Microbes in waste decomposition

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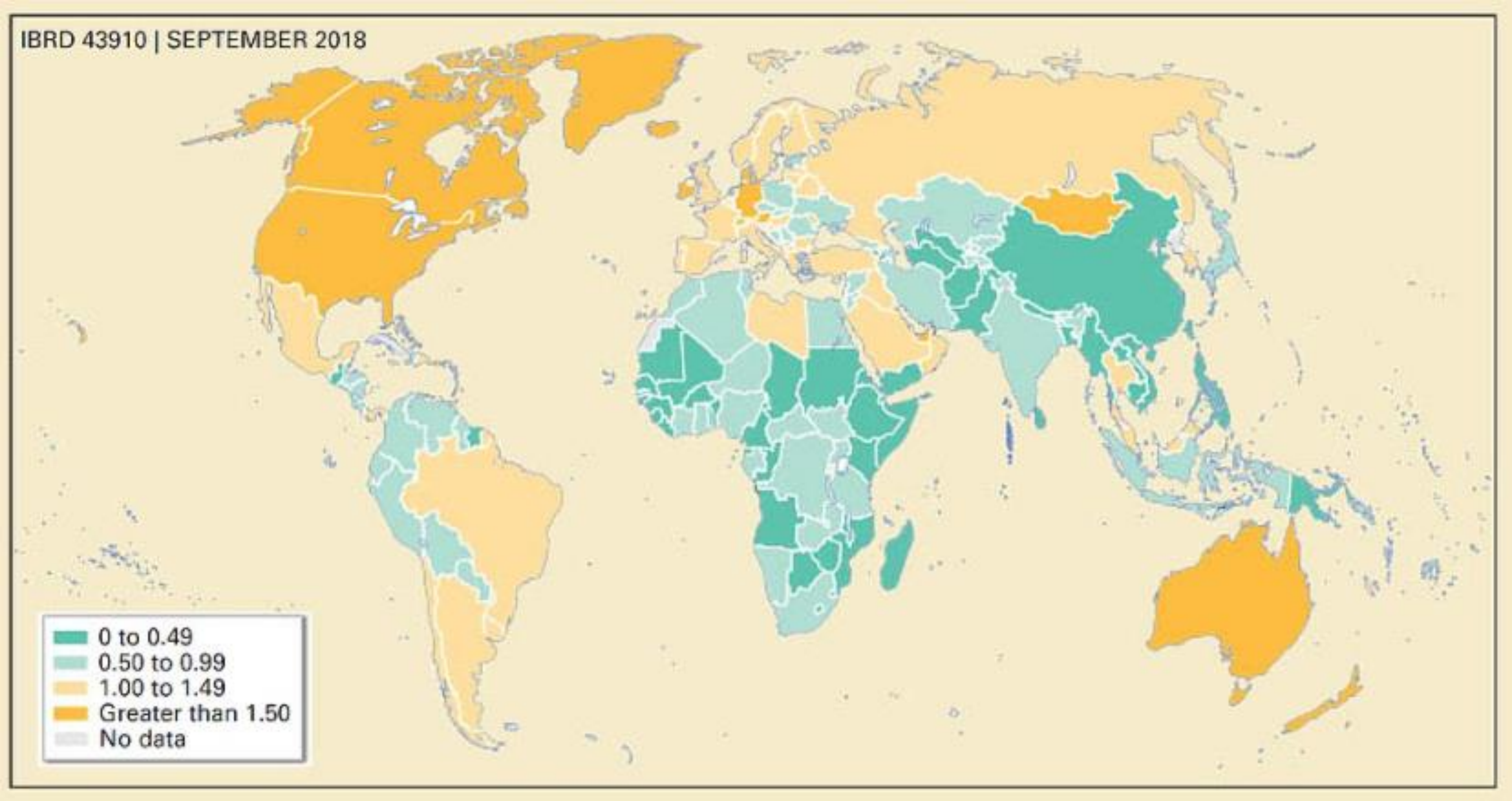
Waste

UNEP: Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal of 1989, Art. 2(1):

“Wastes' are substance or objects, which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law”.

United Nations Statistics Division: The UNSD *Glossary of Environment Statistics*:

"Materials that are not prime products (that is, products produced for the market) for which the generator has no further use in terms of his/her own purposes of production, transformation or consumption, and of which he/she wants to dispose”.



Per capita waste generation (in Kg)

Types of Wastes

- Industrial Waste
- Commercial Waste
- Domestic Waste
- Agricultural Waste
- Biomedical waste

Biodegradable waste

Non-biodegradable waste

Recycling of Waste:

New useful products

Recycling helps in controlling air, water, and soil pollution

Uses less energy

Conserving natural resources and helps in conserving energy

A number of items can be recycled like paper, plastic, glass, etc.

Waste treatment technologies

- Incineration
- Landfill
- Recycling

Specific to organic waste:

- Anaerobic digestion
- Composting (Windrow composting)
- Bioconversion of biomass to mixed alcohol fuels
- In-vessel composting
- Land farming
- Sewage treatment
- Tunnel composting

Alternative waste treatment technologies:

- Biodrying
- Gasification (Plasma gasification)
- Hydrothermal carbonization
- Hydrothermal liquefaction
- Mechanical biological treatment (sorting into selected fractions)
- Mechanical heat treatment
- Molten salt oxidation
- Pyrolysis
- UASB (applied to solid wastes) (Up flow anaerobic sludge blanket technology)
- Waste autoclave

Waste Management Strategies

Solid waste generally includes

Degradable (paper, food waste, straw and yard waste), **50 -60%**

Partially degradable (wood, and sludge)
Non-degradable materials (leather, plastics, metals, glass, electronics)

Degradable wastes constitute

The major fraction in developing countries,
Typically characterized by high water content (>60%)

Requires greater operating cost and lesser chances of material recovery

68.8 million tonnes per year of MSW generated per day in urban India.

Only **24%** of this waste is processed, treated and disposed off by suitable methods.

Waste disposal in India: **open dumping, landfilling, composting and incineration.**

Open disposal being the cheapest and most common method currently practiced.

Biodegradation or Composting

- **Anaerobic, biochemical and microbial process that implicates the hydrolysis of organic fraction into stable and sanitized residue; humus** (Wei et al., 2017).

- The most preferred, eco-friendly and economically viable waste treatment technology when managed effectively.

- Microbes carry out the decomposition of organic matter by utilizing carbon and nitrogen as the energy sources along with oxygen and water; end-products being water, CO_2, heat, and soil-enriching compost.

- **Compost** possesses a significant concentration of biologically stable **humic** substances, acting as excellent soil amendants.

Process of composting has three phases

1. **Mesophilic phase**: Initial phase. **Degradation** of **simple compounds** like sugars, amino acids, etc. is carried out by **mesophilic bacteria** and **fungi** rapidly **elevating the temperature**.

2. **Thermophilic phase**: Thermophilic microbes degrade the **organic matter** (fats, cellulose, hemicellulose and lignin). During this phase, **organic carbon content is decreased**.

3. **Cooling phase**: **Subsided microbial activity** and **decreased temperature**. Compost mass is recolonized by mesophilic micro-organisms that degrade the residual sugars, cellulose and hemicellulose, materializing humic-like substances (Albrecht et al., 2010).

This is followed by a **declined rate of organic matter degradation** and an **increased rate of humification** and **polymerization of the organic compounds**.

Role of microbes/microbial dynamics during composting process

- **Succession of microorganism's** is the key for an effective composting. Appearances of certain microorganisms influence the rate of biodegradation and compost maturity.

- **Variations in microbiome** depend on **composition** of the raw materials and **nutrient supplements**, **environmental conditions** and **interactions** among these factors.

- **Bacteria and fungi**: most abundant and fastest emerging microorganisms during composting.

- Release various substrate based **hydrolytic enzymes** that break the complex molecules, forming water-soluble compounds.

- Also produce **simple usable compounds** that enhance the agricultural possibilities and stabilize the natural ecosystem when added to soil.

Major portions of the MSW (organic portion) is plant biomass

- Processed collectively by the synergy of **cellulase enzymes**.
- Only a few microbial strains capable to secrete cellulase enzyme.
- **Few** known potent cellulose producing bacteria include: ***Cellulomonas, Pseudomonas, Bacillus* spp. and *Thermoactionmycetes***.
- **Fungal species** include ***Aspergillus, Trichoderma, Sclerotium*** and **white-rot fungi**, produce **extracellular enzymes** accountable for cellulose and lignin degradation during composting.

Solid waste as compost feedstocks

Compost feedstock	EM Description	Impact on the overall composting process
Municipal solid waste	**Cellulolytic microbes (*Phanerochaete chrysos-porium* and *Trichoderma reesei*),**	**Rapid composting as indicated by the reduction in C/N ratio**
	Psychrotrophic bacteria *Aspergillus Niger*	Temperature, moisture content, pH, electrical conductivity, C/N, ammonium nitrogen, and nitrate nitrogen indicated that the compost had reached maturity and enhanced the stability of the microbial community structure
	Trichoderma viride, Aspergillus niger and *Aspergillus flavus*	Temperature, pH, TOC, C/N ratio and germination index, high degradation of organic matter and early maturity
Food waste	**Thermo-tolerant lipolytic actinomycete, *Thermoactinomyces vulgaris***	**TOC, C/N ratio, and decreased enzymatic activities (dehydrogenase, polyphenol oxidase, urease); Increased pH, TN content and germination rate**
	Mesophilic yeast *Pichia kudriavzevii*	**Promotes the degradation of organic matter and accelerating the composting process**

Compost feedstock	EM Description	Impact on the overall composting process
Common organic wastes (vegetable & fruit wastes, leaves, news-paper, etc.)	***Bacillus subtilis* and *Pseudomonas, Streptomyces*** sp. and ***Micromonospora*** sp Cellulolytic thermophilic actinomycetes White-rot fungi (*Phanerochaete chrysosporium, Trametes versicolor* and *Fomes fomentarius*)	**Reduction in C/N ratio, NH_4 and NO_3 ion concentrations and increased compost maturity** Increased content of humic substances and alleviated CO_2 emission during composting. Accelerated degradation of solid waste as indicated by changes in C/N, EC and pH. Higher degrading ratio and a better degree of maturity, and increased enzymatic activities (especially dehydrogenase and protease)
Food waste	**Yeast strain *Pichia kudriavzevii*** Lactic acid bacterium *Pediococcus acidilactici, Bacillus thermoamylovorans*, Mixed Bacillus species (such as *B. brevis, B. coagulans* and *B. licheniformis*	**Increase in pH, temp. & accelerated composting process**
Agricultural waste composting	**Cellulolytic and deodorising bacteria *P. Chrysosporium***	**Increasing pile temp, enhancing the substrate utilizability, and change in some physicochemical factors.**

Factors affecting microbial degradation

a) **C/N ratio**: C/N varies with the progress of the composting process and determines the rate of organic degradation i.e., carbon transformed to CO_2. **25 -30 range is ideal** (30 parts of C per unit part of N at start). Higher values slow down degradation due to excess accumulation of nutrients. A lower value produces ammonia through volatilization or leaching and releases undesirable compounds unfavourable for plant growth.

b) **pH**: **5.5 to 8.0** ideal. Decreased pH results volatilization (ammonia) and microbial nitrification producing larger amount of CO_2 and acids.

c) **Moisture content**: Affects microbial activity, oxygen uptake rate, temperature and the porosity level. **50–60% (v/w)** moisture content is effective depending on composition of the raw material.

d) **Aeration/O_2 supply**: **15 – 20% ideal**. Controls micro-biological processes, microbial dynamics, temperature control, moisture optimization and removal of excessive carbon dioxide.

e) **Temperature:** Stimulates growth and metabolic activity of microbial community within compost mass. **50 - 55 ^{0}C** favours waste decomposition and ensure maximal sanitization during composting.

f) **Particle size**: Ensures the porosity level, suitable aeration and regulate the gas/water exchange. Appropriate particle size and shape by **shredding and chipping** of the waste into smaller pieces to ensure more surface area for better microbial activity.

g) **Bulking agents:** Wood chips, sawdust, rice husk and corn-stalks are common bulking supplements that demonstrated an efficient composting of waste.

Microbial Degradation of Plastic Wastes

- Synthetic plastics have become fundamental to almost every aspect of our lives.
- Global yield of plastics reached **348 million tons in 2018** (Plastics Europe, 2018). China (29.4%) and the European Union (18.5%) rank 1st & 2nd in plastic use in the world.
- Up to **26 billion tons** of plastic wastes will be generated by **2050** and more than half will be thrown away into landfills and finally enter **ecospheres**.
- As a result, plastic wastes have become a malevolent symbol of our wasteful society.

ypes and properties of generally used synthetic plastics

Plastics	Abbreviation	Melting temp. °C	Recycling code
High-density polyethylene	HDPE	200–300	02 HDPE
Low-density polyethylene	LDPE	160–260	04 LDPE
Polystyrene	PS	240	06 PS
Polypropylene	PP	130	05 PP
Polyvinyl chloride	PVC	100–260	03 PVC
Polyethylene terephthalate	PET	260	01 PET
Polyester polyurethane	Polyester PUR	8–20 (soft)	07 OTHER
Polyether polyurethane	Polyether PUR	95 (soft) – 100 (hard)	

Current methods for disposing of plastic wastes mainly include landfilling (79%), incineration (12%), and mechanical and chemical recycling (9%).

- **Several microorganisms and enzymes are capable of degrading synthetic plastics.**

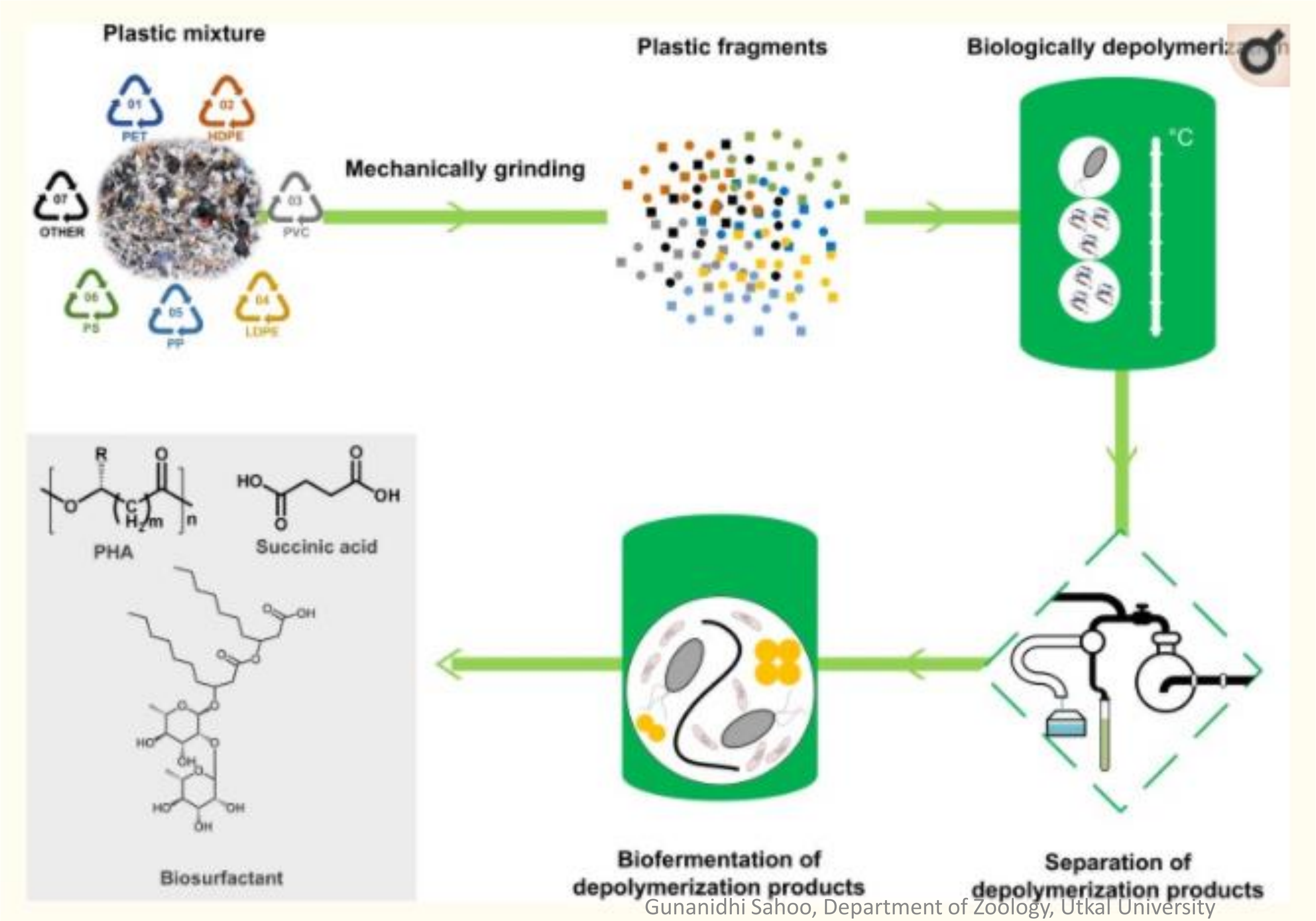
- **Physicochemical pretreatments like:**
  - **UV irradiation**
  - **Chemical oxidizing agents**
  - **Thermo-oxidation**

Macromolecular aggregate structures of plastics, such as the crystalline structures and cross-linking networks, impede their enzymatic degradation.

could facilitate the microbial degradation of long-chain PE since these pretreatments led to the depolymerization of long-chain PE as well as the formation of low molecular weight products.

A number of microorganisms capable of degrading plastics have been isolated from the **open environment**, such as the **soil of a plastic-dumping site, waste of mulch films, marine water, soil contaminated by crude oil, sewage sludge, landfills**, and the **guts of plastic-eating worms**.

Microbial Degradation of Plastic Wastes



The basic conception of bio-upcycling plastic wastes.

Mechanical grinding and biologically depolymerisation of a mixture of plastic wastes by **plastic-degrading microorganisms** and **enzymes**. Separation of depolymerized products from the culture and utilization as feedstocks for microbial fermentation to produce high value chemicals like poly-hydroxylalkanoate (PHA), succinic acid, and biosurfactant.

Strain/Enzyme	Isolated source	Tested PE	Incubation time, day
Rhodococcus ruber C208	Soil of disposal site	LDPE film	30
Bacillus sphericus Alt *Bacillus cereus* BF20	Marine water	LDPE film	180
Arthrobacter sp. GMB5 *Pseudomonas sp.* GMB7	Plastic waste dumpsites	HDPE film	30
Bacillus subtilis H1584	Marine water	LDPE film	30
Pseudomonas sp. E4	Soil	LMWPE	80
Pseudomonas sp. AKS2	Waste dumping soil	LDPE film	45
Enterobacter asburiae YT1 *Bacillus sp.* YP1	Gut of waxworm	LDPE film	60
Serratia marcescens	Ground soil	LLDPE film	70
Manganese peoxidase	*Phanerochaete chrysosporium*	PE film	12
Soybean peroxidase	Soybean	HDPE film	2 h
Laccase	*Rhodococcus ruber* C208	LDPE film	30
alkB gene	*Pseudomonas* sp. E4	LMWPE sheet	80
alkB1, alkB2 gene	*Pseudomonas aeruginosa* E7	LMWPE film	50

Bacteria, fungi, and enzymes associated with polyethylene (PE) biodegradation

Conclusion

- A number of **plastic-degrading microorganisms** and enzymes have been sourced from the environment.

- However, an understanding of **depolymerases** contributing to the breakdown of plastics remains scarce.

- Identifying **more depolymerases** from the plastic-degrading microorganisms should be the future goal.

- Enhancing the **efficiency of enzymatic degradation** is a big challenge.

- The small depolymerization products would be incorporated into cells as the **feedstocks for metabolism**.

- It will be fascinating to apply **synthetic biology** to build **microbial cell factories** that could depolymerize plastic wastes and utilize the small depolymerization products to produce chemicals with high value.