ISSN: 2320-5407 Int. J. Adv. Res. 8(06), 1526-1533

Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

ISSN NO. 2320-5407

Article DOI:10.21474/IJAR01/11243
DOI URL: http://dx.doi.org/10.21474/IJAR01/11243

RESEARCH ARTICLE

REVIEW ON POTENTIAL SOURCES AND APPLICATIONS OF BIOPLASTICS

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Manuscript Info

Manuscript History
Received: 25 April 2020
Final Accepted: 30 May 2020
Published: June 2020

Key words:-
Bioplastic, Biodegradation, Sustainable, Biomass, Waste Management

Abstract

The interest in study of waste management is being increased worldwide presently as the pollution by various means is made day by day. Currently pollution due to plastic is a crisis threatening worldwide. Due to environmental concern, our society is facing an emergency to find a replacement to conventional plastics. Thereby, bioplastic is a suitable option, as they can be synthesized from various waste supplements .The waste utilization plays a vital role to overcome these pollutions and make possible to utilize the waste. Bioplastics are obtained from the biomass such as corn, sugarcane. Use of bioplastics is given more prominence in the present days as it reduces the environment pollution and accumulation of plastic wastes. Plastics have more applications in the packing industries, hence the accumulation of plastic as waste is on a higher rate, as it degradation of plastic is complex and slow. Hence, demand for the degradable bioplastic can be used as a substitute in most of the cases. This review indicates the applications, types of bioplastics and use of cheap substrates for bioplastic production.

Introduction:-

Increase in world's population along with the changing climate is adversely affecting the earth's natural renewable resources. It is due to the increase in the dependency and utilization of materials leading to fundamental changes in the society and dependency with the nature having wider expansion of socio- economic system. Thus leading to the transformation of natural systems. Production of materials has improved at an average rate of 1% perpetually per year. Worldwide materials consumption increased 8-fold during the last century. According to the estimates, humans currently use virtually 60 billion tons of materials per year [1].

Of the materials, plastics are in much demand, plastics are the that are capable of flowing at a particular stage while processing and treating at various durations of heat and temperatures. Thus, plastics are defined with the characteristics; it can be extruded, casted, spun, moulded or can be used as coating. There is a rapid increase in the production of plastic from 300,000 to 135,000,000 tons from 1939 to 1998. Globally the utilization of plastic in tonnes per annum is 260 million which approximately represents 8% of the world oil production [2]. With the increased demand for plastic all over the world, along with increased in the accumulation of plastic as waste, alternate ways are preferred to compensate the use of conventional plastic with the biodegradable plastic or the bioplastic.

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Over the last few years, production of biopolymers from the renewable resources has a significant impact. Renewable sources such as vegetable oil, corn, pea starch have been synthesized by microbes known as bioplastic. Currently, demand for bioplastic is increasing so as to replace the fossil fuel based polymers. Conventional plastics requires fossil fuel resources, price volatility, impact on the environment and waste disposal problems are some of the main reasons for the shift towards bio-based plastics.

Bioplastics are bio-based and/or biodegradable. All bio bio-based materials are not often characterized as biodegradable and similarly not all biodegradable materials are bio-based. Material is considered biodegradable when materials are broken down under the influence of microbes and right conditions and use them as food source. When a complete microbial assimilation of the fragmented food source happens within 180 days in a compost environment, it is considered as compostable.

Classification of bioplastics is as follows [3]:
1. Bioplastics that are bio-based or partly bio-based non bio-degradable such as bio-based Polyethylene (PE), polyethylene terephthalate (PET), polylactic acid (PLA), and poly trimethylene terephthalate (PTT)
2. Bioplastics that is bio-based and biodegradable (polylactic acid (PLA), poly hydroxyl alkanoates (PHA), poly butylene succinate (PBS) and starch blends).
3. Bioplastics that are fossil based and non-biodegradable (conventional Polyethylene (PE), polyethylene terephthalate (PE), polypropylene (PP), and polyethylene terephthalate (PET).
4. Bioplastics that are foPssil based and are biodegradable such as Polybutylene adipate terephthalate (PBAT) and Polycaprolactone (PCL).

Bioplastics have following benefits, such as, increment in efficiency, renewable resource that can be cultivated annually, reduction in carbon footprint. Therefore, bioplastics can be considered for sustainable production and for usuage. Currently, bioplastics is through the growth phase [4].

The durability, compatibility, affordability and sustainability are the challenges of converting renewable resources into industrial materials. Therefore, when a new material is designed and manufactured, some of the factors that are to be considered are resource availability, environmental impact, energy efficiency, sustainability and impact on the global social community. Besides a favourable life cycle analysis, research and development of bio based products should consider limits that will maintain the sustainable development. The design of biobased materials should favour increased materials supplements, optimized land use, improved plant biodiversity, minimized environmental pollution and improved energy efficiency, while at the same time meeting consumer demands [5].

Biodegradable polymers contribute to material recovery, reduction of landfill and utilization of renewable sources. They can be buried in the soil along with the plant remains for the decomposition by microorganisms. Development of packaging materials from the biodegradable natural resources is gaining popularity as it would reduce the environmental impact upon disposal.

Examples for the bioplastics include Poly- lactic acid (PLA) and starch based polymers are commercially used polymers. Also, microbial poly hydroxyl alkanoates (PHA) biodegradable plastics are environmental friendly bio-plastics with less carbon dioxide emissions.

Cellulose was found higher in nanosized particle (50nm) than without nanosized particle. However, pH was found alkaline of nanosized particle which was under the standard value [6].

Cellulose acetate based biodegradable plastics are decomposable in soil or in water which can be recycled or incinerated without the residue formation. It has good mechanical strength and durability; hence it has applications in the photographic films, ultra -filtration membranes, fibers [7].

Different sources of production of bioplastic:
Sugar cane molasses, corn syrup, corn steep liquor , starch based products , paper waste, acid hydrolysed malt waste, diary whey are some of the cheaper substrates commonly used in the production of bioplastics [8].

Biodegradable polymer, Poly Hydroxy Butarates (PHB) can be synthesized by bacterial systems under certain conditions or as a biosynthetic product, it possess characteristics similar to that of synthetic polymers. It possess properties such as biodegradable, durable, temperature resistant and it is eco friendly plastic.

Synthetic plastics are non- recyclable, non biodegradable material. Hence, the study is focused on replacing the petroleum plastics with natural, biodegradable, recyclable plastics. PHB has gained attention due to its characteristic features which is comparable to that of the synthetic plastics [8].

Cellulose acetate:
Agricultural waste flax fibers and cotton linters on treating with bleaching agent (5% NaOCl and 5%NaOH), will be subjected to acetylation process on mixing with acetic anhydride, glacial acetic acid and sulphuric acid in proper proportions .It will be hydrated and subjected to aging followed with centrifugation and then treated with plasticizer polyethylene glycol 600 for the production of cellulose acetate which can be compared with polyethylene and polypropylene with respect to its resistance.

Flax fibers are preferred for the production of cellulose acetate due to higher production yield and it is available in large quantities compared with cotton linters. This CA is a suitable material for packages, salt containers, fiber and plastic tools manufacture. This CA has the potential to replace or minimize the use of nonbiodegradable and petroleum-based materials [7].

Starch:
Starch is a major polymer for the development of bioplastic. Many ongoing studies are carried out on the capability of starch as the biopolymer for bioplastic. Starch consists of a long chain of two glucose units joined together, namely branched polymerized amylopectin and amylose, which gives its granular structure. Starch is preferred for the production of bioplastics, as it is abundantly available, cheap source also due to its renewability and biodegradability. Starch can behave like a thermoplastic in the presence of plasticizer, with application of heat and mechanical treatment. As native starch-based films are limited to high water affinity and brittleness, other natural substances like nanoparticles and plasticizers are often added as fillers to modify and improve films' properties [9]. Starch is cheap, abundant and renewable. It is found in several forms. Starch films are produced through the grafting of polymers i.e., Polyethylene (PE). [10] Some of the common sources for the starches are as follows:

Corn and rice starches :Bioplastic obtained from the rice and corn thermoplastic starch, in which different plasticizers glycerol, gelatin, and citric acid were added to 100 mL distilled water in various ratios were used indicating the improvement in the mechanical properties and good water solubility Bioplastic obtained from corn and rice starches have better biodegradability than the existing plastic materials. Citric acid as an additive improves the shelf life of the material and improves the mechanical properties [11].

Banana peels:
One of the most common waste forms of starch is the banana peels. The disposal of these large amounts of wet organic waste can eventually harm the environment and lead to health problems such as respiratory disorders [12]. Banana peels consists high sources of starch, which is about 18.5% and it forms the source for the bioplastics [13]. Studies are also focused on the potential of banana peels in forming starch based plastic film.

Corn is a source for starch and it is a potential biopolymer for bioplastics. Even though several studies have been done using cellulose as natural reinforced filler in starch based films [14]. Striving to achieve cost-competitive biomass-derived materials for the plastics industry, the incorporation of starch (corn and potato) to a base formulation of albumen and glycerol was considered.[15]

Plasticisers are used to change the properties of polymer. Commonly used plasticizers are glycerol, gelatin, and citric acid. Propan-1,2,3-triol is used as plasticizer to change the properties of the plastic obtained from starch source such as potato. Plasticizer combines with the polymer chains and prevents them from forming into a crystalline structure. In the absence of plasticizers, polymer acts as a crystalline, this will be brittle and inflexible. Plasticizer is a small molecule, that gets between the polymer chains and helps them to slide easily over each other and the polymer behaves like a plastic.

The use of natural and biodegradable plasticizers, with low toxicity and good compatibility with bioplastic in substitution of conventional plasticizers, such as phthalates and other synthetic plasticizers attracted the market along with the increasing worldwide trend towards use of biopolymers.[14] Plasticizers, such as glycerol and sorbitol, have been researched to increase the flexibility and improve the processability of starch/PLA blends; however, no significant improvement in the mechanical properties has been observed [16].

Global production capacities of bioplastics is trending to increase every year , with the expected total capacity of 2426 tonnes by 2024. According to the source of European bioplastics, 2019, Global production of bioplastics includes 55.5% of biodegradable plastics (21.3% is based on starch blends, 13.9% PLA, 13.4% PBAT, 4.3% PBS, 1.2% PHA and 1.4% other (biodegradable)) and 44.5% of bio based / non biodegradable plastics (PE- 11.8%, PA- 11.6%, PET- 9.8%, PTT -9.2%, Other (Biobased/ non biodegradable- 1.1%)) [17]

Applications:

Bioplastic represents promising alternative to conventional plastics with their improved characteristics such as mechanical, thermal, barrier as well as other physical and chemical properties. Bioplastics find applications in flexible packaging, rigid packaging, textiles, consumer goods, agriculture & horticulture, coatings and adhesives, buildings and construction, electronics and electrical appliances .

Automotive components:

Polymer bioplastic offer better performance with significant weight reduction and affordable materials for transport industries such as automotive and aerospace.

They have been used to fabricate engine covers, oil reservoir tank and fuel hoses in the automotive industry due to their remarkable increase in heat distortion temperature (HDT) as well as their enhanced barrier properties and mechanical properties. In recent years, there has been increased use of biopolymer nanocomposites by various vehicle manufacturers to make both external and internal parts such as mirror housings, door handles etc. The weight advantage of polymer bioplastics has a significant impact on environmental protection [18].

Packaging Materials:

Bioplastics offer outstanding barrier properties that are considered for enhancement of shell life of packaged food materials. Usually starch based materials are preferred; they indicated optical transparency along with the biodegradability. Starch based packaging plastics are odorless, non toxic and display low permeability to oxygen especially at low relative humidity [19].

Starch based food packaging containers with the ability to withstand high temperature, which is especially important during transport and storage [20]. Therefore, starch based packaging materials have great potential in providing proper packaging materials for safe, wholesome food products which has been the focus of food packaging industry for many years.

Biodegradable bioplastics are used in the making of packaging films and containers which have short service life. Also, because of their properties, they have applications in biomedical field in making bone plates and screws, in drug delivery carriers and tissue engineering scaffolds [21,22].

Drug Delivery:

Studies have been made on polymer membrane to hold the drug through which if diffuse into the tissue which the membrane is implanted. Duncan and Kapecek [23] reported that various polymers to which certain drugs were attached could be used to release the drugs after cleavage of the bonds attaching them to the backbone.[18]

Film coating:

Sprayable form of liquid bioplastic formulation has been considered for the use as an microbial biocontrol agents for agricultural and horticultural crops. Bioplastic formulation has been evaluated for use in film-coating seeds of two agronomic species, corn and canola.[24]

Bayer research group played a significant role in developing a new grade of plastic films for food packaging made from nylon 6 nanocomposites [25, 26]. Bio-based bioplastics are at the right of the pyramid, indicating they are most preferable, as they are made from renewable resources, and theoretically are biodegradable and compostable [27].

Cellulose is the most used biopolymer in the food industry, where edible coatings are produced to improve food quality and can be consumed together with the packaged products. Novel edible films with different morphological, mechanical and permeability properties and containing various antimicrobial and/or antioxidant additives are increasingly issued from the scientific literature in order to improve the shelf-life of different foods.

Starch is the preferred biopolymer, constituting about 50% of the total bioplastics market. It is often blended with caprolactones and other biodegradable esters for better application. Packaging is the largest field of application for bioplastics covering almost 40% of the produced biodegradable articles (consumer goods, 22%; transport sector, 14%; construction and building sector, 13%).[28]. Globally, demands for the bioplastics have been increasing by about 20-25% every year [29].

Other applications of bioplastics are as follows:
Biobased Polyethylene is widely used commodity thermoplastics, eg, for packaging (plastic bags, plastic films, geomembranes, and containers including bottles).[30]

Biobased Polypropylene is the preferred commodity plastic, obtained from the renewably sourced feedstock. Propylene is accessible from methane via ethylene dimerization followed by metathesis. A major market for biobased polypropylene is the automotive industry, as approximately 50% of plastic in cars is of polypropylene. [31]

Biobased PET is a thermoplastic polymer resin under the group of polyester. It is mainly used for synthetic polyester fibers and for packaging, primarily bottles. Biobased PET contain renewable monoethylene glycol (MEG), produced, from sugarcane-derived ethylene. [32]

Biobased PVC is synthesized with bio based ethylene as PVC is least environment-friendly synthetic polymers, setting free HCl and supporting dioxin formation in combustion. Also, soft PVC contains plasticizers with special environmental challenges, eg, phthalates.[18]

Biobased polycarbonates are obtained from isosorbide from double dehydrogenation of sorbital and sorbital obtained by the hydrogenation of glucose. This isosorbital is partly used for making polycarbonate which has good temperature resistance, impact resistance, and optical properties.

Biobased PU:
Polyurethanes (PU, RPUR, and BUR) are thermosetting polymers commonly formed by reacting a di- or polyisocyanate with a polyol. Applications are rigid foams. The polyols can be obtained from plant oil to make a biobased PU.[28]

Cellulose esters have applications as bioplastics. Common cellulose esters comprise CA, cellulose acetate propionate (CAP), and cellulose acetate butyrate (CAB). They are thermoplastic materials produced through esterification of cellulose. It is used in synthetic fibers, cigarette filters, and formerly photography film.[33]

Polylactic Acid or polylactate, polyester is obtained from the monomer lactic acid, which is produced from the microorganism-catalyzed fermentation of sugar or starch. It is similar in properties to PET and has FDA approval for food contact. Common raw materials are corn starch, sugarcane, and tapioca (starch extracted from cassava root).

Polyhydroxyalkanoates can be produced by approximately 250 different bacteria. The bioplastics are then harvested through the destruction of the bacteria and are separated from the microbial cell matter (centrifugation/filtration and PHA extraction using solvents such as chloroform). PHAs have good barrier properties and, since they are biodegradable, are attractive for biomedical uses. PHA can also meet ASTM D7081, which is the standard specification for marine degradability.

The main attributes of PHAs are as follows [17]:
1. Fully biodegradable in soil, water, and compost.
2. Good printability.
3. Good resistance to grease and oils.
4. Can withstand boiling water (HDT >120^0C)

Advantages and disadvantages:
Both plastics and bioplastics have many advantages. But bioplastics are assessed as most preferential from an environmental point of view. Main sustainability drivers are energy savings and greenhouse gas emission cuts, apart from biodegradability and compostability. [34,35]

Conventional plastics:
Pros:
1. low cost
2. good and excellent technical properties
3. easy processability
4. can save energy and resources compared with other materials, depending on application
5. thermal recycling possible (cascade use)

Cons:
1. based on petrochemicals
2. difficult to recycle
3. mostly not biodegradable
4. uncontrolled combustion can release toxic substances
5. ecotoxicity, particularly microplastics in the marine environment
6. partly toxic raw materials and additives

Bioplastics (compared with conventional plastics):
Pros:
1. (partly) biodegradable
2. (partly) based on natural feedstock, hence reducing the emission of GHG and the dependence on crude oil
3. interesting properties
4. generally, standard manufacturing processes and plants can be used for biobased feedstock, and standard processing machines can be used for biobased plastics
5. positive image among consumers

Cons:
1. costly
2. (partly) use of genetically modified organisms
3. potential food competition
4. narrow processing window (lower melting temperature)
5. brittleness
6. thermal degradation

Bioplastics are commonly, promoted as a ‘‘green’’ alternative to regular plastics. The following aspects have to be considered to access the bioplastic impact on the environment.

Composting:
Bioplastics can only be composted in industrial, high temperature composting facilities but it limits the use of bioplastic bags for home composting.

Recycling:
Recycling of bioplastics is not preferred since a small fraction of PHB in PET can render the recycled material useless for high value applications. Dedicated infrastructure for bioplastics collection will be necessary. Also contamination of recycling stream is one of the major concerns with respect to bioplastics.

Performance:
The density of bioplastics (1.2–1.3g/cm^3) is generally higher than that of polyolefins (0.9g/cm3). Thus, bioplastics possess more weight, resulting in higher fuel consumption, for instance.

Costs:
Cost involved in the synthesis of bioplastics is higher than the conventional plastics.

Also for bioplastics, economies of scale apply, so pilot plants cannot compete with established, large petroplastics plants, and new commercial bioplastics plants are typically smaller than petrochemical ones are essential.

Material and processing knowledge:
Knowledge on the processing of bioplastics is comparatively less than the conventional plastics, for example bioplastics will be processed at lower temperature, at high temperature bioplastics will be damaged very easily.

Sustainability of the feedstock:
In case the feedstock is obtained from food or grown of valuable cropland, food prices might increase due to competition. Land use change can have an adverse effect on climate change. Here, non-food feedstock, eg, cellulose or algae, could pose a solution.

The advantage of bioplastics is that organisms are able to feed on them better and faster when weather conditions are right. Thus, this allowed the bioplastics to be broken down into smaller pieces, reducing pollution in the process. With this, pollution is reduced and there will be no problem with litter or harms on wildlife.

The main disadvantage with oil-based biodegradable plastics is that when they break down, carbon dioxide is released in the process and contributes to global warming. Another disadvantage with biodegradable plastic is that degradation will take place very slowly underground, even if it disintegrates completely. Also, biodegradable plastics when mixed with normal plastics would reduce the worth of the plastic itself if it is recycled and make the recycled plastic useless [22, 36, 37, 38, 39].

Conclusion:-

Present review highlights about the bioplastic which serve as potential alternative to the conventional plastic material. Substrate with a addition of plasticizer helps in the formation of plastic with the characteristic features of pliability, user friendliness and strength, other tests like solubility and swelling studies were conducted to ensure commercial properties of these bioplastic materials. One of most significant result obtained during the research is degradation tractability of the developed product as plastic has a potential demand in the market for sustainable application and has a commercial role in the development of value added product. The bioplastic will be substantial and the biodegradable tractability is one of the main challenges in developing bio plastic material.

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