposition of waste (Rastogi, Nandal, & Khosla, 2020). Composting is divided into two stages: 1) microbial characterization and 2)

organic material conversion. The microbiome starts the composting process in the first stage by raising temperature through the oxidation of organic matter, biodegradable material's decomposition, and enhance the reliability of the organic residue. Protozoa, bacteria and fungus, while composting, create the microbiome, which vary depending on the C/N ratio, temperature, the composition of organic materials, moisture content, and other factors (Azim et al., 2018; Risse, 2009).

The amount of waste collected during composting decreases over time, resulting in a reliable product with an increased nutrient level, which is the consequence of microbial transformation of raw organic components. This compost which has lot of organic matter, in agriculture, due to its high inorganic and fiber component content, it is used as a natural fertilizer, and has a favorable impact on environment and soil. In comparison to raw organic materials, stable compost contains more nutrients and does not form intermediary metabolites that can obstruct plant growth (Mondal, Palit, Mondal, & Palit, 2019). One of most adopted method for bioremediation of household food waste treatment is Liquefaction. Liquefaction is a thermochemical procedure wherein biomass is subjected to complex chemical reactions in a solvent media, resulting in primarily liquid products (biooil or bio-oil) (Y. Zhang et al., 2019). To speed up the process, nutrients or microorganisms can be introduced to the material; this is known as biological liquefaction, and it is a more complicated but more successful method (Isaac Griffith-Onnen, Zak

Patten, & Wong., 2013). Mechanical Biological Treatment (MBT) is a catch-all name for a combination of mechanical processes often seen in various waste management facilities such as, composting, and anaerobic digestion plants. A MBT plant can combine a variety of different processes in a number of different ways ("Mechanical Biological Treatment of Municipal Solid Waste," 2013).

## **2.2 Food Processing Industries and Bioremediation**

The farming industry has a reputation for producing a lot of waste. According to a recent FAO research, Every year, one-third of the food produced worldwide is wasted, resulting in 1.3 billion tons of waste (Gowe, 2015). Fruit and vegetable wastes, olive oil, wastes from dairy, meat, fermentation industries, seafood by-products and poultry, as well as massive amounts of aqueous waste, are the most significant waste streams produced by the food-processing industry (Insam, Gómez-Brandón, & Ascher-Jenull, 2018).

One major untapped energy source is the food industry that is mainly disposed of in dumps, releasing greenhouse gases into the atmosphere. Because of its composition, food waste is extremely difficult to recycle and treat. The amount of waste produced is mostly governed by 2 factors: the population of a specific area and the consumption patterns of that population. Advanced and efficient waste methods of management that can bridge the management gap between waste generation and disposal must be implemented to deal with massive waste production (Punnagaiarasi, Elango, G, & Subramaniyan, 2017).

There are several reasons for the large amount of food processing waste, some of which are economical and others which are technological in nature. Traditional food preparation techniques produce very little domestic waste, which was formerly disposed of as feed, composted, or disposed of in the garbage collection system of the municipality. However, food processing in the 21st century, in particular those connected to the creation of ready-to-eat meals, has resulted in enormous, waste streams that have tended to expand in a geographically confined manner in size over time as businesses tried to capitalize on economies of scale (Waldron, 2007). Sludges, product residues, kiln dust, ashes, and slags are just a few examples of the manufacturing waste that can come from a variety of processes. Non metallurgy, metallurgy and industries for food processing include the three groups of industries that produce the most industrial waste (Arockiam JeyaSundar, Ali, Guo, & Zhang, 2020).



Waste, effluents and residues from the food sector are widely produced on a global basis. They are primarily handled as wastes of ecological concern around the world, which has detrimental effects on the ecosystem and the long-term viability of the agro-food industry (Agathos & Stenuit, 2019). Food processing residuals (FPR) are by-products of the food processing process. Fruit and vegetable peels, tofu whey, pits, cheese whey, seeds, blood, bone, sludge from wastewater treatment, process water, and so on are examples of these materials (HANG, 2004; Russ & Meyer-Pittroff, 2004). The food sector generates a huge amount of waste and wastewater, with carbs, lipids, proteins, and organic fibers accounting for the majority of the contents. There are a variety of approaches for treating food waste with biological organisms such as a) Bio electrochemical systems and b) Anaerobic digestion process.

Bio electrochemical systems (BESs) use microorganisms to biochemically accelerate the conversion of complicated materials into useful energy outputs. The catalytic reactions occur on electrodes. It could be of 2 types. Microbial fuel cells (MFCs) and microbial electrolysis cells (MECs)(Ziara, Dvorak, & Subbiah, 2018) . Another technique for treating industrial food waste is anaerobic digestion that involves microorganisms. Since 2005, KEEP has employed an anaerobic digestion technology to collect methane gas from food wastes at a low cost. An anaerobic digestion tank (2300 m<sup>3</sup>) treats organic waste collected from food manufacturing facilities. Fuel cells (250 kW) and gas engines employ methane created from food waste to generate electricity (Ike et al., 2010). Moreover, Food waste treatment method mentioned in the section 2.1 can also be used for industrial food waste treatment.

### **2.3 Organic Crop Residue and Bioremediation**

Crop leftovers are materials left behind after a crop has been harvested on farmed land. Organic Agricultural Residue is the retention of crop remains after harvesting. The term "crop residue" describes the leftover organic material, such as leaves, stalks, and roots, after harvesting. Corn stover, for example, is an organic crop residue. Other examples are, soybean straw, corn cobs, rice hulls, and wheat straw.

Phosphate (P<sub>2</sub>O<sub>5</sub>), Potash (K<sub>2</sub>O), Sulfur (S) and Nitrogen (N) are parts of crop residue if, they left over on harvesting land they cause to improve soil health and have much more benefits for example, in addition to lessen soil erosion, old crop leftover can catch as well as retain moisture content in soil, attenuate soil temperature shifts during extreme conditions and grant to soil organic matter. These benefits are too many to measure and often lose out to short term gain. Till recent studies, fossil fuels (oil and gas) fulfill approximately 54% from energy requirements, and rest of required energy is met through biomass fuel such as agricultural residues and burning of wood (Tahir, Rafique, & Alaamer, 2010). Crop residues are organic remnants that provide value to agricultural crops after they've been harvested and processed. Crop leftovers are frequently burned in the field due to a lack of understanding about their importance(Jain, Bhatia, Pathak, & Research, 2014). Burning crop residue increases greenhouse gas emissions. ( N<sub>2</sub>O,CO<sub>2</sub>, CH<sub>4</sub>), particulates, air pollutants (NH<sub>3</sub>,CO, NO<sub>x</sub>, SO<sub>2</sub>, volatile organic compounds) and smoke, creating a health threat (Singh et al., 2020). As a result, the degradation of air quality in the cities near significant agricultural industries is perhaps unsurprising. Incomplete and uncontrolled open-field burning, in particular, emits hazardous air pollutants and greenhouse gases(Kanabkaew & Kim Oanh, 2011). Farmers need to change their strategies in management of crop residues so that in economically, they at least get break-even point means net outcome should be zero. Keeping this in mind, there is still need of more advance research at regional, national and international level that explore benefits and as well cost needed to shift burned crops residue to retaining it on cultivated land (Zhao et al., 2018). Crop residue management studies have looked at the costs and advantages of keeping burned crop wastes, but they were based on field site experiments (Xia, Wang, & Yan, 2014). As the burned crops residue causes high level of air pollution, so, this issue must be resolved. This issue is now a days is resolved by more feasible and

minimum secondary pollutants known bioremediation. This technique uses biomaterials such as microbes according to target properties. These materials use crop residues in such a productive and unique way that results in increase of soil properties and health that cause to ease in cultivating machines and in results lessen fuel consumption. All this helps in reducing air pollution (Naujokienė et al., 2018; Hongxing Zhang et al., 2011).

Scientific community is considering biogas technology through microorganism. This technology gained attraction because this is responsible to fulfil demand of renewable energy as well as environmental protection. Cellulosic biomass was treated with fungi, *Aspergillus terreus* and *Trichoderma viride*, to increase its digestibility. The investigation looked at the impact of physio-chemical pretreatment on the decomposition of cellulose. Prior to fungal treatment physical and chemical treatment was done. This is efficient way to increase efficient degradation of crops residue and appreciated production of biogas and production of methane. (Ali & Sun, 2015). Further efforts are required to guarantee that recycling of both treated and untreated lignocellulosic wastes improves agriculture.

#### **2.4 Catering Waste and Bioremediation**

Catering waste refers to remaining food from catering facilities, restaurants, and kitchens. It includes cooked food includes processed food fish and mean, bakery products uncooked vegetables, vegetable and fruits peels and cooking oil that has been utilized for fish fry and cooking meat. Development of this catering industry, number of environmental problems are observed such as oil fume, highly concentration of oil wastewater, noise and food waste (Gao, Lu, Zhang, Li, & Zhang, 2019). It's a worldwide problem like that in China, untreated wastewater is directly discharged into the network of municipal water pipes in large quantities and the setting of catering wastewater discharge standards is lagging (F. Chen & Yao, 2015).

A considerable amount of vegetable and animal oils are used during cooking result in catering wastewater because these oils create a high-risk value of chemical oxygen demand (COD) and biological oxygen demand (BOD). More specific, oils from restaurants wastewater consist of a high fat concentration, oil concentration and greases concentration collectively known as FOGs. These are suspended matters that causes bad smell or foul and blockage sewage. This oily effluent not only increases the workload for the wastewater treatment facility but also impairs drain performance. Eutrophication of water is also caused oily wastewater coming as effluent from catering industry and this threatens the human and environmental health. So, restaurant waste mainly oily water is one of fundamental cause of water pollution (Huiming Zhang, Wang, Mortimer, & reviews, 2012).

Restaurant food waste (RFW) has gotten increased attention recently around the world than domestic food waste because of its production on a large scale and collection convenience. In recent years, it has also gotten more academic, government and public attention in China, owing to widespread worries over collecting and consumption practices that are unethical or perhaps illegal, which causes environmental issues and puts people's health at danger (Yang, Bao, & Xie, 2019). The amount of RFW is predicted to increase during the next 25 years as a result of demographic and economic growth, particularly in Asian countries (Seufert, 2013).

For treatment of oily wastewater, many physical methods have been established, such as precipitation and oil separation, as well as chemical approaches such as electrolysis, flocculation and desorption (Wahi et al., 2013). However, these techniques are limited to oil removal that is floating, spersing and emulsifying. Secondary pollutants, high-cost investments and a difficult process were all common features of these approaches. Oily wastewater can be treated biologically to remove dissolved oil and other organic particles,

allowing it to meet discharge standards. Microorganisms have been observed to utilize oils for energy sources and carbon during their metabolism and fatty acids and glycerol are also hydrolyzed from oils, which then turned into water and CO<sub>2</sub> (Aluyor, Obahiagbon, Ori-Jesu, & Essays, 2009). Biological approaches and bioremediation have improved in recent times, despite the fact that microbial treatment methods take a long time to decompose Fogs, and now offer efficient, cost-effective, and environmentally friendly treatment options, they are now a high priority the process of treating oily wastewater equally at home and around the world (Chanthamalee, Wongchitphimon, Luepromchai, & Pollution, 2013).

It worked so well that certain microorganisms like *Bacillus sp*, *Acinetobacter sp*, *Pseudomonas sp*, yeasts *Escherichia sp* etc for FOGs degeneration on a laboratory scale had been studied. In the initial FW, *Kazachstania*, *Pyrobaculum*, *Sulfophobococcus*, *Candida* and *Lactobacillus*, all had strong linkage to lipid metabolism ( $P < 0.05$ ). In the anaerobic fermentation (AF) system, the presence of large amounts of *Methanobacterium*, *Xeromyces*, *Aspergillus*, *Pelomonas*, *Corynebacterium*, *Faecalibacterium* and *Staphylococcus* was significantly and favorably associated with increased metabolic energy metabolism activities and metabolism of amino acid, carbohydrate, fatty acid, sulphur and nitrogen and also with glycosaminoglycan degradation. As for Anaerobic co-digestion (AcoD system), dominant genera *Methanosaeta*, *Methanobacterium*, *Fastidiosipila*, *Methanoculleus*, *Rikenellaceae* RC9 *Xeromyces* and *Bifidobacterium* had approximately deep relations to metabolism of cofactor and methane metabolism, vitamin, energy metabolism, carbohydrate metabolism and glycosaminoglycan degradation. In several large-scale FW treatment operations, these findings are probably going to boost the metabolic efficiency of functional microorganisms. (Sugimori, Utsue, & Biotechnology, 2012). Lipase Producing Microorganisms are used in biotreatment for lipids and oils. Fat and oils that discharged from the food industries, slaughterhouse, restaurants, households are also treated by these microorganisms (Bhumibhamon, Kopraserstak, Funthong, & Resources, 2002).

## 2.5 Miscellaneous Food Waste and Bioremediation

Miscellaneous food waste assigns to items that are not contemplated as electronic waste, hazardous waste, or regular waste. Although not included hazardous or electronic or regular waste, there is still needed to dispose of them with safe and proper manner.

Miscellaneous waste includes, Adhesives, photo chemicals & pools, cooking oils and grease, mortars & uncured cement, glues, epoxies, chemicals and nails polishes, fire extinguisher, carbon monoxide alarms, and smoke detectors, are waste but NOT be thrown in the recycling bin or trash. WCO (waste cooking oil) used cooking oils are those bio-based oils which have been utilized in restaurants, food-manufacturing industries, homes and at food shops for frying, cooking and other processing types. During the use of already used oil, chemical reactions will occur in it which will cause many chemical and physical changes, including thermal degradation, polymerization, oxidation and hydrolysis (Awogbemi, Kallon, Aigbodion, & Panda, 2021). This oil is waste cooking oil (WCO), and as there are several free fatty acids in WCO, which are primarily responsible for creating a terrible odor and causing metals and concrete components to corrode. More significantly, this discarded oil has been categorized as a type of municipal trash (domestic wastes and related commercial, institutional, and industrial wastes) because although it does not render as hazardous waste, but it may cause some environmental problems.

Oils and fats are major components of wastes from dairy industries, food processing plants, bakeries and beverage industries, kitchen activities etc which are discharged into sewage systems and clean water without treatment, causing significant harm to not only the environment but also to ecosystem fauna and flora. Cooking oil waste is a major source of concern for environmentalists since without being properly

handled, it is released into drains and other bodies of water (S. Kumar et al., 2012). The sewerage system is currently the most common method for disposing of used cooking oil (UCO). Large amounts of UCO are discharged into pipes and toilets every year, polluting water sources and posing major technical issues at wastewater treatment plants (S. Kumar et al., 2012). UCO accumulation within a drainage system, in particular, generates blockages that can result in sanitary sewer overflow, land flooding, and sewage contamination of water bodies (Ramos, Gomes, & Barbosa-Póvoa, 2013). Furthermore, because of its bio-uncontrollable and unmanageable nature, UCO disposal to the drainage system slows the treating wastewater process, and because of its low degradation and solubility rate in biological processes, it typically escapes conventional wastewater treatment processes intact, resulting in pollution of water and soil (Mandolesi de Araújo, de Andrade, de Souza e Silva, & Dupas, 2013). When it is disposed of in the sewerage systems, it requires the use of several extra facilities and, as a result, increases the expenses of wastewater treatment processes (Hajjari, Tabatabaei, Aghbashlo, & Ghanavati, 2017).

There are many processes, techniques, and facilities to remove, degrade or utilize these miscellaneous food waste. In these techniques, chemicals, enzymes, hormones are utilized to degrade this. Biodegradation uses microorganism to utilize miscellaneous components into useful products. For example, yeast uses WCO with glucose for lipase fermentation (Patel & Matsakas, 2019). UCO also used for production of biosurfactants using *Bacillus sp. HIP3* and this is used for heavy metals removal (Md Badrul Hisham, Ibrahim, Ramli, & Abd-Aziz, 2019). Grease, oils, and fats can be effectively treated by lipase producing microorganism. In this isolates KUL8 and KUL39 showed excellent performance (Bhumibhamon et al., 2002). Dyes in nail polishes can be treated through bioremediation. *Allium cepa* is most commonly used microorganism used for treatment of dyes used in nail polish (Nandi, Das, Singh, & Verma, 2020).

### 3. Metagenomic Screening

Although there are many bacteria in the biosphere, only around 1% can be grown using traditional laboratory techniques. By establishing an ambient DNA genomic library and carefully looking for open reading frames that might contain potential new enzymes, metagenomics has emerged as a viable alternative to traditional microbe screening (Gilbert & Dupont, 2011). The majority of metagenomic screening is done using either function or sequence techniques. Direct phenotyping, heterologous complementation, and induced gene expression are all used in function-based screening to extract genes that perform the required function (X. Wang, Li, Yang, Yang, & Zhu, 2012). Sequence-based screening, on the other hand, is carried out by using techniques related to either hybridization or polymerase chain reaction (PCR). The strategy that is used the most frequently is the use of a set of degenerated primers based on consensus amino acid sequences. Due to the present popularity of genome sequencing software, sequence databases are currently saturated with data, allowing database mining to uncover new natural products (like enzymes) (Van Lanen & Shen, 2006). Next-generation sequencing systems (such as Roche's 454 platform, Illumina's Solexa platform, or ABI's Solid platform) have the ability to reduce genome sequencing cost and time. Utilizing these platforms and also innovative technologies like resequencing, numerous entire genomes can be completed in under two weeks. The NCBI database now contains over 2,000 genomic sequences and draft assemblies. To find novel enzymes, two techniques are being used (Luo, Yu, & Xu, 2012). Finding open reading frames in a microbe's genome is a step in the genome hunting process. After that, sequences that have been annotated as candidate enzymes are cloned, over-expressed, and screened for activity. Utilizing the homology alignment of every database sequence, a different technique is data mining which is also used. A search for conserved sections between sequences using various bioinformatics

methods (e.g., BLAST) provides similar protein sequences that have been found to be potential candidates for more investigation. For starters, long reads sequencing (e.g., PacBio/Nanopore) would allow us to improve microbial consortia resolution by obtaining more high-quality genomes. Furthermore, by minimizing the noise generated by functional gene redundancy in microorganisms, met transcriptomic and metaproteomic paired with metagenomics could be useful methods for giving direct and solid evidence to ascertain the genetic functions of the recovered MAGs. Finally, a better validated and up-to-date database will help to unlock the anaerobic process's black box and reveal the microbial ecology in this designed system.

#### 4. Advantages and Limitations of Bioremediation

Whenever we want to process something at industry or laboratory level, overall expenses are calculated first. Bioremediation is preferable because expenditures are less as compared to other technologies as it conserves the resources. Absence of any secondary pollutants and harmful by products makes it environmentally friendly. Rather to transfer from one medium to other, it destroys, hydrolyzes, degenerate the contaminants. One of major advantage is that on-site treatment of huge waste can be done its means there is now no need to take off-site to huge waste for treatment. For example, in 2010, Deepwater horizon oil spill, where 3.19 million barrels of oil shed over Gulf of Mexico. Bioremediation was preferred due to cost effective and efficient technique. Injection of small amount of oil- degenerating bacteria and nutrients to stimulate their growth also shed to this area (Herrero & Stuckey, 2015).

Biodegradation and bioremediation are environmentally benign processes that result in less hazardous residue production and the release of confined nutrients during the mineralization process (Aziz & Technology, 2018). Bioremediation used to degrade waste material from kitchen, restaurants, municipals, solid waste, food, plastics, rubber, paper, leather. Waste in solid, gas and liquid form can be treated through bioremediation (Garg, 2020). The use of bacteria in soil bioremediation for oil is prevalent, with fungi being a technique with critical mass and high growth potential. Recent advances in oil bioremediation of soils include the use of both fungi and bacteria as bioremediation agents in the same procedure, which makes the process more resilient to changes in the environment (Quintella, Mata, & Lima, 2019). Heavy metal bioremediation relies heavily on microorganisms. Genetic engineering can be used to create genetically modified organisms that are expected to minimize various types of polycyclic hydrocarbons (PAHs). *Aspergillus niger*, *Stereum hirsutum*, *Pseudomonas*, *Arthrobacter*, *Rhizopus arrhizu* *Methosinus*, *Mycobacterium*, *Nocardia*, *Methanogens*, *applantus*, *Azotobacter*, *Alcaligenes*, *Flavobacterium*, *Corynebacterium*, *Rhodococcus*, *Pleurotus ostreatus*, are some microbial species that help in bioremediation of heavy metals (Quintella et al., 2019).

Only biodegradable pollutants can be treated using bioremediation. For microbial activity we need to pay special attention towards pH, temperature etc. Bioremediation is Tedious process. It takes much time as compared to other treatment process. In Bioremediation we cannot say that remediation is completed. It's a continuous and uncontrolled process. Because of this, bioremediation evaluation is complex, and the process has no endpoint. Biological processes are specific. They need suitable environment for growth, enough nutrients, optimum pH and temperature and specific type of contaminants. Some process in bioremediation takes longer time than other techniques such as removal of soil and incineration. Regulatory confusion still exists about acceptable performance standards for bioremediation. A challenge in evaluating bioremediation efficacy is the lack of a broadly accepted definition of "clean," as well as the lack of suitable endpoints for bioremediation treatments (Kensa, 2011).

#### 5. Conclusion

Waste from household, catering industry, crops residue, food industry is the major issue from past few years. Hence, there proper treatment and remediation was needed that must be cost effective and environmentally friendly. The development of technologies that reduce environmental problems has received less attention and interest. Enhancing the degradation process as one of its modes of action, bioremediation is one of the most effective practical methods for treating food waste. A final breakthrough in waste management research studies could result from a better knowledge of the interactions between microbial communities and food waste and how microorganisms behave when exposed to specific levels of contaminants. Though the bioremediation is a complete package of detoxify or degrade pollutants, but it has some disadvantage of time consuming, its continuity and its uncontrollable process and the prediction of 100% clean process is also not possible. . Managing food waste is one of the biggest concern as the conventional method are time consuming and highly cost. Hence, more researches need to be done to explore the potential of bioremediation in reducing and eliminating highly toxic contaminants in aquaculture sludge like food waste management for a better future ahead.

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