IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)
e-ISSN: 2319-2402,p- ISSN: 2319-2399.Volume 15, Issue 7 Ser. II (July 2021), PP 40-53
www.iosrjournals.org

Applications and Effective Production of Bioplastics From Food Waste

Syed Salma and Priya R Iyer
PG & Research Department of Biotechnology,
Women`s Christian College, Chennai-600006.
(An Autonomous Institution Affiliated to the University of Madras)

Date of Submission: 10-07-2021 Date of Acceptance: 26-07-2021

I. Introduction

Plastic pollution, regarded a major environmental issue demands great attention as it leads to other hazardous pollutions due to its long term of degradation process of plastics and release of toxic substances into the environment during the degradation process. The International union for conservation of nature (IUCN) has estimated that around 300 million tons of plastic waste is produced in a year which is disposed into the environment (1).Plastics have favourable properties like high tensile strength, malleability and economically cheap, hence are widely used for various applications in manufacturing of majority of products from household products to industrial products. But these are not eco-friendly having high carbon footprint (Samer et al., 2019). Due to surplus use of plastics, it gets accumulated in the environment. It has been reported that most of plastic waste that is produced is from the use of the food packaging products and single use plastics. Zalasiewicz et al., 2016 in their study have reported various methods for the removal of the plastics waste such as deep burial, recycling and burning(Dhawan et al., 2019), but when continuously buried for a long duration of time degradation leads to adverse effects on the living organisms and wildlife of that region, and also greatly affects the aesthetic value. Similarly, Alabi et al., 2019 in their study have anticipated that deleterious pollutants such as the persistent organic compounds are released into the environment due to the burning of the plastics. Besides, some literature has focused on finding innovative technology to remediate the pollutants and high organic compounds containing wastewater. These recycling process also demands high costs and energy values (Chen et al., 2019).

1.1 BIOPLASTICS

According to the European Bioplastics organization, bioplastics can be defined as plastics obtained from renewable resources (bio-based) that are rich in the contents of the carbohydrates, proteins and lignin or as plastics which are biodegradable and/or compostable. (Molenveld, 2010).

Bioplastics are alternative for the plastics derived from the conventional source of petroleumthat increase hazards of the plastic pollution.The biodegradability depends on various factors such as plant biomass used, and certain environmental conditions(Rajendran et al., 2012). They contribute to sustainability as conserve fossil fuel resources, and support plant growth if disposed of properly(2).

The advantages of bioplastics arereduces carbon dioxide production and amount of waste sent to landfillsdecreasing associated environmental problems (Barnett, 2011). It can be mass-produced into the marketable products(Boonniteewanich et al., 2014).

1.2 RAW MATERIAL FOR BIOPLASTICS PRODUCTION

Food waste generated totals around 1.3 billion tonnes per year globally(Gustavsson et al., 2011).Presently, these wastes are disposed of in the environment, causing pollution issues. This waste can be utilised in the production of bioplastics in the large commercial and industrial scale(Amini et al., 2020).

The agro-industrial wasteavailable in large amounts includes citrus skin and pulp (orange, grapefruit, mandarin/tangerine, lemon, lime), seed waste (mango, grape, pumpkin), skin (potato and banana), peanut husk, jackfruit, coffee, sugar bagasse,and straw. These wastes possess high contents of organic matter - protein, and carbohydrates suitable for bioplastics production(Calabrò& Grosso, 2018).

Apart from the food and agro wastes, many of the microorganisms play a vital role in the increased production of the bioplastics which are *Bacillus sp., Pseudomonas sp., Aeromonashydrophila, Rhodopseudomonaspalustris, Burkholderiasacchari, and Halomonasboliviensis*.

The purpose of this review study is focused on the utilization of inexpensive sources of raw materials and use of various microorganisms by innovative production methods for the production of bioplastics.

II. Types Of Bioplastics

The biodegradable polymer are placed under two categories:
(i) The agro based polymers (polysaccharides, proteins).
(ii) The bio polyesters (biodegradable polyesters) that includes the poly lactic acid (PLA), Polyhydroxylalkanoates (PHA),Polyhydroxylbutyrate(PHB) and Polyglycolic acid (PGA) .

2.1CELLULOSE

Cellulose-based bioplastics are produced from wood pulp and crops such as potatoes or maize (Reddy et al., 2013)are employed to make film-based products such as wrappers. Pure starchabsorbs humidity, so plasticizers like sorbitol and glycerine are added for more flexibility and widely used for the production of drug capsules in the pharmaceutical industry.

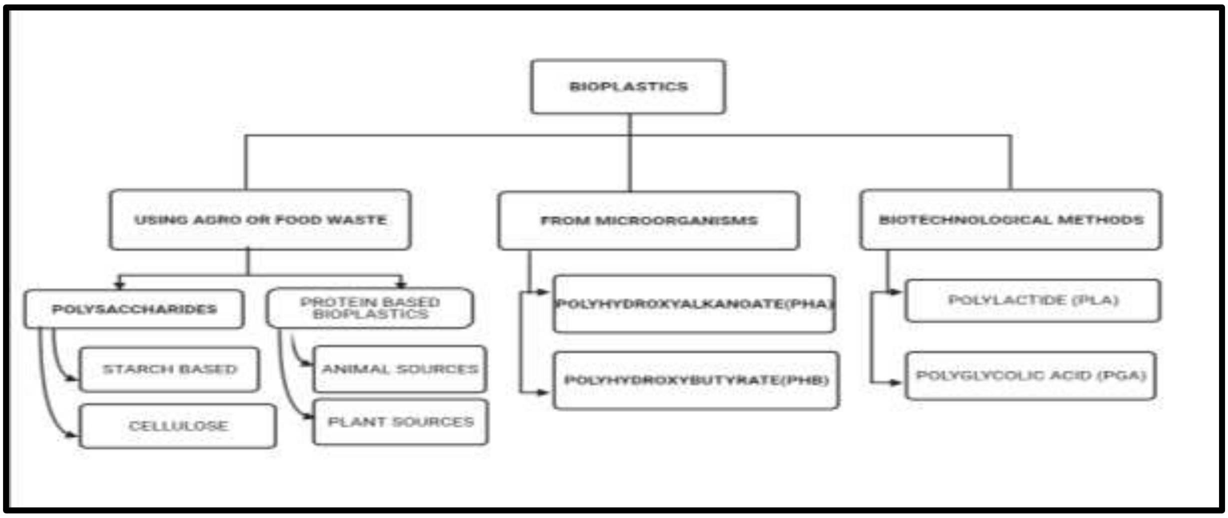


FIGURE 1: TYPES OF THE BIODEGRADABLE POLYMERS

2.2POLYLACTIC ACID

Polylactide (PLA), transparent plastic having similar properties like polyethylene and polypropylene, produced from the fermentation of starch from crops like starch or sugarcane, into lactic acid then polymerized. Its blends are used in computer and mobile phone casings, foil, biodegradable medical implants, moulds, tins, cups, bottles and other packaging material (Goldstein & Block, 2000).

2.3POLYHYDROXYALKANOATE (PHA)

PHA,biodegradable thermoplastic polymers, produced by a wide range of microorganisms through conversion of natural sugars and oils in fermentation methods. Accumulated PHA is extracted the from microorganisms which is harvested by using solvents such as chloroform, methylene chloride or propylene chloride (Cyras et al., 2009). It is processed into a number of materials including molded goods, fibre and film with water resistant coatings(Ratto et al., 1999). They possess good chemical and physical properties(Singh, 2011).

2.4 POLYHYDROXYBUTYRATE (PHB)

PHB is a transparent film similar to polypropylene, in which more research to expand production capacity is done by the South American sugar industryon an industrial scale (Innocenti, 2003).
In biodegradable packaging (Peelman et al., 2013), it is used to encapsulate bioactive compounds such as antioxidants, vitamins, proteins, and lipids (De Morais et al., 2016). In the medical field, PHB used in micro and nano encapsulation of drugs and bio-compounds withimproved absorption properties to protect compounds from interacting with the external environment.The biocompatibility of PHB with cells and tissues arises from its monomer, D-3-hydroxybutyrate, which is a natural constituent of human blood(Bucci et al., 2007)(Lins et al., 2016).

2.5POLYGLYCOLIC ACID (PGA)

PGA,biodegradable aliphatic polyester synthesized from glycolide by ring-opening polymerization has similar biodegradation profile to cellulose (Hill, 2005; Yamane et al., 2014). The molar mass of the PGA polymer is determined by time, temperature, concentration of the catalyst and chain transfer agents (Hill, 2005). PGA-based materials are resistant to most of the organic solvents, but sensitive to hydrolysis (Song et al., 2011). Currently PGA is used in medical applications and food packaging (Yamane et al., 2014). It isused to form copolymers, such as poly (lactic-co-glycolic acid) (PLGA) due to its intrinsic characteristics such as high hydrophobicity, rapid degradation, insolubility in most organic solvents and brittleness (Paresh Kumar Samantaray et al., 2020).

III. Sources For Production

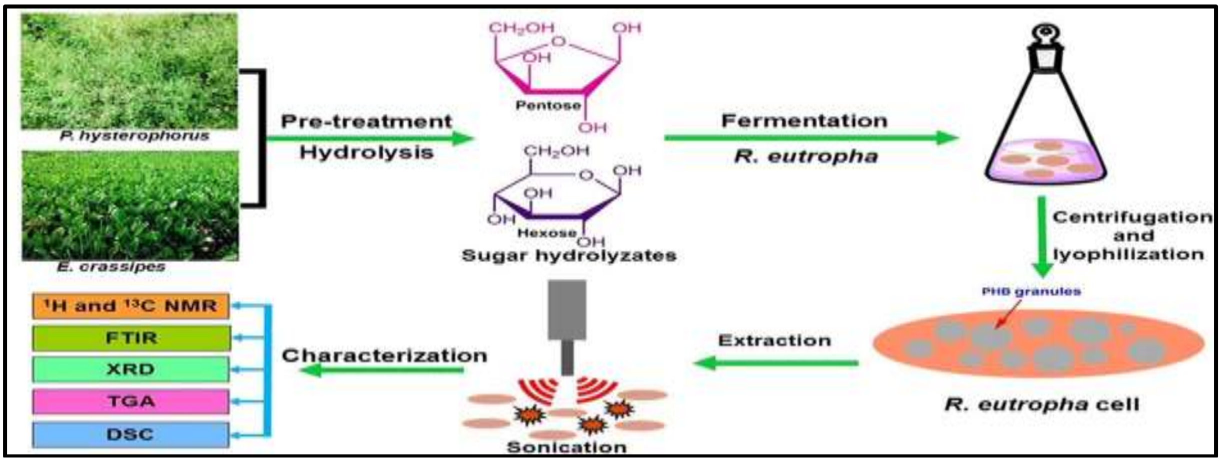
Bio plastic production methods can be divided into four main groups based on raw material origin:
1) Extracted directly from biomass;
2) Produced by natural or genetically modified organisms;
3) Synthesized from bio-based monomers; (Thakur et al., 2018)(Song et al., 2011).

Synthetic biology, an interdisciplinary research field which is a unique combination of life science and engineering provides new approaches to redesign biosynthesis pathways for the synergistic actions of biomass conversion leading to cheap and effective processes for conversion of biomass into useful products such as biopolymers (Pei et al., 2011).

3.1WATER HYACINTH

Water hyacinth arecommon aquatic weeds thatblooms rapidly in all water bodies and abundantly increases in the lakes, dams and irrigation channels. It causes blockage of waterways, but are rich source of carbohydrate and can be used to make biodegradable plastic. Water hyacinth derived sugar molecules like lignin, cellulose and hemicelluloses can be successfully converted into poly hydroxyl butyrate (PHB), a polymer that is a raw material for making biodegradable plastic(Reddy et al., 2013).

The hydro lysate of water hyacinth with a minimal nutrient media used for production of PHA by different bacterial species like *Pseudomonas aeruginosa*and *Cupravidusnecator*. Extraction of PHA from the fermentation media yielded 65.51% of PHA after 72 hours of incubation(Radhika & Murugesan, 2012).



(FIGURE 2: PREPARATION OF BIOPLASTICS FROM WATER HYACINTH)
(https://www.mdpi.com/2073-4360/11/5/751/html)

3.2FISH WASTE

Protein based bioplastics can be produced using different fish waste(for example sardine and mackerel) in combination with different plasticizers like polyethylene glycol, triethylene glycol and glycerol (Bechtel et al., 2017).

Fish waste (sardine by product (SBP), mackerel fillet powder (MFP) and mackerel by product powder (MBP) was processed into protein powders which was transformed into bioplastics by using extrusion and compression moulding method.

The use of various plasticizers lowers the temperature of thermal decomposition and improves the elongation at break qualities. Glycerol, due to low molecular weight, high water solubility, and wide protein miscibility was used that increased the mechanical qualities of the material. The results obtainedusing thermo gravimetric analysis (TGA) and mechanical testingshowed that plasticizer types and concentration improved the film properties and their suitability for agriculture applications(Alias &Ishak, 2020).

3.3DATE WASTE

Date waste is used for production of the (Poly 3-hydroxybutyrate-hydroxyvalerate)PHBV bya halophilicarchaeon*Haloferaxmediterranei*.a promising candidatesfor the economical large scale production of PHA(Alsafadi et al., 2020; Koller, 2019)

H. mediterranei feeds on date fruit waste as a sole carbon sources and accumulates PHBV with high 3-hydroxyvalerate (18%). Isotope Ratio Mass Spectrometry(IRMS) is used to investigate biopolymer origin and biosynthesis mechanisms. *H. mediterranei*prefers lighter bonds to break and lighter atoms for biosynthesis(Yue et al., 2014).

3.4 MANGO SEED

The peel and seedof mango generated as waste materials yields approximately 15.7 million tonnes of mango waste per annum. The kernel obtained after decortication of the mango seed contains high quantities of carbohydrates fat, and fibre is used in the production of polysaccharide based biopolymer films using the starch (carbohydrate) from mango seed waste.(S. A. Sanchez-Vazquez et al.)

3.5TEA LEAVES WASTE

Hydrophobicbio plastic films from tea waste were produced by a green, waste free method whereonly the spent tea leaves, an industrial by- product of tea brewing industry were used along with citric acid and water all of which are sustainable. Tea leaves are composed of cellulose, hemicellulose, lignin, polyphenols, proteins, carbohydrates, and caffeine (Hussain et al., 2018).

This technique is non-toxic, generates zero waste, and requires mild conditions and short processing times. The resultant bioplastics were chemically characterized by (X-ray photoelectron spectroscopy) XPS and HPLC-MS, mechanically characterized by uniaxial tensile tests,scanning electron microscope (SEM), and confocal microscopy. Unreacted citric acid acts as a hygroscopic plasticizer exhibited an ultimate tensile strength. The tea waste bioplastics established strong hydrophobic character quantifying the surface roughness of the films. These bioplastics are biodegradable and sustainable, that occupies a great place in the sustainable packaging methods (M. Liu et al., 2020).

3.6 SEWAGE SLUDGE

Large quantities of sewage sludge produced from the waste water treatment plants (WWTPs) is one of the most critical issues. Recent studies describe primary sludge and Waste activated sludge as carbon sources which are low-cost substrates for PHAs production can be readily converted into volatile fatty acids (VFAs) during an acidogenic fermentation, which can be achieved by inhibiting the methanogenic step during the anaerobic digestion process. (Morgan-Sagastume et al., 2016)(Kleerebezem et al., 2015).

Waste activated sludge has many bacteria that accumulate PHAs. Certainly, PHAs content in Waste activated sludge has been reported to range from 0.3 to 22.7 mg PHAs/g WAS(Frison et al., 2015; Raheem et al., 2018; Tyagi & Lo, 2013).

3.7 LEPIDIUM PERFOLIATUM SEED GUM

Bioplastics were produced using the gum extracted from *Lepidiumperfoliatum* seeds (LPSG), gum is extracted from the water slurry of seeds (Hernandez-Izquierdo & Krochta, 2008; Seyedi et al., 2014).

The authors believe that preparation of LPSG films without plasticizer addition is impossible. Glycerol had an essential role in making flexible films and influences physical, mechanical and microstructure properties of LPSG films. Increased glycerol concentration improved the mechanical and thermal properties. Therefore, blends of LPSG and glycerol were prepared mixing LPSG (0.6%, w/v) and glycerol (40%, 50%, 60% and 70%, w/w) had great impact of for packaging a wider variety of food products (Koocheki et al., 2013).

3.8 ORANGE PEEL

Bioplastics in food packaging should be regarded GRAS (generally recognised as safe) by the (Food and Drug Administration) FDA(Perotto et al., 2018). Orange peel powder, corn starch, modified potato starch, glycerol and distilled water with hydrochloric acid 1N and 10% NaOH were mixed and reduced the pH of the mixture to induce polymer formation(Ángel Siles López et al., 2010). Once formed, the pH of the polymer was returned to a neutral pH of 7.0 so that the acid pH would not interfere with the food while being in contact with the bio plastic container.

Hauenstein et al. (2016) produced a high tensile thermoplastic polymer from limonene, a compound found in orange peels that is flexible and degrades in 90 days. In comparison to this, vegetable starch based bio plastic is transparent and less flexible(Wikandari et al., 2015). This study provides basis for future research using similar food waste and agro waste.

3.9 JACKFRUIT SEED

In the study conducted by Rajakumari et al., raw materials used include jackfruit seeds powder, glycerol, and gelatin, for starch based bio plastic preparation. Indian jackfruit seeds collected from local market was prepared into a jackfruit seed powder and starch was extracted towhich (0.5N) HCL and 1000ml of plasticizer (500ml of glycerol and 500ml of castor oil) was added to prepare the biofilm.

Tensile strength test, Acid and Alkalinity test showed the strength and solubility of the test sample. Flame test result confirms the biodegradability of test sample. This study was concluded reporting that the synthesis of starch based bio plasticfrom jackfruit seed powder exhibits good mechanical properties and oxygen barriers.

3.10. PINEAPPLE WASTE

Pineapple (*Ananascomosus*), an abundant tropical plant generates lignocellulosic fibres. Pineapple leaf fibres (PALFs),a by-product of pineapple farming can be obtained at a low cost (Faruk et al. 2012). Kim et al. (2012) created pineapple flour/PLA biocomposites and pineapple leaf fiber bio-composites showed variability. It was found that 30 wt. % of flour yielded the best overall mechanical properties. Furthermore, (glass transition temperature)Tg increased with the addition of flour, while Tm was divided into two peaks, likely due to the quick decrease in molecular weight and rearrangement of polymer chains (W. Liu et al., 2005).

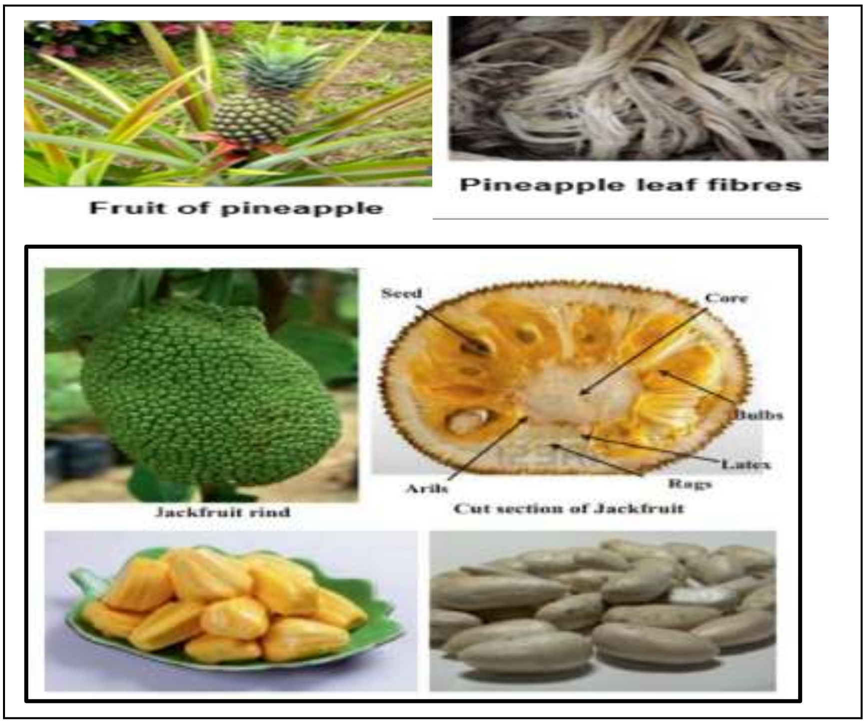


FIGURE 3: Pineapple and jackfruit waste utilization for bioplastic(Asim et al., 2015)(**https://www.semanticscholar.org/paper/potential-of-jackfruit-waste)**

IV. Bioplastics From Microorganisms

Biosynthetic pathways has allowed in the construction of the recombinant organisms such as the microbes, yeasts, and other plants for the large scale production of the bioplastics using bio wastes (Tsang et al., 2019).Many limitations are faced such as first, the special growth conditions required for the production of these compounds (usually unbalanced nutrient conditions that cause slow growth); second, the difficulty involved in synthesising them from inexpensive precursors; and third, the high cost of their recovery (Jose´ M Luengo et al.,2012).

The production of PHAs from bacterial culture is more economical than production from other living organisms, especially plants, due to their higher accumulation capacity (Verlinden et al., 2007). *Cupriavidusnecator, R. eutropha, or A. eutropha* are the commonly studied bacterial species for the biosynthesis and generation of PHAs (Vandamme et al, 2004; Vaneechoutte et al., 2004). Recently, production of economical PHAs using *C. necator* in fermentation process or PHA synthase genes of *C.necator*, *Bacillus sp., Pseudomonas sp., Aeromonashydrophila, Rhodopseudomonaspalustris, Burkholderiasacchari, and Halomonasboliviensis*has been reported.

Commercial production of PHB through waste paper, sugarcane bagasse and wheat straw by efficient microbial strain *Burkholderiasacchari*(Saratale et al, 2015) utilizes the sugars found in lignocellulosehydro lysate mainly glucose and xyloseand accumulates PHB in high amounts (Silva et al., 2004; Lopes et al., 2011).

Among the species of the Pseudomonas genus, several of them have the ability to accumulate PHAs .An interesting work about a new secretion mechanism of PHAs in *Alcanivoraxborkumensis* gives us information that PHAs could be deposited in the extracellular environment (de Smet et al., 1983;Ganapathy et al., 2018).

Different methods used for extracting PHAs from the C*yanobacteriumSpirulina* sp. LEB-18 show different efficiencies. The use of sodium hypochlorite in the initial extraction stage increases polymer accumulation, while the use of methanol at the end process yield high purity PHAs. The extraction methods influencesthe molecular mass, degree of crystalinity, and monomeric composition of PHAs. The PHAs extracted from the *Spirulina*sp. were composed largely of the 11-hydroxyhexadecanoate monomers and hydroxyl tetradecanoate, which is a scientific novelty because these building blocks are constituents of completely new polymers.

4.1 BIO PLASTIC PRODUCTION BY NATURAL OR GENETICALLY MODIFIED ORGANISMS.

Viral, bacterial, plasmid or genetically modified organisms are used for production of bioplastics using food waste or other type of organic wastes, pre-treatment procedures must be applied to enhance or modify biological, chemical or physical properties (Morone et al., 2019; Nayak and Bhushan, 2019; Tsang et al., 2019). The purpose of the pre-treatment process is to reduce the substrates size and to remove inert materials that are not suitable for processing (Strazzera et al., 2018; Tsang et al., 2019). Some of the functional parameters like pH, temperature and hydraulic retention time must be determined specifically to maximize the outcome (Strazzera et al., 2018; Sharma et al., 2020).

It is important to highlight the use of genetically recombinant strains that produce PHAs where the structural genes of three key enzymes for PHA biosynthesis in *R. eutropha*and *A. eutrophus* have been cloned, sequenced, and expressed in *E. coli* to normally produce PHAs.

4.2USING COPOLYMERS AND BIOCOMPOSITES

Bioplastics made from copolymers and biocomposites have improved material properties such as biodegradability, mechanical properties and cost effectiveness. Common copolymer blends are food gelatin and potato starch(low cost and available on large scale) with plasticizers such as glycerol and sorbitol (Podshivalov et al., 2017). The final material is similar to conventional plastics such as polyvinylchloride (Podshivalov et al., 2017). If the material is produced from food grade raw materials, the final material may also be edible.

4.3ENZYMATIC SYNTHESIS OF THE BIOPLASTICS

Although enzymatic synthesis of bioplastics in the laboratory is economically inadvisable,but knowledge of biosynthetic enzymes and energetic requirements facilitates scaling-up for production of new or modified bioplastics in bioreactors.

Microbial transglutaminase, a microbial enzyme used to prepare bioplasticsreplaces the high polluting plastics of petrochemical origin which strengthens the matrix of protein-based bioplastics(Giosafatto et al., 2020).PHA synthase (PhaC) enzyme has a vital role in the polymerization of the PHA which is obtained from the *Cupriavidusnecator and Chromobacterium sp.*(Chek et al., 2019).

V. Methods Of Production Of Bioplastics

A huge variety of bioreactor systems and cultivation systems are used to produce bio polymers of different molecular architecture by different microbes. Different combinations of production strains and substrates require different fermentation equipment, bioreactor facilities and feeding regimes. The cultivation system and process design have to be adapted according to the physiological and kinetic particularities of the biological system in order to optimize PHA productivity and product quality (Koller, 2018).

5.1 SOLID STATE FERMENTATION FOR PHA PRODUCTION

The fermentation processes preferred for the PHA production is carried out in aqueous phase(Sindhu et al., 2015). Solid state fermentation describes the cultivation of microbes on wet solid particles in substrate beds with a low amount of free water present between the solid particles, allows use of inexpensive cultivation media. This strategy provides an alternative both for waste disposal and for generation of value-added compounds under reduced costs without downstream processing steps (Oliveira et al., 2004). PHA-containing fermented solids could directly be used for manufacturing of easily biodegradable composite materials. The benefits of SSF over submersed fermentation are higher substrate concentration resulting in smaller reactor volumes, or the easier feasibility of strong ventilation through the spaces between the solid particles (Castilho et al., 2009). A Gram-positive strain, *Bacillus sphaericus*for PHB production on Jack fruit seed hydrolysatecarried out the process using physical inert solid poly(urethane) foam (PUF) in SSF process(Ramadas et al., 2009).

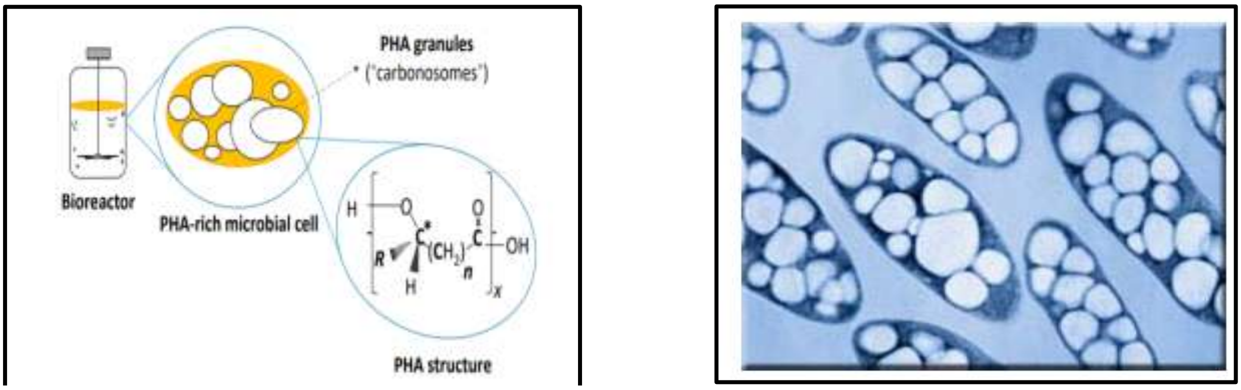


FIGURE4: A PHA rich microbial cell in a schematic bioreactor and the general chemical structure of the PHA (Koller, 2019)&Microorganism Filled With Polymer Material (Www.Metabolix.Com).

5.2 BATCH SYSTEMS

Batch cultivations for PHA production is simple in operation, but has low productivity.Favourable yields and productivityusing mixed microbial consortia(MMC) processes with either defined substrates like acetate, or inexpensive complex compounds from wastewater , olive oil mill effluents , sugar cane molasses and crude glycerol phase (CGP),These complex substrates can either be used directly for PHA production, or have to be fermented in a anaerobic step towards volatile fatty acids (VFAs). Furthermore, continuous feeding strategies enable PHA production with the additional effects of a more stable process and altered copolymer composition(Rhu et al., 2003;Y. Zhang et al., 2018)..

5.2 FED BATCH FERMENTATION

High productivity of PHA is obtained by fed-batch or continuous fermentation wherebacteria such as *Bacillus sp., Pseudomonas sp., Aeromonashydrophila, Rhodopseudomonaspalustris, Burkholderiasacchari, and Halomonasboliviensis*, are employed in two step process where in one step no nutrient limitation. When nutrient limitationoccurs, the cell mass increases because of the intracellular accumulation of PHA (Villano et al., 2014).

Other bacteria like - *R.eutropha, Hydrogenomonaseutropha, A. eutrophus, and Wautersiaeutropha,*produce high yield of PHAs since the cell growth and PHAaccumulation need to be balanced to avoid incomplete accumulation of PHA or premature termination of fermentation at low cell concentration (Dionisi et al., 2004).

The disadvantage in intracellular accumulation of biopolymers is the cytoplasm capacity and downstream processing for PHAs recovery from biomass. Whereas, the extracellular PHAs production is not limited by the cell space and does not require cell breakage procedures making this process less complex.

5.3 CONTINUOUS FED-BATCH SYSTEMS

Continuous fed-batch for PHA production was reported by Du and Yu, used 1.6 L airlift-type bubble column bioreactor without mechanical stirring, where food waste was digested by an MMC, yielding a cocktail of organic acids, predominately acetate, propionate, butyrate and lactate(García-Pérez et al., 2018). The acidic sludge was recycled by a peristaltic pump through a tubular membrane module immersed in the fermentation broth of the aerobically operated bubble column airlift reactor and enabled permeation of low molecular mass compounds into the culture broth in the bubble column, but retained biomass(Alias & Ishak, 2020). Gaseous carbon sources, CH_4 (methanotroph production strains) and CO_2 (autotrophs like cyanobacteria) are limited by the solubility of CH_4 or CO_2, which decreases production costs; this solubility of substrates and substrate availability for the cells are strongly influenced by parameters like temperature, pH-value, size of gas bubbles (Valentino et al., 2015).

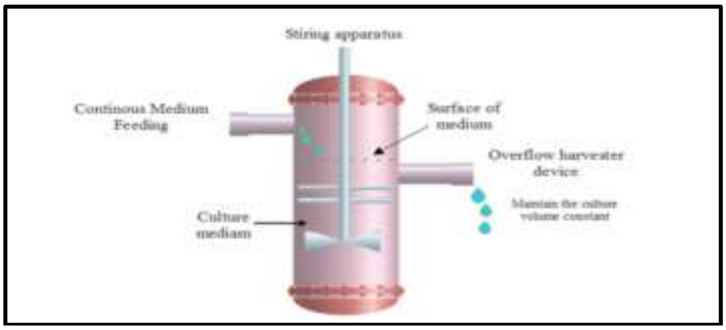


FIGURE 5: CONTINUOUS CULTURE (El-malek et al., 2020)

A long-term process for PHA production based on CH_4 was described by a Methylocystis-dominated enrichment culture strain *Methylocystis sp*. WRRC1 was isolated capable of producing PHB from $CH_4$and PHBHV when co-supplied with CH4 and the 3HV precursorsvalerate or n-pentanol. This organism can efficiently be cultivated in gas-recycling bubble column bioreactors(Chen et al., 2015).

VI. Additives Used In The Bioplastics

According to the IUPAC, a plasticizers is a substancethat is incorporated into another materialtoimprove the physical properties of the biopolymer-the flexibility, workability, or distensibility and reduce the tension of deformation, hardness, density, viscosity and electrostatic charge of a polymer(Natarajan, 2015). Commonly used plasticizer are polyols such as glycerol, ethylene glycol, diethylene glycol, triethylene glycol and tetraethylene glycol which are effective in plasticized hydrophilic polymers (Peña et al., 2014). Glycerol (GLY),highly hygroscopic molecule is incorporated hydrocolloid films to prevent film brittleness (Kristo & Biliaderis, 2006)(Vieira et al., 2011).
There are two major types of plasticizers such as the:

- Agents that interrupt polymer–polymer interactions and maintain a farther distance between polymer chains.
- Agents involved in the absorption of more water molecules, thus resulting in high moisture content and greater hydrodynamics radius.

6.1 CLASSIFICATION OF PLASTICIZERS

The type of the plasticizer used affects the film formation from the polymeric aqueous dispersions (Lindström & Hakkarainen, 2006). Plasticizers are classified into following types:

TYPES OF PLASTICIZERS	PROPERTIES	REFERENCES
External Plasticizers	interact with polymer chains, but not chemically attached by primary bonds to polymers	(Sothornvit&Krochta, 2005)
Internal Plasticizers	inherent parts of the polymer molecules, either co-polymerized into the polymer structure or reacted with the original polymer	
Primary Plasticizers	gels the polymer rapidly under the normal processing temperature range does not exude the plasticized material	(Williams & Hillmyer, 2008)
Secondary Plasticizers	show lower gelation capacity and compatibility with the polymer	
Hydrophilic Plasticizers	easily dissolved, but in higher concentration causes an increase in water diffusion in the polymer and cause phase separation leading to flexibility losses and formation of discontinuity zones	(Siepmann et al., 1998)
Hydrophobic Plasticizers	micro-voids in the film leads to decrease in the uptake of the water, but complete uptake is achieved by an optimum stirring polymeric dispersion with the plasticizer	(Vieira et al., 2011)

TABLE 1 : Types of Plasticizers

When plasticizers are used above critical concentration can cause disadvantages like increase in gas, solute and water vapour permeability and the decrease in cohesion affects mainly mechanical properties(Yang & Paulson, 2000).The characteristics of films, depend therefore on an equilibrium between the degree of cross linking of the polymer matrix and the addition of plasticizers for better workability (Silva et al., 2009)

VII. Applications Of Bioplastics

Biopolymers have been utilized in many applications from food industry to medical application whichpossessproperties of the conventional polymers such as the polyethylene (PE) , polypropylene (PP), polyethylene terephthalate (PET)(Kirwan et al., 2011).
The basic steps involved in the processing of any biopolymer by melting of the biopolymer mix followed by casting, extrusion and blow molding. (Mangaraj et al., 2019)

METHOD	PROCESS	REFERENCE
Extrusion	biopolymers made up of aliphatic esters are processed at low melting point. It	(Malathi et al., 2016)

	includes two methods: single screw extrusion and twin screw extrusion. Single screw extrusion is most preferred method due to low cost of production and simple operation	
Film blowing	The typical film thickness obtained by this method is 0.007-0.125mm have toughness and resilience. The prepared film when cooled down has better orientation of the molecular structure	(Avérous & Pollet, 2012)
Casting	film is usually prepared by drawing molten resin onto rollers for cooling that have lower mechanical properties due to the less orientation of the molecular structure and fast cooling of the film. One advantage of high melting temperature gives better optical properties. Films made from this method are soft and easy to stretch	(van Tuil et al., 2000)

TABLE 2: Steps In Processing Of Bioplastics

7.1 BIOPLASTICS IN FOOD PACKAGING

In food industry, modified atmospheric (MA) food packaging or active packaging is an emerging technique involves the incorporation of antimicrobials in packaging films to suppress the growth of board spectrum of microbes that cause the spoilage of the food. It is a simple and economical method used for following reasons:

- Increasing the safety of food by inhibiting the pathogen
- Preservation of the flavour and odour
- Extension of the shelf life (Daeschel, 1989)

7.2 ANTIMICROBIAL COMPOUNDS IN SMART PACKAGING

Different antimicrobial compounds like plant based compounds include cinnamon, clove, thyme, rosemary, oregano,pepper, cinnamon, coffee and other plants extracts like onion, garlic have better effects on the microbes.Nisin, natamycin,chitosan, and pediocin derived from bacterial and fungal origin. When infused on the biopolymer forms edible films.

Non – edible films where nano silver based chitosan biofilms and Ag-Ion incorporated Nano composites films enhance food quality and safety by inhibiting contaminant microorganisms. The types of the active packaging:

- Antimicrobial agents/coatings incorporated into sachets/pads
- Polymers having volatile or non-volatile antimicrobial agents
- Ionic or covalent linkages of antimicrobials and polymer by immobilization technique (Jabeen et al., 2015)

7.4 EFFECTIVENESS OF ANTIMICROBIAL PACKAGING

- Essential oils and Enzymes

Essential oils include linalool, thymol, carvacol, clove oil, cinnamaldehyde and basil essential oils have high potential to inhibit a board spectrum of microorgansms. The extract of grape seed incorporated in the soya isolate films inhibiting the bacterial species *Listeria monocytogenes*(Marsh & Bugusu, 2007).

Lysozyme enzyme when incorporated into packaging materials repel larger pests and insect larvae. When incorporated with lactoferrinimproves effectiveness of the lysozyme enzyme.

- With chitosan

Chitosan coated polymers inhibit the *Penicilliumexpansum* species compared with the *Rhizopusstolonifer*. Chitosan blended with lemongrass essential oilscontrols the anthracnose disease of the bell pepper(Bourbon et al., 2011).

7.5 MEDICAL APPLICATIONS OF BIOPLASTICS

Bioplastics like the PLA, polylacticcoglycolic acid (PLGA) and their co polymers are utilized in the biomedical application which are biocompatibleand suitable for stable long term treatment.

TYPE OF BIOPOLYMER	APPLICATION	REFERENCES
Polylactic acid (PLA)	• Tissue engineering- PLA is considered as one of the most bio dissolvable polymer in the human body(Bano & Pandey, 2018) PLA composites showed no toxicity in murine osteoblast (Radhika & Murugesan, 2012)	(Bostman et al., 1989; Haers et al., 1998; W. Zhang et al., 2008)

	• Wound management – successful trials were carried out in wound management using PLA by creating surgical sutures, in dental wound healing process and postoperative adhesions.	
	• Drug delivery system- PLA shows better properties of encapsulation,biocompatibility and less toxicity. • Polymeric drug - three forms- erosion, diffusion, and swelling.	(Dalton et al., 2009; Freiberg & Zhu, 2004)
	• Orthopaedic devices- PLA based suture anchors, screws and pins used in bone fracture treatment show better tensile strength and bio compatibility in the human body.	
Polylactic glycolic acid(PLGA)	• Porous PLGA scaffoldsand blends like PLGA/HA showed intensified mechanical properties	(Baji et al., 2010; Mouthuy et al., 2010; Zhou et al., 2004)
	• Fibrous scaffolds- hollow fibres have good potential in bone tissue formation.	
	• Hydrogels- another type of the scaffolds like the fibrin , where hyaluronic acid can be blended with PLGA plasticizers	
	• Injectable microspheres used in the homogenous dispersion.	
	• Dentistry	
Polycaprolactone (PCL)	• PCL blends used for controlled drug delivery being biocompatible gets excreted out of the body.These have high permeability hence mixing with polymers improves stress	(Ehrahimian-Hosseinabadi et al., 2011; Goldstein &Block, 2000; Merkli et al., 1998)
	• Tissue engineering- PCL possess low melting &superior rheological used in the scaffold preparation have been utilized for cardiovascular purposes.	

TABLE 3 :Novel Medical Applications Of Bioplastics

❖ LIFE CYCLE ASSESSMENT OF THE BIOPOLYMERS

Life cycle assessment is an important standard to evaluate the sustainability and the performance of the material with the environmental impacts (Seydim & Sarikus, 2006). LCA can be evaluated by gathering information on some of important criteria such as the material extraction, manufacturing, waste production, packaging, transportation, product use and product disposal(La Rosa, 2016).

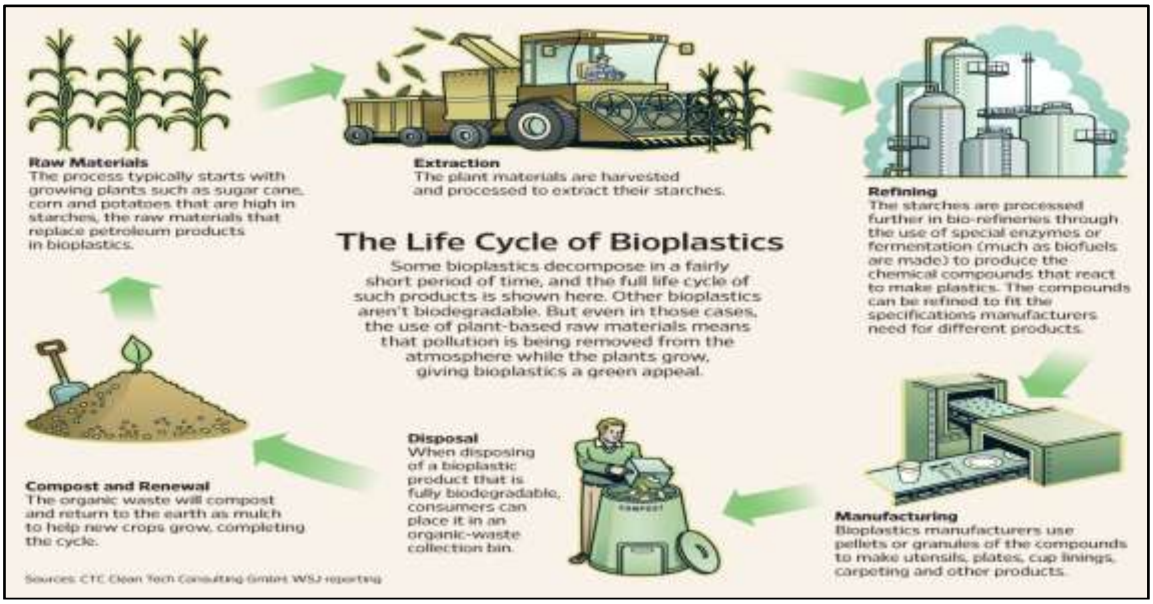


FIGURE 6: OVERVIEW ON THE LIFE CYCLE OF THE BIOPLASTICS (https://plasticpollutionblogsite.wordpress.com/2016/10/31/solution-technology-1/)

VIII. Conclusion:

This review bring outs the potential of bioplastics produced for management agro waste and food waste majorly utilized in agricultural, medical field and food industry for the packaging purpose. Innovative strategies applied to enhance the properties of the biopolymers such as the smart packaging and modified atmospheric packaging involves incorporation of the antimicrobial substances of both natural and synthetic sources which preserve the quality and freshness of the food increasing the shelf life of the food by protecting it from contamination by inhibiting the growth of the microorganisms.Besides this, utilized in wide range of biomedical fields for the tissue engineering purpose in the preparation of the scaffolds where the biocompatibility and biodegradability of the material is the biggest concern.

Different agricultural waste, food waste and waste water treatment plant sludge are used as the renewable sources. Various fermentation methods and number of microorganism species like the bacterial species and algal species for efficient production of the bioplastics films such as the PLA, PHA and PHB which also pave way towards sustainability reducing production cost were reviewed and it is clear that continuous fermentation is most efficient.

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Syed Salma , et. al. "Applications and Effective Production of Bioplastics From Food Waste."*IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)*, 14(7), (2021): pp 40-53.