Chapter

Introductory Chapter: Biodegradation – New Insights

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1. Introduction

Microbial breakdown of any matter or compound is called biodegradation, which is carried out by bacteria, fungi, or yeasts [1]. Though it is a natural process but it is somewhat different than a composting process. Composting is a human-interfered systematic and safe process where organic matter is a breakdown within a specific time, whereas biodegradability is the conversion where it is not necessary that it will be beneficial always [2]. All natural organic matters and chemical compounds are biodegradable provided with time as a major constraint. Organic materials, including food wastes and vegetables, are degraded in few days; however, the plastic degradation may take several years.

Biodegradation occurs in three stages of biodeterioration, biofragmentation, and bioassimilation [3]. Biodeterioration is the superficial but surface-level degradation *via* alteration of all physical, chemical, and mechanical properties of the material. This process is generally occurred abiotically where environmental factors, including light, temperature, chemical exposure, and mechanical compressions, weakening or deteriorate the material. Thus, biodeterioration is the first stage of biodegradation and is in parallel to the microbial action for the fragmentation of the material. Biofragmentation is a very crucial and important stage where high-molecular-weight molecules or polymeric structures are disturbed by either bond cleavage by enzymatic action or chemical modification. Resultant into a generation of oligomeric or monomeric fragments. This biofragmentation is an oxidation-reduction process and energy intensive. The biofragmentation process that occurs in the presence of oxygen is called aerobic degradation, and if it occurs in the absence of oxygen, then it is called anaerobic degradation. Comparatively, each process generates water and CO_2; however, methane and hydrogen are strictly produced by anaerobic process only. Aerobic digestion is a rapid process, but anaerobic digestion is more efficient in terms of mass reduction by producing natural gas. Hence, the anaerobic process is most widely used in waste management and for renewable energy generation. Bioassimilation is the last stage of biodegradation where microbes utilize the bio-fragmented material for their metabolic activities either for energy generation (adenosine triphosphate, ATP) or as precursors of any other biosynthetic pathways.

Factors affecting material biodegradation are water, light, oxygen, and temperature. For biodegradation of any organic compound, it is necessary to make that compound available for microbial action where the compound is absorbed by the system. Biodegradability of solid and liquid is also differing where CO_2 and methane gas are produced during aerobic and anaerobic digestion processes, respectively. Factorial studies in the lab must have their working feasibility in the field and hence sometimes lab results are not workable in a large scale. Considering the biodegradation of landfilled solid waste, where physical factors of water, light, and microbial activities are varies and are directly affecting the biodegradability efficiencies. And plastic degradation which is environmentally dependent is altogether very different and completely unpredictable. It is also important to find out the methods of degradability and one such method is DINV 54900 [4]. Bioremediation is another form of biodegradability where toxic chemicals are converted into simpler form and the best examples are the textile dyes. Our earlier studies showed decolorization of textile dyes using microbial cultures and contributed to environmental protection by remediating the textile dyed effluent [5, 6].

2. Biodegradability

Biodegradability of any compound is measured by the respirometer method which measured the gas (CO_2), which is a metabolic product from microbes, especially

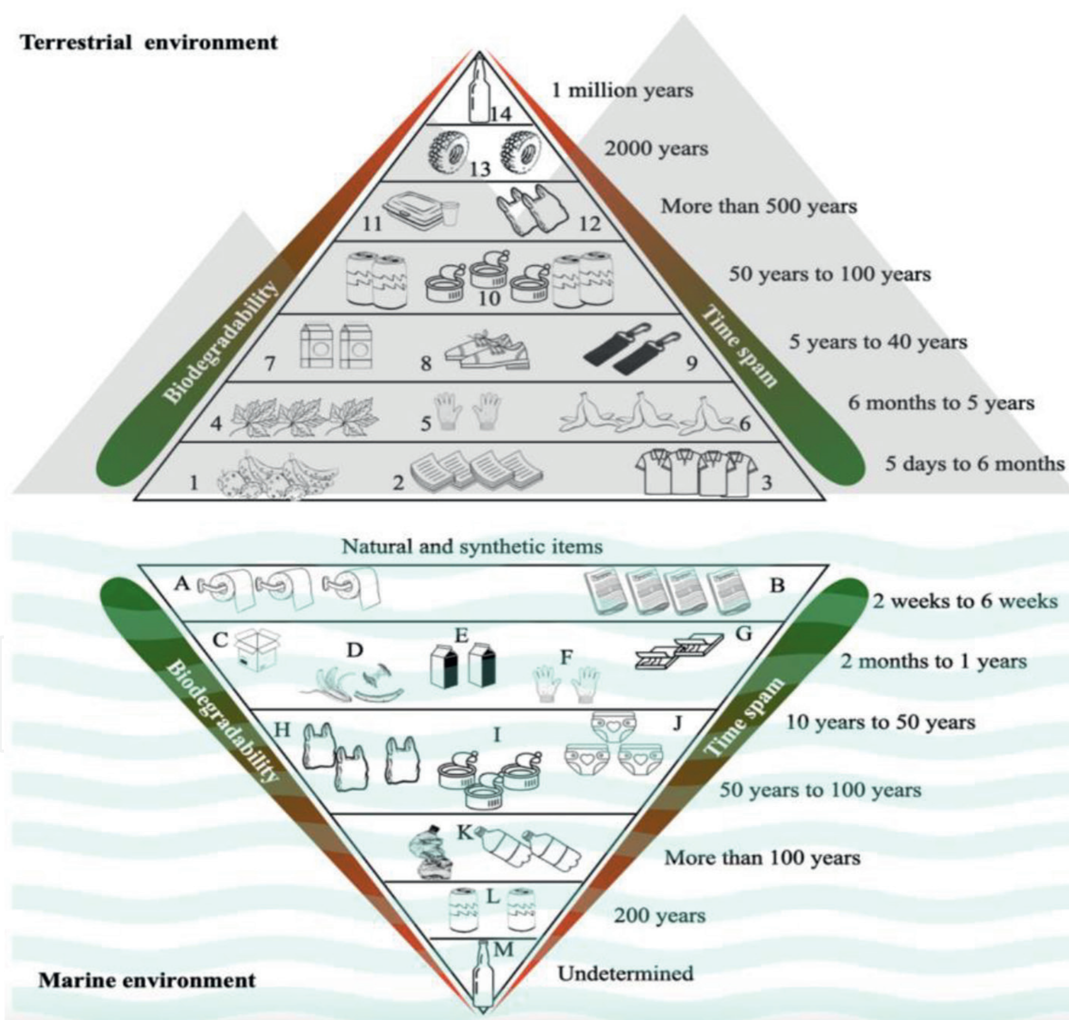

Figure 1.
Timely biodegradability of representative natural and synthetic items in terrestrial environment [9] and marine environment [10] (1, food and vegetables; 2, cellulose and paper; 3, cotton cloths; 4, plant leaves; 5, wool products; 6, fruit peels; 7, plastic coated food boxes; leather products; 9, nylon products; 10, tin and aluminum cans; 11, Styrofoam products; 12, plastic bags and items; 13, vehicle tires; 14, glass items; A, tissue paper (toilet); B, daily newspaper; C, cardboard; D, fruit wastage; E, wax coated milk carton; F, cotton & woolen gloves; G, plywood; H, plastic bags; I, tin cans; J, diapers; K, plastic bottles; L, aluminum cans; M, glass items).

aerobic microbes [7]. The present article is discussing the time-wise trend of biodegradability of some representative natural and synthetic items under terrestrial and marine environment. Biodegradability is depending on light, water, temperature, oxygen, and of course microbes, which is widely distributed and differentiated on the terrestrial and marine environment [8]. Hence, the degradability period would be differently affected. **Figure 1** is showing an integration of biodegradability trends in both terrestrial and marine environment and looks like marine environment showed more efficient biodegradability. That might be due to a lot of shear and stress conditions as well as climatic conditions of availability of light, oxygen tides frequencies, and diversified microflora. Though terrestrial environment has some limitations of light availability in case of heap or land filing but each environment has its advantages and limitations. Biodegradation occurs through various processes such as biotransformation of toxic to nontoxic compounds [11], volume reduction *via* biodeterioration by microbial and enzymatic action, formation of minerals *via* biomineralization [12], convert waste to another usable or high-value form *via* recycling or valorization [13]. Thus, all forms of material will have biodegradability but it is time-dependent. Some might take few weeks to several years. Organic materials like plant-based fruits, vegetables, and lignocellulosic materials can be easily degraded and are based on their structure and crystallinity [14]. There are some semi-synthetic and metallic materials that took almost 100 years for degradation; however, the toughest and harder to degrade in both terrestrial and marine environment are plastic, rubber, and glass materials [15]. As long as rubber is a natural material, it is biodegradable but once it is converted into a crosslinked tire (as composite), then it takes more than 2000 years to degrade it [16]. Glass is a natural and very toughest material where no biodegradability is predicted. But the most alarming and dangerous is the plastic which is 100% synthetic.

3. Challenges and opportunities

High biodegradability of products is always prioritized but products with no or low biodegradability are interfering in agriculture, human, animal health, and aquatic life. Especially, plastic biodegradability is a major concern. Domestic and wildlife animals accidentally eat the plastic as food items and showed entanglement in the intestine [17]. Polyhalogenated compounds, pesticides, dyes, hydrocarbons are slowly degrading and also interfere in the animal food chain. Indirectly, these chemicals showed very slow but bad impacts on human health by biomagnification and bioaccumulation process of food which ended in serious health complications such as cancer, neurological disorder, and hormonal dysfunction [18]. Mercury is one of the known contaminants and some fish with high mercury affected the human hormonal problem when entered in the human food chain [19]. Overall, nonbiodegradable items are real challenges for researchers and scientists. Many researchers have initiated biodegradation research on plastic [20–23]. These findings showed various bacterial and fungal strains for plastic biodegradation by enzymatic as well as photodegradation and thermo-oxidative activities. Polyethylene (PET) is one of the widely spread and a major contaminating plastic present everywhere but with research efforts, its degradation has been identified by *Ideonella sakaiensis* with an enzyme PETase [24]. With the advancement and use of genetic engineering, the PETase has been modified with MHETase for fast degradation of PET as well as polyethylene furan-2,5 dicarxylate (PEF) [24]. Adaptability of microbial strains might be altering their metabolic pathways and thus resulting into the findings of plastic degrading enzyme secretions which is also evidenced by Quartinello et al. [25] from cow gut microbes for breakdown of three different types of plastic. Though research is in the direction of positive output but more efforts and multilevel research methodologies need to be utilized for innovation-based findings related to novel strains, biocatalyst, or genetic modification. One more challenge of formation of microplastic and nanoplastic which is ended in the marine environment and acts as major contaminants affecting the marine flora [26].

Another opportunity for development of biodegradable alternatives but the major limitations are the enough tensile and mechanical strength. With a wider scope, cellulose, starch, chitin, based materials, and some polymers such as polyhydroxyalkanoates, polyhydroxybutyrate, polylactic acid, and polycaprolactone are some of the highly biodegradable polymeric materials obtained from plants and microbes [27]. Again, these microbial and plant-based polymers have some limitations in stability, mouldability, and consistency. Hence, an opportunity for a composite technology for novel material of desirable properties as well as biodegradability is open. A technology related to biodegradability of material needs to be developed for packaging, production, and medicine using some oxo-biodegradable formulations. Sometimes, the biodegradability of material generates greenhouse gases and has an opportunity to valorize this polymer to another but more useful and nontoxic precursor. Overall, there are several opportunities to develop cutting edge research on existing plastic like tough material degradation or investigate a new microbial strain or modification in existing strain for more efficient and 100% biodegradable materials having affordable economic and industrial feasibilities.

4. Conclusions

Biodegradability "deals with the waste management concept where proper disposal and reduction in volume" is required with the use of completely biodegradable products or the need to develop a robust biocatalyst from a microbial system.

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Conflict of interest

All authors have no conflict of interest.

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