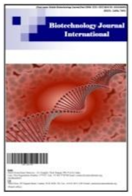

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Emerging Trend of Bio-plastics and Its Impact on Society

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Authors' contributions

This work was carried out in collaboration among all authors. Author SS designed the study, performed literature searches and wrote the first draft of the manuscript. Authors FM and SG performed literature searches and improved the first draft of the manuscript. Authors AN and SN also contributed in literature search and improved the manuscript. Author AK designed and supervised the study, gave instructions to all the co-authors, contributed in adding recent references and finalized the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Bio-plastics are either bio-based polymers or capable of degradation into simple compounds. The rising development in the production and use of bio-plastics has globally revolutionized the dependency on traditional plastics. The conventional plastics prepared from petroleum, coal and natural gas have been extensively used by humans since antiquity as a prime component of almost all the materials used in day to day life. Since, these plastics are non-biodegradable; they cause serious impact on the environment. Recent years have witnessed the introduction of a wide variety of bio-plastics derived from natural polymers such as starch, cellulose, chitin etc. These bio-plastics are now being utilised in packaging materials, electronics, medical devices; holding immense potential for utility in future. This mini-review confers about types of bio-plastics, their utility in different sectors and their future prospective.

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Keywords: *Bio-plastics; biodegradable plastics; starch; cellulose; protein; lipid; green polyethylene; polyhydroxyalkanoates; polylactic acid.*

1. INTRODUCTION

Conventional plastics such as polypropylene (PP), polyethylene (PE), polytetrafluoroethylene (PTFE), polyvinyl chloride (PVC) prepared from non-renewable petroleum oil; not only take several decades for decomposition, but are also responsible for production of toxins during degradation [1]. With the growing human population, there is heavy accumulation of solid non-decomposable stuffs on the earth, of which, superfluous accumulation of plastics has become a major concern globally [2].

Considering ill-effects of traditional plastics, it is being realized to search their effective substitutes (bio-plastics) which possess similar physico-chemical properties compared to petro-based plastics. Bio-plastics are made from bio-based materials like polysaccharides, lipids and also proteins capable of degradation in the environment [3]. Alternatively, bio-plastics can be derived from natural biopolymers which are synthesized and catabolised by various microorganisms [4]. However, one of the major challenges faced by these polymers is to hold the strength and other properties as of petroleum based plastics in addition to have the capability to degrade in a shorter time and non-toxic to humans.

2. FEW REPORTS CITING DREADFUL EFFECTS OF PETRO-BASED PLASTICS

As reported in Green Biz, Plastics will account for more than a third of the global growth of oil demand by 2030 and nearly half by 2050 even more than trucks, aviation and shipping combined [5].

Most of the marine debris deposited so far comprises of non-biodegradable plastics which further breakdown into smaller pieces. Long term durability, low cost, and malleability has encouraged the use of plastics for more and more consumers and industrial products [6].

It has been predicted that if plastic production and use grows at the current rate, then by 2030, the greenhouse gas emissions will reach to an alarming level up to the extent of total emissions by nearly 300 coal based power plants. With traditional non-degradable plastics, there may be emission of nearly 3 x 10^9 tons of CO_2 in the atmosphere after 30 years. It is equivalent to emissions by nearly 600 coal plants of 500 megawatts capacity [7].

Currently, bio-plastics represent only one percent of the 335 million tons of plastic produced annually. According to reports, the global bio-plastics production capacity is set to increase up to nearly 2.6 mega tons by 2023 [8]. Several multinational companies have already begun using bio-plastics. There are reports that sneakers and bricks are being manufactured/ planned using corn stuff and sugar-cane by Reebok and Lego, respectively. Similarly, bio-plastic bottles are also being used by renowned soft drink companies. The need of the hour is to switch towards eco-friendly manufacturing and utilization of plastics for a greener and healthier future. Assessing the need of bio-plastics, work is in progress in our laboratory on isolation of polyhydroxyalkanoates producing bacteria. In the present review, an attempt has been made to describe the research work being carried out for different types of bio-plastics, their utility/applications in various sectors and economics involved. Besides, a comparative account of traditional plastics and bio-plastics and the present status of commercial production of various types of bio-plastics have been discussed.

3. TYPES OF BIO-PLASTICS

In 1850, a British chemist created plastic using cellulose derived by wood pulp which was termed as bio-plastic. In the later years, plastics produced from soybean oil were tested as an alternative to fossil based plastics [9]. Since then, much interest is being exhibited for manufacturing of plastics from plant derived materials owing to rising environmental concerns on the pollution caused by plastics. The European Bio-plastics Organization has classified plastics into different families as outlined in Fig. 1. Bio-plastics can be defined as a family of materials with varying properties chiefly derived from bio-based materials and must get degraded fully into CO_2, H_2O and other inorganic substances [10]. Demand for pro-nature materials is increasing day by day and an annual growth rate of 10 to 20% is being expected [11]. Bio-plastics derived from biodegradable polymers are broadly either plant based polymers viz. protein, cellulose, starch and chitin, or microbes derived polyesters like polyhydroxyalkanoates. However, some of the plastics like PET, PA, PTT can be made from petroleum (fossil-based) as well as renewable resources such as biomass [12].

3.1 Starch-based Bio-plastics

In recent times, thermoplastic starch has become one of the most widely used bio-plastic covering nearly 50 percent of the bio-plastics market [13]. Starch is one of the abundant polysaccharide present on earth synthesized by plants as an energy storage material. Corn is the main cash crop enriched in starch and grown globally [14]. Pure starch has ability to absorb humidity promoting its use for producing drug capsules in the pharmaceutical industry. Moreover, flexibilisers and plasticisers such as sorbitol and glycerol can be easily added to starch to create a diverse range of products having varying characteristics [9].

In the present trend, blending of starch is done with other bio-polymers like polylactic acid, polycaprolactone or polybutyleneadipate-co-terephthalate to prepare bio-plastics [15]. The plasticware are being manufactured on the commercial scale out of these starchy blends and the same have been found to be degradable. Saraswat et al. [16] reviewed the status of bio-plastics derived from starch. Gadhave et al. [13] discussed starch based bio-plastics and their importance in sustainable packaging.

3.2 Cellulose-based Plastics

Cellulose is known to be one of the most abundantly available natural polymers and is obtained from wood pulp or cotton linters by delignification. For preparing cellulose bio-plastics, cellulose esters like cellulose acetate, nitrocellulose and their derivatives, and celluloid are mostly used [17,18]. Some of the cellulosic derivatives like hydroxypropyl cellulose, hydroxypropyl methylcellulose andcarboxymethyl cellulose are used to form films or edible coatings [19].

3.3 Chitosan-based Plastics

Chitin is a polysaccharide having N-acetyl glucosaminyl moieties linked through β-1, 4 linkages. It occurs mainly in skeletons of invertebrates like arthropods and has also been reported in the cell wall of various fungi including yeast. At commercial level, it is extracted from prawns and crab wastes using chemical methods. Chitosan obtained from deacetylation of chitin can form films without addition of any additive, which exhibit good carbon dioxide and oxygen permeability, as well as have excellent mechanical properties [20].

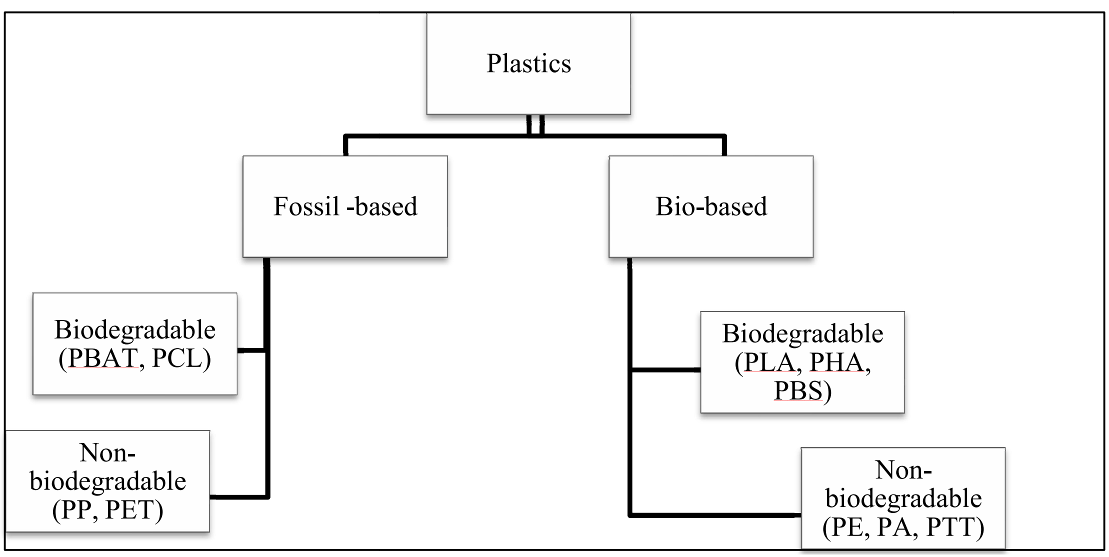

Fig. 1. Classification of plastics based on their composition and degradation

PBAT-polybutyleneadipate terephthalate; PCL- polycaprolactone; PLA-polylactic acid; PHA-polyhydroxyalkanoates; PBS-polybutylene succinate; PP-polypropylene; PET-polyethylene terephthalate; PE-polyethylene; PA-polyamide; PTT-polytrimethylene terephthalate

3.4 Protein-based Plastics

Bio-plastics can be made from proteins like gluten, zein, soy protein, keratin andgelatin etc. isolated from different sources. Most of the proteins derived from different sources like wheat gluten and milk casein are shown to be good candidates for the manufacture of degradable plastics [10]. Proteins can serve as potential candidates for producing bio-plastics due to their renewable nature, biodegradability and excellent gas barrier properties. However, the hydrophilic character of proteins restricts their use for commercialization. Therefore, blending of these proteins with other biodegradable polymers is recommended or changes in the physical properties of these proteins must be carried out using either chemical or microbial method(s) [19].

3.5 Polyhydroxyalkanoates (PHAs) Based Bio-plastics

The aliphatic bio-polyesters which have been used for manufacture of bio-plastics are poly-3-hydroxy butyrate (PHB), polyhydroxyvalerate (PHV) and polyhydroxylhexanoate (PHH). These polyesters belong to the group, polyhydroxylalkanoates (PHAs). Many researchers including our laboratory are engaged in carrying out research on the microbes producing these PHAs. The PHAs are linear polyesters which are produced by bacteria as a result of fermentation of sugars or lipids. These PHAs act as a source of energy and carbon for the bacteria. In PHAs, many different monomer units may be present and depending on the monomer units, these polyesters exhibit different characteristics. The PHAs derived plastics have been found to be more ductile and have lesser young's modulus compared to other plastics. These bio-plastics have also been found to be bio-degradable [21].

The PHAs derived plastics have found their place in pharmaceutical industries. Current research activities are dedicated towards making PHA bio-polyesters marketable. In recent researches, emphasis is on searching new microbes capable of producing PHAs and their manipulation/ exploitation for better yield and also production of highly efficient biomaterials from advanced manufacturing techniques [22].

The commonly used PHA for bio-plastics is PHB which is produced by specific bacteria using corn starch, glucose or wastewater. The PHB derived plastic exhibits properties similar to petroleum oil derived plastic having polypropylene. The PHB-bio-plastic may be exploited for manufacturing transparent film having melting point nearly 130°C and is bio-degradable. In developed countries, sugar based industries have come forward to manufacture PHB on an industrial scale [23].

3.6 Polylactic Acid (PLA) Derived Bio-plastic

The PLA derived bio-plastic is transparent and it also exhibits properties similar to petroleum oil derived plastics like polyethylene terephthalate (PET) plastic, polystyrene plastic (PS) [24].

In addition to PLA derived bio-plastics, PLA blends plastics are also available in the market in the form of granules having different properties. These PLA and PLA blends bio-plastics have been used for the manufacture of fibres, films, cups, bottles etc. The PLA derived bio-plastic is also available as plastic filaments [25].

3.7 Polyamide (PA) Derived Bio-plastic

The polyamide (PA) is also a biopolymer produced from natural oil. However, it is not bio-degradable. The PA derived bio-plastic has more thermal resistance as compared to aliphatic polyesters and polycarbonates [26]. PA based bioplastics have been used in the manufacture of various items like sports shoes, electronic device components, flexible oil and gas pipes, anti-termite sheathing, automobile fuel lines, pneumatic airbrake tubing etc. [27]. A specific polyamide called as polyamide-410 has been derived from castor oil. It has high melting point (more than 200^{o}C), low moisture absorption and much higher resistance to chemical substances [28].

3.8 Green Polyethylene (PE) Derived Bio-Plastic

The polyethylene has ethylene moieties in its structure. Petroleum based polyethylene is used since long time. Nowadays, green PE is also available. For green PE, ethylene is derived from ethanol and ethanol is produced mostly by using ligno-cellulosic biomass (second generation bio-fuel). Green PE is similar in properties to chemically derived PE. Similarly, like chemically produced PE, green PE is also not biodegradable but is recyclable. It has been found that in production of green PE, there is much decrease in greenhouse gas emissions.

Green PE derived bio-plastic can be used for packaging, closures, bags etc. [29].

3.9 Genetically Modified Bio-plastics Producing Bacteria

To the best of authors' knowledge, at present, no genetically modified bacteria is used for production of bio-plastic. However, much work is in progress where people expect to exploit genetically modified crops or bacteria for production of bio-plastic. Carroll et al. [30] reviewed strategies of genetic modification in *Cyanobacteria* to enhance PHB production.

3.10 Lipid Derived Bio-plastic

A number of polymers like polyurethanes, polyesters, epoxy- resins have been prepared using fats and oils isolated from plants as well as animals. These polymers are used for manufacture of bio-plastics. These polymers are also prepared using petroleum oil. Both types of polymers have comparatively similar type of properties. Therefore, there is emphasis on plants and animals derived polymers [31-34]. A metathesis approach for preparation of polymers from plant oils is considered to be important for bio-plastic production. On the other hand, recent advances in microalgae production enriched with oil may be exploited for bio-production of polymers used in bio-plastic preparation [35,36].

3.11 Seaweed Polysaccharide Based Bio-plastics

In recent years, polysaccharides such as alginate and carrageenan derived from marine algal species like *Macrocystis, Laminaria, Chondrus, Mastocarpus* are considered as potential candidates for bio-plastic production. Alginate is an un-branched polysaccharide having mannuronyl and guluronyl moieties joined through β-1,4glycosidic bonds. It. is widely used in biomedical applications. The blend of calcium alginate and polyacrylamide has been reported to exhibit strength, and therefore is capable to serve as an environment friendly packaging material in future. Another seaweed polysaccharide, carrageenan is also a good raw material for bio-plastic. It is made of β-1,4 glycosyl bonds linked disaccharide units having α-D-galactopyranosyl and β-D- galactopyranosyl moieties. Carrageenan has double helical coil in its structure which shares anion-hosting position and facilitates rigidity in bio-plastic formation. The bio-plastics from this seaweed polysaccharide can be considered as good edible packaging material and serve as excellent food coating material in the future market [37].

4. CURRENT UTILITY OF BIO-PLASTICS

4.1 Packaging

The packaging industry is one of the biggest marketing segments of bio-plastics accounting for 53% of the annual production. In recent years, manufacturers of various agriculture related materials like plantlets, manures, agricultural foils and horticultures; cosmetics; toys; alcoholic drinks; and clothing use bio-plastics derived packaging materials. Alternatively, they are used for packing of disposable utensils including cutlery, cups and plates etc. Besides, they are also being used for wrapping material in food industry [38]. Numerous multinational Companies manufacturing soft drinks, ketchups and mineral water have started using polyethylene terephthalate derived bio-plastic bottles. Various faster moving consumer goods (FMCG) companies like Johnson & Johnson and Procter & Gamble have started using bio-based PE for packaging of cosmetic products. Several studies have reported that use of PLA for food packaging is found to be more efficient than conventional PET plastics as there is minimal change in food coloration, ascorbic acid degradation with reduced limonene scalping [39,40]. Currently, McDonald's, Frito-lay, Mont Blanc Primeurs, McCain are using PLA based plastics for packaging food materials.

4.2 Bags

As per estimate, there is an annual use of about five million tons plastic shopping bags worldwide. On an average, sixty thousand plastic shopping bags are used every five seconds [41]. With increasing awareness about the cons of single-use high density plastic bags, biodegradable or compostable shopping bags are turning out as a superior substitute being environment friendly. These bags are usually made of resins composed of starch, polyethylene and heavy metals or starch combined with biodegradable polymers such as PLA. Another category of bags is oxo-biodegradable containing totally degradable plastics additives (TDPA). These additives are known to speed up the biodegradation process by oxidation. Companies like PepsiCo, Snyder's of Hanover and Delhaize now use PLA based bags instead of conventional bags.

4.3 Disposable House ware

Biodegradable plastics have been used in manufacturing of disposable house ware including items used in washroom such as buckets, mugs, soap holders, bottle containers for shampoos, moisturizers, conditioners, shower gels etc, utensils like knives, forks, spoons, bowls etc, hangers etc. Fantastic Beach toys are made of Mirel bio-plastic derived from corn manufactured by Zoëb Organics. Cereplast is a biodegradable resin marketed under the brand name Nat-Ur, made from corn and potato starch is used for manufacturing of cutlery [42]. The company ‘Natur Bag’ sells bio-plastic derived cutlery with a trade name ‘Natur-Ware’ [43]. United Colors of Benetton have started using 100% recyclable biodegradable hangers[44].

4.4 Agricultural Applications

Bio-plastics have been used for the production of agricultural mulches, seeding strips, and tapes [45]. The bio-plastics have also been used in the manufacture of seed belts and active component capsulations. Bio-plastics derived foils and nets are also available nowadays which are used to cover mushroom plants, tree and bush-roots. Besides, these nets and bio-based yarns have also been used to avoid erosion of slopes and mounds till roots of the plants grow well.

4.5 Consumer Electronics

In electronics market, there are reports that SUPLA has optimized polylactic acid compounds derived from lactides developed by Corbion Pura. The company has attempted to develop world’s first bioplastic high gloss touch screen computer made from high heat PLA in collaboration with a Taiwanese Original Equipment Manufacturer (OEM)/original design manufacturer (ODM), Kuender. Besides, PLA blends are also being used for manufacturing of computer monitor screens, computer keyboards, laptops, computer tablets etc. and also games consoles, mobile phones and ear phones etc. The use of bio-plastics in the electronic industries has proven to be beneficiary in terms of environmental credentials. Moreover, there became improvement in many properties like gloss finish, impact resistance and precise processing of these electronic products [46].

4.6 Medical Devices

Bio-plastics derived from PLA and PEG have found their uses in many biomedical fields like manufacture of orthopedic devices, wound filling, drug delivery, tissue engineering, manufacture of porous and fibrous scaffolds. These bio-plastics have proved to be better due to better storage modulus, bio-resorbable property, crystalline nature and transition temperature [47]. Nontoxic biodegradable polymers are also being used in sutures, implants, dental devices, screws, staples, pins, tacks etc. It has been shown that these bio-plastic based sutures stay intact up to the completion of healing of tissues, get dissolved and also get completely metabolized inside the body. TYRX is a biodegradable tyrosine-derived polyarylate marketed by TyRx Pharma, Inc. and is used in a hernia repair device. Itacts as an absorbable antibacterial envelope. Parietex Pro Grip^{TM} is a first bio-component mesh used for laparoscopic self-fixation that facilitates tension-free repair [38].

5. COMMERCIAL PRODUCTION OF BIO-PLASTICS

The speed of change in the production of bio-plastics space for utility in various disposable or non-disposable items revealed that there is not much difference between the costs of petroleum derived plastics and bio-based plastics. The higher cost of the latter is attributable to requirement of lower temperature in processing bio-plastics and constant supply of biomass. Production of biopolymers is gaining impetus nowadays because of their sustainability quotient and industries are trying to utilize waste materials as a source for production of bio-based plastics. This accounts for a revolutionary move, synergizing environment conservation and economic benefits. Further it can help in reducing current oil consumption, as plastic production leads to 4% consumption of the worldwide oil reserves every year. Moreover, increasing oil scarcity is contributing to a sharp increase in prices of petroleum based materials. Thus, it is inevitable that large-scale industrial production of bio-plastics will take over the conventional plastics in time to come. An account of various bio-plastics with cost of production has been given in Table 1.

5.1 Bio-plastics Versus Traditional Plastics

Traditional plastics have become a menace for the society due to their ill-effects exhibited on the environment and ecosystem. Due to harmful effects and alarming environmental pollution, many countries like Tunisia, China, Korea, Bangladesh, India etc. have taken the lead to put a ban on single-use plastics. It is expected that more countries will come forward in putting the ban on single-use plastics. As a result of new rules and legislations, the role of environmentally and economically viable bio-plastics has become important. Considering the market demand, it is being speculated that more industries will come forward for manufacturing biodegradable plastics/ bio-plastics.

Conventional plastics are dependent on fossil fuel as a key raw material. The price of petroleum oil has been tremendously increased in recent years and the available stock is likely to exhaust in the near future. In addition, these plastics require comparatively higher energy during the development process as compared to bio-plastics. Studies have reported that typical petroleum based plastic shows much higher carbon dioxide emissions compared to PLA derived bio-plastic [9]. On the other hand, bio-plastics which are prepared from sustainable raw materials like ligno-cellulosic biomass and vegetable oils have been globally accepted as a greener alternative for replacing petroleum based plastics [48]. With equivalent strength and versatility as that of traditional plastics, bio-plastics have made a mark in various sectors like packaging, wrapping, medicines, textiles, agriculture etc. In USA, McDonald Group has started manufacturing biodegradable containers for their fast foods. Similarly, other companies such as Bayer, DuPont, Dow Cargill and Nike have also started producing biodegradable packaging materials. Likewise in India, various companies like Envigreen, Eco-life, Plasto-bags, Earthsoul India and True green have ventured in manufacturing a variety of bio-plastics.

Evolution of bio-plastics across the world in past few years has brought a positive change in environment conservation and is the first step towards a greener environment. Although the potential of bio-plastics is still not fully explored, but looking to the demand of plastics in every sphere of life, it is destined to take over the traditional plastics in future. Various International Committees including Committee of Agricultural Organization in the European Union (COPA) and General Committee for the Agricultural Cooperation in the European Union (COGEGA) have assessed the potential requirement of bio-plastics and it has been predicted that it is increasing year by year. As per a prediction, there will be requirement of nearly six billion tons of bio-plastics by 2021. However, it is also important to note that all bio-plastics are not compostable and may require industrial treatment while the recycling treatment of bio-plastics must be separated from the conventional plastics which could otherwise lead to environmental hazards [50].

Table 1. Various bio-plastics being manufactured commercially along with their applications

Company	Origin	Type of Bio-plastic	Cost (Eur/kg)	Applications
Novamont	Italy	Mater-Bi starch based resins	3.4-5.1	Filming, Thermoforming, Fillers
Arkema	France	PA10, PA11	2.5-6.9	Thermoforming, Bottle blow molding, Injection molding
Yield10 Bioscience	USA	PHA, PHB		Water treatment
Neste	Germany	Bio-based polyethylene and Bio-based polypropylene		Food packaging materials
NatureWorks	Thailand	PLA	1.5-2.0	Extrusion, Thermoforming, Injection Molding, Films, Cards
Natur-Tec	USA	PLA		Extrusion, Injection Molding, Films, Apparel Packaging

(Source: OECD (2014-09-29), "Biobased Chemicals and Bioplastics: Finding the Right Policy Balance", OECD Science, Technology and Industry Policy Papers, No. 17, OECD Publishing, Paris. http://dx.doi.org/10.1787/5jxwwfjx0djf-en) [49]

6. CONCLUSION

The ever-increasing environmental pollution caused by the excessive use of petroleum based plastics; continuous depletion of fossil fuels and its consequences seen on the carbon foot-prints has imposed serious hazards on the planet. On the other hand, bio-plastics have emerged as a greener alternative for the society because of its ease in degradability, reusability and production from bio-based materials. The budding awareness and ascending growth of bio-plastic producing industries has helped in filling the lacuna of using bio-plastics by the consumers and has successfully encouraged researchers to build cost effective technologies for production of bio-plastics.

DISCLAIMER

The products used for this research are commonly and predominantly used products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Saharan BS, Ankita SD. Bioplastics-for sustainable development: A Review. Int J Microbial Res Technol. 2012;1:11-23.
2. Gross RA, Kalra B. Biodegradable polymers for the environment Science. 2002;297(5582):803-807. DOI: 10.1126/science.297.5582.803
3. Sinan M. Bioplastics for sustainable development: General scenario in India. Curr World Environ. 2020;15(1). Available:http://dx.doi.org/10.12944/CWE.15.1.05.
4. Braunegg G, Lefebvre G, Genser KF. Polyhydroxyalkanoates, biopolyesters from renewable resources: physiological and engineering aspects. J. Biotechnol. 1998: 65(2-3):127-161.
5. Kaufman H. Why plastics are also a climate issue. 2020. Available:https://www.greenbiz.com/article/why-plastics-are-also-climate-issue
6. Brassey Charlotte. A mission to the Pacific plastic patch. BBC News; 2017. Retrieved 21 July 2017.
7. Plastic and Climate: The Hidden Costs of Plastic Planet; 2019. Available:https://www.ciel.org/wp-content/uploads/2019/05/Plastic-and-Climate-Executive-Summary-2019.pdf
8. European Bio-plastics Report, Bio-plastics market data. (Marienstraße 19-2010117 Berlin); 2018.
9. Reddy MM, Vivekanandhan S, Misra M, Bhatia SK, Mohanty AK. Biobased plastics and bionanocomposites: Current status and future opportunities. Prog. Polym. Sci. 2013;38(10-11):1653-1689. DOI:10.1016/j.progpolymsci.2013.05.006
10. Song JH, Murphy RJ, Narayan R, Davies GB. Biodegradable and compostable alternatives to conventional plastics. Philosophical Transactions of the Royal Society B: Biological Sciences. 2009;364: 2127–2139. DOI:10.1098/rstb.2008.0289
11. Kumar S, Thakur KS. Bioplastics-classification, production and their potential food applications. Indian J. Hill Farming. 2017;8(2):118-129. Available:http://dx.doi.org/10.5958/2230-7338.2017.00024.6
12. Shah TV, Vasava DV. A glimpse of biodegradable polymers and their biomedical applications. e-Polymers. 2019; 19(1):385-410.
13. Gadhave RV, Das A, Mahanwar PA, Gadekar PT. Starch based bio-plastics: The future of sustainable packaging. Open J. Polymer Chem. 2018;8:21-33. DOI: 10.4236/ojpchem.2018.82003
14. Asaf Kleopas, S. Synthesis and Properties of Starch Based Bio-Materials. University of Groningen, Groningen; 2008.

15. Khalid S, Yu L, Meng L, Liu H, Ali A, Chen L. Polylactic acid/starch composites: Effect of microstructure and morphology of starch granules on performance. J. Appl. Polymer Sci. 2017;134.
DOI:10.1002/a45504
16. Saraswat Y, Patel M, Sagar T, Shil S. Bio-plastics from starch. Internation J. Res. Sci. Innovation. 2014;1(8).
ISSN: 2321-2705.
17. Hossain AS, Ibrahim NA, AlEissa MS. Nano-cellulose derived bioplastic biomaterial data for vehicle bio-bumper from banana peel waste biomass. Data in brief. 2016;8:286-294.
DOI:org/10.1016/j.dib.2016.05.029
18. Mostafa NA, Farag AA, Abo-dief HM, Tayeb AM. Production of biodegradable plastic from Agricultural wastes. Arabian J. Chem. 2018;11:546-553.
Available:http://dx.doi.org/10.1016/j.arabjc.2015.04.008
19. Majid I, Thakur M, Nanda V. Biodegradable packaging materials. Elsevier Inc; 2018.
DOI:10.1016/B978-0-12-803581-8.10356-X
20. Thakur VK, Thakur MK. Handbook of sustainable polymers: Processing and applications. Pan Stanford Publishing: Singapore; 2016.
21. Wang Y, Yin J, Chen GQ. Polyhydroxyal-kanoates, challenges and oppurtunities. Curr. Opin. Biotech. 2014;30:59-65.
22. Koller M. Advances in Polyhydroxyal-kanoate (PHA) Production. Bioeng. 2020; 7(1):24.
23. Petrasovits L, Purnell M, Nielsen L, Brumbley S. Production of polyhydroxy-butyrate in sugarcane. Plant Biotechnol. J. 2007;5:162-72.
DOI:10.1111/j.1467-7652.2006.00229.x
24. Lim LT, Auras R, Rubino M. Processing technologies for poly (lactic acid). Prog. Polym. Sci. 2008;33(8):820-852.
25. Jem KJ, van der Pol JF, de Vos S. Microbial lactic acid, its polymer poly (lactic acid), and their industrial applications. In Plastics from bacteria. Springer, Berlin, Heidelberg. 2010;323-346.
26. Tokiwa Y, Calabia BP, Ugwu CU, Aiba S. Biodegradability of plastics. Int. J. Mol. Sci. 2009;10(9):3722–3742.
Available:https://doi.org/10.3390/ijms10093722.
27. Thomas S, Ninan N, Mohan S, Francis E. (Eds.) Natural polymers, biopolymers, biomaterials, and their composites, blends, and IPNs. CRC press; 2012
28. Chen GQ, Patel MK. Plastics derived from biological sources: present and future: A technical and environmental review. Chemical reviews. 2012;112(4):2082-2099.
29. Morschbacker A. Bio-ethanol based ethylene. Polym Rev 2009;49:79–84.
30. Carroll AL, Case AE, Zhang A, Atsumi S. Metabolic engineering tools in model cyanobacteria. Metab. Eng. 2018;50:47–56.
DOI: 10.1016/j.ymben.2018.03.014
31. Meier MA, Metzger JO, Schubert US. Plant oil renewable resources as green alternatives in polymer science. Chem. Soc. Rev. Chemical Society Reviews. 2007;36(11):1788-1802.
DOI:10.1039/b703294c
32. Pillai PK, Floros MC, Narine SS. Elastomers from renewable metathesized palm oil polyols. Acs Sustain. Chem. Eng. 2017;5(7):5793-5799.
33. Can E, Küsefoğlu S, Wool RP. Rigid thermosetting liquid molding resins from renewable sources. I. Synthesis and polymerization of soy oil monoglyceride maleates. J. Appl. Polymer Sci. 2001;81: 69–77.
DOI :10.1002/a1414
34. Stemmelen M, Pessel F, Lapinte V, Caillol S, Habas JP, Robin JJ. A fully biobased epoxy resin from vegetable oils: From the synthesis of the precursors by thiol-ene reaction to the study of final material. J. Polymer Sci. Part A:Polym. Chem. 2011; 49:2434–2444.
DOI:10.1002/pola.24674.
35. Meier MA. Metathesis with oleochemicals: New approaches for the utilization of plant oils as renewable resources in polymer science. Macromol. Chem. Phys. 2009: 210(13-14):1073-1079.
36. Mata TM, Martins AA, Caetano NS. Microalgae for biodiesel production and other applications: a review. Renew. Sust. Energ. Rev. 2010;14(1):217-232.
DOI: 10.1016/j.rser.2009.07.020
37. Zhang C, Show PL, Ho SH. Progress and perspectives on algal plastics- A critical review. Bioresour. Technol. 2019;121700.
38. Ashter SA. Commercial applications of bioplastics. In Introduction to Bioplastics Engineering, William Andrew Publisher. 2016;227-49.
39. Koide S, Shi J. Microbial and quality evaluation of green peppers stored in

biodegradable film packaging. Food Control. 2007;18(9):1121-1125.

40. Almenar E, Samsudin H, Auras, R., and Harte, J. Consumer acceptance of fresh blueberries in bio-based packages. J. Sci. Food Agric. 2010;90(7):1121-1128. Available:https://doi.org/10.1002/jsfa.3922
41. Sabbah M, Porta R. Plastic pollution and the challenge of bioplastics. J. Appl. Biotechnol. Bioeng. 2017;2:00033. DOI: 10.15406/jabb.2017.02.00033.
42. Thomas J. Compostable cutlery made from Cereplast; 2005. Available:http://www.treehugger.com/clean-technology/compostable-cutlery-made-from-cereplast.html.
43. Bio-based compostable cutlery, Natur Bag. Available:http://www.naturbag.com/biobased-compostable-cutlery.
44. Chua JM. Benetton gets greener with biodegradable hangers and organic cotton. Available:http://www.ecouterre.com/benetton-gets-greener-withbiodegradable-hangers-organic-cotton-garments/
45. Agriculture and horticulture. European Bioplastics; 2019. Available:http://en.europeanbioplastics.org/market/applications/agriculturehorticulture
46. PLA bioplastic debuts in touch screen computer housing. Plastics Today; 2013. Available:http://www.plasticstoday.com/articles/k-2013-pla-bioplastic-debuts-touchscreen-computer-housing
47. Bano K, Pandey R, Jamal-e-Fatima, Roohi. New advancements of bioplastics in medical applications. Int. J. Pharm. Sci. Res. 2018;9(2):402-416. DOI: 10.13040/IJPSR.0975-8232.9(2).402-16.
48. Gill M. Bioplastic: A better alternative to plastics. Int. J. Res. Appl. Nat. Soc. Sci. 2014;2:115-120.
49. OECD (2014-09-29). Biobased chemicals and bioplastics: Finding the right policy balance. OECD Science, Technology and Industry Policy Papers. No. 17, OECD Publishing, Paris; 2014. Available:http://dx.doi.org/10.1787/5jxwwfjx0djf-en
50. Arikan EB, Ozsoy HD. A review: investigation of bioplastics. J. Civ. Eng. Arch. 2015;9:188-192. DOI:10.17265/1934-7359/2015.02.007

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