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S & T REVIEW

CURRENT DEVELOPMENT ON BIOPLASTICS AND ITS FUTURE PROSPECTS: AN INTRODUCTORY REVIEW

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ABSTRACT

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Bioplastics are kind of plastics produce from natural and renewable raw materials biomass sources such as sugarcane, corn starch, wood, waste paper, vegetable oils and fats, bacteria, algae, etc. Mostly, the commercial plastics in the marketplace are made from non-renewable petroleum based and this product can cause damaging to the ecosystem of the nature. Bioplastics are not harmful to nature environment because it can decompose back into carbon dioxide. Thus, the demand for applications of bioplastics are growing rapidly. The products made from bioplastics should be commercialize because they are renewable, biodegradable, compostable and environmentally friendly. The aims of this short review are to present about classifications of bioplastic, their advantages and disadvantages, processing, applications and challenges. Finally, the possible future developments of bioplastics are prospected.

KEYWORDS

Biodegradable, bioplastics, renewable, environmentally friendly.

1. INTRODUCTION

Plastics is a synthetic polymeric molecules which exhibits desirable features like softness, heat seal ability, good strength to weight ratio and transparency [1]. Petrochemical-based plastics like polyethylene (PE), Polypropylene (PP), Polystyrene (PS) Polyvinyl chloride (PVC), Polyurethane (PUR), Poly ethyl terephthalate (PET), Polybutylene terephthalate (PBT), and Nylons are the most widely used polymers in daily life due to their versatile, light weight, excellent thermal and rheological properties, inexpensive, easy to manipulate and easily formed into diverse products [1, 2, 3].

For over the years, overuse of plastics has brought significant impact to environment, it is estimated 34 million tons of plastic produced per year and only 7 percent is recycled with remaining 93 percent dumped into oceans and landfills [4]. Synthetic polymeric materials are non-biodegradable [5] have caused a serious environmental problems to the freshwater, natural terrestrial and marine habitats [3]. They are taking decades to degrade in nature or environment and also produced from non-renewable sources like petroleum, coal and natural gas [6]. Therefore, the advancements of new materials were developed biodegradable and environmentally friendly alternative to conventional plastics [7].

Recently, bioplastics are one of the most innovative materials that are biobased and biodegradable which is made from waste, biomass and renewable sources such as jackfruit [8], waste banana peels [9], organic waste [10], agriculture waste [11], newspaper waste [12], oil palm empty fruit bunch [13], sugar cane [14], corn starch [15], potato starch [16], rice straw [17], rapeseed oil [18], vegetables oil, cellulose from plants, starch, cotton, bacteria [19] and sometimes from several nanosized particles like carbohydrate chains (polysaccharides) [20]. Bioplastic can be degraded by the natural microorganisms such as bacteria [21, 22, 23], algae and fungi [24]. This article begins with briefly describes about classification of bioplastics then followed by advantages and disadvantages of bioplastics. The article also covers the processing, applications, challenges of bioplastics and finally explain on future prospects of bioplastics.

2. CLASSIFICATION OF BIOPLASTICS

Plastic can be made from fossil-based or bio-based materials and can be biodegradable or non-biodegradable plastics while bioplastic can be fully made from renewable-material, whereas biodegradable plastic is made of either fossil-based polymer or a combination of renewable and fossil materials. There are three main types of bioplastics which are biodegradable and biobased, biodegradable and fossil-based, and non-biodegradable and biobased while non-biodegradable and petroleum based are known as plastic. The Table 1 summarizes types of bioplastics:

Table 1: Types of bioplastics

	Bio-Based	Petroleum Based	Ref.
Biodegradable	Bioplastics -Eg: Polylactic acid, Polyhydroxy alkanoates, Cellulose, Starch	Bioplastics -Eg: Polybutylene succinate, Polybutylene adipate terephthalate, Polycaprolactone	[9], [25],[26],[27]
Non-biodegradable	Bioplastics -Eg: Bio- polypropylene, Bio- polyethylene	Conventional plastics -Eg: Polypropylene, Polyethylene, Polystrene, Polyvinyl chloride	[6], [25],[26],[28]

Bio-based plastics are made using polymers derived from plant based sources e.g. starch, cellulose, oils, lignin etc [29]. Bio-based polymers can be used to make plastic packaging [30] that behaves like conventional plastic. It can also be used to make biodegradable and compostable plastics. Both types are referred to as bioplastics [31].

Petroleum-based plastics is made from a wide range of polymers derived from petrochemicals. Petroleum based plastic is generally long lived, durable and non-biodegradable [32]. This is usually referred to as conventional plastics. However, petroleum-based plastic also can be designed to biodegradable plastic and this type is considered as bioplastic [6].

To produce biodegradable plastics and compostable biopolymers, the renewable raw materials are commonly used are wood and annual plants (cellulose, lignin, hemicellulose), maize, wheat, potatoes, rice, tapioca, sunflower, rapeseed, etc. (starch, vegetable oils, proteins), Sugar from sugar beet and sugarcane (biosynthesis: PLA, PHA, dextran, pullulan, xanthan [25].

However both starch and cellulose are not plastic in the native form but it can be converted to plastics thorough innovative fermentation or through polymer technology [33] by using techniques such as casting [34], internal mixing [35], extrusion [36] and injection molding [37].

Most plastic products are made from petroleum [38] which are have been widely used for food packaging applications due to their excellent thermal and rheological properties, lightweight, easy to manipulate and install in a diverse range of applications, gas and water barrier properties, esthetic qualities and cost [25].

This group of mixed sources (bio/petro) includes biopolymers based on blends of Polyhydroxy alkanoates (PHA), Polylactic acid (PLA) produced by fermentation, biobased epoxy, biobased polyesters such as polytrimethylene terephthalate which are obtained from sugarcane bio-methanol.

All these polymers have the prefix bio-, indicating that they are synthesised from a renewable raw material, but their properties are identical to the properties of standard polymers synthesised from petrochemical raw materials [39].

3. ADVANTAGES AND DISADVANTAGES OF BIOPLASTICS

It is known that plastic is one of the main pollutants resources in the environment which is daily produce [22]. Therefore, to decrease the environmental pollution, an alternative must be developed by changing the use of conventional plastic. The progress in bioplastics offerings the valuable potential to nature and the world. Many environmental issues can be solved by using natural fibers with polymers based on renewable resources. For examples, by adding biofibers with renewable resource-based biopolymers such as starch plastics, cellulosic plastics, soy-based plastics, polyhydroxyalkanoates and polylactides [40].

The properties of bioplastics like aroma barrier and facilitate of moulding which is make bioplastics is good alternatives compare to conventional plastics. Besides, bioplastics also have unique features such as biodegradable, eco-friendly, energy efficient and compostable [19].

Conventional plastics have various hazardous effects to the environment likely nonbiodegradable, hard to recycle and create pollutions to environment [40]. Therefore, the need of rethinking first before using this kind of materials is crucial to save atmosphere. Thus, replacement conventional plastic to bioplastic materials can be a revolutionary way for sustainable because of the similarity properties between conventional plastic and bioplastics materials. Moreover, in certain case bioplastic exhibit better properties compare to conventional plastic such as good in mechanical properties, thermal properties, oxygen permeability, gas barrier and water vapour transmission rate [41]. Table 2 describes briefly the advantages and disadvantages of bioplastics compare to conventional plastics that reported by previous researchers.

Table 2: Advantages and disadvantages of bioplastics compare to conventional plastics

Types	Advantages	Ref.	Disadvantages	Ref.
Bioplastic	Sustainable	[19]	Costly	[42],[43]
	Reduced Carbon Footprint	[19], [31], [44]	Thermal instability	[20], [31]
	Reduce energy efficiency	[19], [31],[44]	Recycling problem	[43],[45]
	Partly based on natural feedstock	[19], [31],[43]	Brittleness	[20],[25]
Conventional plastic	Low cost	[27],	Based on petrochemical	[27]
	Good and excellent technical properties	[27],[46]	Difficult to recycle	[27]
	Can save energy and resources	[27],[46]	Mostly not biodegradable	[27]
	Thermal recycling possible	[27]	Uncontrolled combustion can release toxic substances	[27]

4. PROCESSING OF BIOPLASTICS

The demand to process development of bioplastics into large scale of production are still ongoing. Bioplastics materials can be processed by several different techniques according to the final purpose of the desired material. The selected processing method is important because the quality of particle dispersion is major challenge in nanocomposite processing. Table 3 shows an overview of techniques normally used to produce bioplastics depend on their material.

The fermentation processing for bioplastics are received widespread interests among researchers. This processing is worked at two stage process whereby in the first stage (growth) is to develop a high cell density culture and then in the second stage is to increase materials concentration [47]. For examples in PHA materials, the limited production in pure cultures can occur by an external nutrient whereas production in mixed cultures is encouraged by an intracellular limitation. The usage of activated sludge in mixed cultures can reduce of materials cost, hence can increase the market potential of bioplastics [48].

As mentioned by Kargarzadeh *et al.*, (2017), the nanomaterials formed by casting and evaporation processing are dumped from suspensions of nanoparticles and polymers. The films are obtained after solvent is removal by evaporation. Highest mechanical reinforcement properties of nanocomposite can be produced since the sample preparation is taking place over long time periods and can make the particles have adequate time to react toward polymer and create an excellent bonding. Usually, this processing method is limited to the laboratory scale or small scale only.

The polymerization of nanomaterials is such an effective alternative method to simple mixing of dispersing particles in a matrix which can involve a previous step of drying with existence of nanofillers [49]. The adding of nanofiller can adjust the properties of viscosity materials and it also can increase the reaction time to complete the polymerization process. The amount used of nanofillers usually moderate loading can provide better dispersion during a polymerization reaction.

Injection molding method is one of the solid-state process to develop materials with outstanding surface softness and multifaceted shapes. This method is most appropriate to form polymer granules or mixtures granules within a metallic barrel whereby the petite fibers can be added, mixed and heated. Hence, the smoothness material is carrying out into the mold cavity using air pressure [48].

The extrusion equipment is classified into three main categories which are ram, radial screen and screw extruders [50]. This processing method ensues by mixing the materials with the support of a screw and without essentially shaping the melt material in an equipment die. The extrusion parameters are important factors because the retaining time of the polymer within the machine and the screw-imposed stress can avoid the creation of a percolation network. However, typical problems in the extrusion processed materials are directly connected to the physical response of the screw-imposed stress [49].

Table 3. Techniques processing of bioplastics

Material	Techniques	Source Material	Ref.
PHA	Fermentation	Bacterial	[51]
	Casting	Bacterial	[52]
	Evaporation	Bacterial	[53]
	Evaporation	Bacterial	[54]
PLA	Polymerization	Commercial PLA	[55]
	Polymerization	Lactic acid	[56]
	Polymerization	Waste paper	[57]
PVA	Casting	Commercial PVA	[8]
	Casting	Commercial PVA	[58]
	Casting	Commercial PVA	[59]
Cellulose	Polymerization	Rice straw	[60]
	Casting/Evaporation	Oil Palm fruit bunch	[61]
	Polymerization	Citrus waste	[62]
	Polymerization	Corn leaf biomass	[63]
Starch	Casting	Corn starch	[17]
	Polymerization	Potato peels	[10]
	Polymerization	Banana peels	[64]
	Casting	Cassava	[65]
Protein	Injection	Rapeseed Oil	[18]
	Extrusion	Oil palm mesocarp fibre	[66]

5. APPLICATIONS OF BIOPLASTICS

Bioplastics are receiving more attention in various application in industries [27]. This is because develop bioplastics materials is good alternative in order to decrease the capacity of inert materials disposed in landfills and create sustaining the pollution free environment which is too importance to both consumers and also industries.

Natural polymers and polysaccharides when fabricated into hydrophilic matrices is well popular in biomaterials for controlled-release dosage forms by creating a prolongation of release dosage form as reported by Kalia *et al.*, (2011). Once bioplastics is blended with other pharmaceutical excipients, the material becomes extremely good compaction properties whereby the drug-loaded tablets form dense matrices suitable for the oral administration of drugs. Crystalline nanocellulose is advanced pelleting systems which is the rate of tablet disintegration and drug release can be controlled by tablet coating or microparticle inclusion [67].

Moreover, in biomedical industry based bioplastics has been named as the eyes of biomaterial because it is highly applicable in skins replacements for burnings and wounds, scaffolds for tissue engineering, bone reconstruction, nerves and gum reconstruction, drugs releasing system, blood vessel growth and stent covering [40, 51, 66]. Besides, in dental industry bioplastics based nanocellulose has been used in dental tissue regeneration in humans which is produced from microbial cellulose by the *Glucanacetobacter xylinus* strain [69].

Bioplastics have been the great of interesting exploration such as in construction and building industry. However not only builder but home owners are also attracted to use bioplastics for different products such as in fencing, decking and so on [65].

Furthermore, in companies that manufacturing the electroacoustic devices, bioplastics is purpose as a membrane for high quality sound [70]. The advantage of this kind materials is providing the same sound velocity as an aluminium or titanium diaphragm and along with the delicate sound. Besides, it also produces the trebles sparkling clear sound and bass notes are remarkably deep. On the other hand, bioplastics also is applied in membrane for reinforcement for high quality electronic paper (e-paper), combustible cells (hydrogen) and as an ultrafiltration membrane for water treatment [40].

The development of bioplastics in packaging industry is being slowly by grocery store delis or food service industry for examples as film for sandwich wraps, for clamshell packaging or for fresh products packaging such as vegetables, fruits, salads, pasta or bakery goods [71]. Therefore, it is looking forward to becomes important materials as biodegradable or durable plastic alternatives especially in instant packaging and disposable applications. Table 4 is showing the various application of bioplastics depend on their material.

Table 4. Applications of bioplastics

Material	Application	Ref.
Starch	Food packaging, medical devices, agriculture foils, textiles, automotive and transport, building and construction	[72], [73], [74], [75]
Cellulose	Reinforced films, packaging, disposal household, medical devices, electronic devices	[74], [75], [76], [77]
PLA	Films, food packaging	[14], [78]
PHA	Coating, food packaging, medical implant	[14], [19], [79]

6. CHALLENGES OF BIOPLASTICS

Bioplastics are usually promoted as a sustainable and alternative to conventional plastics. However, production of bioplastics become most challenging point because the production must be not to disturb the potential food sources. This circumstance can be reduced by utilizing the non-food resources for the purpose. There are called as second-generation bioplastics. However, these must be manufacture via processing ways such as extrusion, compression and injection molding. The possible environmental problems and the impacts of bioplastics have not yet been completely investigated and understood. Therefore, further study is needed to overcome limited sources available, increase resource efficiency and reduce environmental problems.

Furthermore, some of bioplastics which modified from bacterial polymer PLA are only biodegradable in certain conditions of temperature and humidity because the properties of this materials only fixed on that condition to degradable [11]. This restriction must be overcome to ensure that bioplastics can be degrade any condition in landfills. The usage of agricultural fibres as bioplastics production can give a good chance for fortune market. However, economic influences alone will not cause this technology to take off. The improvement performance in natural fiber composites and green composites is required to provide more applications by industries [33].

The production of bioplastics increases significantly comparable to the conventional plastics whereby bioplastics can give a positive impact on the environment, by reducing space for waste storage, decrease the greenhouse gas emissions and reducing the risk of for marine pollution and human health [80]. Therefore, the assimilation of bioplastics might be the great resolution for reducing the problems. This is because bioplastics have good properties such as biodegradable, environmentally friendly, sustainable etc [31].

The development of bioplastic is mainly exposed to the authenticity achieved by the new technology and the legitimacy of the companies who manufacture, marketing and encourage the sustainable technology [81]. The sustainability requires a communication with societies about how bioplastics takeover in service in the future? How to improve a biodegradability? Recovering agricultural applications? Reasonable and appropriate recycling plants?[82].

7. CONCLUSION AND FUTURE PROSPECTS

The environmental impact caused by the large quantity of non-degradable waste materials is promoting research to develop new biodegradable materials that can be manufactured from natural resources like biomass, plants, bacteria. The new developments of bioplastics in the future can

cause the efficiency of production will be increase, built up the new applications and new opportunities of bioplastics. Furthermore, the future market for bioplastics will be is increasing owing to its sustainability. Besides, the biotechnology of microorganism gives an opportunity to bioplastic manufacture because it could significantly apply and commercialize for various industries such as agriculture, medical, pharmaceutical, veterinary, etc.

Hence, a new guideline and standard for bioplastics should be develop for production, usage and waste management of bioplastics over the world. Thus, labeling legislation must be enhanced depend on products raw material usage, energy consumption, emissions from manufacture and use.

The biobased materials or biodegradable materials have major potential of being compostable purpose. Recent developing of technology, continued innovation and global support is important to commercialize and demonstrate the bioplastics.

But nevertheless, the bioplastics must be based on an integrated environmentally friendly to increase the sustainability of materials and processes throughout its lifetime. Bioplastics materials must be not competing with traditional sources and reduce in need of non-renewable resources in long term.

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