Era Of Biodegradables: Bringing Alternative of Plastic Bottles to Forefront

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Abstract

BACKGROUND/INTRODUCTION:

The population around the world accounts for around 7.53 billion (753.04 crores) out of which 1.33 billion (133.92 crores) reside in India. As per the 2018 report published by United Nation, 8.30 billion (830 crores) tonnes of Plastic have been generated in the world so far which is more than the global population.

According to another published report, 630 Cr metric tons of plastic that were generated in 2015 had 9% recyclable, 12% incarnated, and 79% discarded in landfills. If this continues, by the year 2050, there will be the generation of 1200 Crore tons of plastic which will end up in landfills.

Plastics are primarily used in packaging, building and construction work, textiles, consumer and institutional products, transportation, electronics, industrial machinery, and other areas. Out of all areas of its application, packaging has the highest share which accounts for 146 million tones as per 2015 published data.

Polyethylene (PET), polystyrene and Polyvinyl chloride (PVC) are highly used materials in the packaging industry due to their tremendous mechanical, chemical, and electrical properties. According to the International Trade Centre (ITC), the trade value of polyethylene was estimated to be $85.30 billion in 2018 and the market size was evaluated to be $174 billion in 2018. Plastic is non-biodegradable in nature, it takes around 400-1000 years to degrade.

Even though they have a negative impact on our environment, and health, plastics have still widely been used around the globe. As per the UN annual report 2018, on World Environment Day Indian government pledged to ban the utilization of single-use plastic followed by which Uttar Pradesh State Road Transport Corporation (UPSRTC) has discontinued providing water bottles to the passengers traveling through buses and are not allowed to carry plastic bottles with them. Stopping the use of plastic does not provide a solution where we are completely dependent on plastic. Myriad materials are being investigated which could be used to reduce the environmental burden example corn starch, paper, casein formaldehyde, red algae etc.

OBJECTIVE: To determine various alternatives to plastic bottles which can create a bridge for the future growth of India and facilitate the preservation of the environment.

METHODOLOGY: A literature review of the status and future perspective on the introduction of biodegradable material all over India.

RESULTS: The country's first private semi-high-speed train named Lucknow-Delhi Tejas Express, provides biodegradable drinking water bottles which are manufactured at the Mumbai bottling plant of Indian Railway Catering and Tourism Corporation (IRCTC) on a trial basis, explains the cost of bottles to be 15 paise extra in manufacturing (2018). In past, a Vegan bottle made from the bagasse of sugarcane has been manufactured by the French packaging company- Lyspackaging. Not only this, an Edible water bottle is a blob-like water container (named ooho) that is prepared using brown algae, sodium alginate gel, and calcium lactate are also available. Another brand-named Biota sells spring water in bottles made from corn starch.

RECOMMENDATION: The feasibility of biodegradable bottles could be explored in various geographical locations in India.

Keywords: Biodegradables, Plastic, bioplastics, algae, casein, environment

INTRODUCTION

In the beginning of 20th century, Leo Baekeland invented first completely synthetic plastic polymer by reacting formaldehyde and phenol at controlled temperature and pressure. The material got its name as Bakelite which was highly used for making weapons in second world war, preparing household appliances and telephones (1).

In 1838 and 1872, Henry Victor Regnault (French physicist) and Eugen Baumann (German chemist) respectively discovered PVC (Polyvinyl chloride); however, they were unable to determine the use of this material.

Eventually, in 1926 Waldo Semon and the Goodrich Company identified a way to plasticize PVC by blending it with various additives followed by which it was used commercially for water resistant coating of fabrics, making waterproof piping, electric cables, flooring etc. (2).

Few years later, in 1941 PET (polyethylene terephthalate) was discovered which is highly used for preparing plastic bottles (1). Plastics is prepared by incorporating cellulose, coal, salt, natural gas, and crude oil. As crude oil is made of many lighter and heavier components that can be separated through distillation with formation of crude oil fraction (contains hydrocarbon chains); therefore, the plastic can be prepared either by polymerization or by polycondensation like thermoplastic and thermoset plastic respectively. In a polymerization reaction, long polymer chains are formed by linkage of monomers such as propylene and ethylene. Each polymer has its own structure, properties, and size (5).

In 1973, polyethylene terephthalate was introduced for beverages packaging which caused economic boom for the plastic industry. Since then, the production of petrochemical polymers plastics has increased 20 times and more than 99% of all the plastics are produced by crude oil, it is possible that by 2050 world's 20% of the total oil could be consumed by the plastic industry (1,3,5).

There is various type of plastics been used all over the world; however, the most common types of plastics used are –

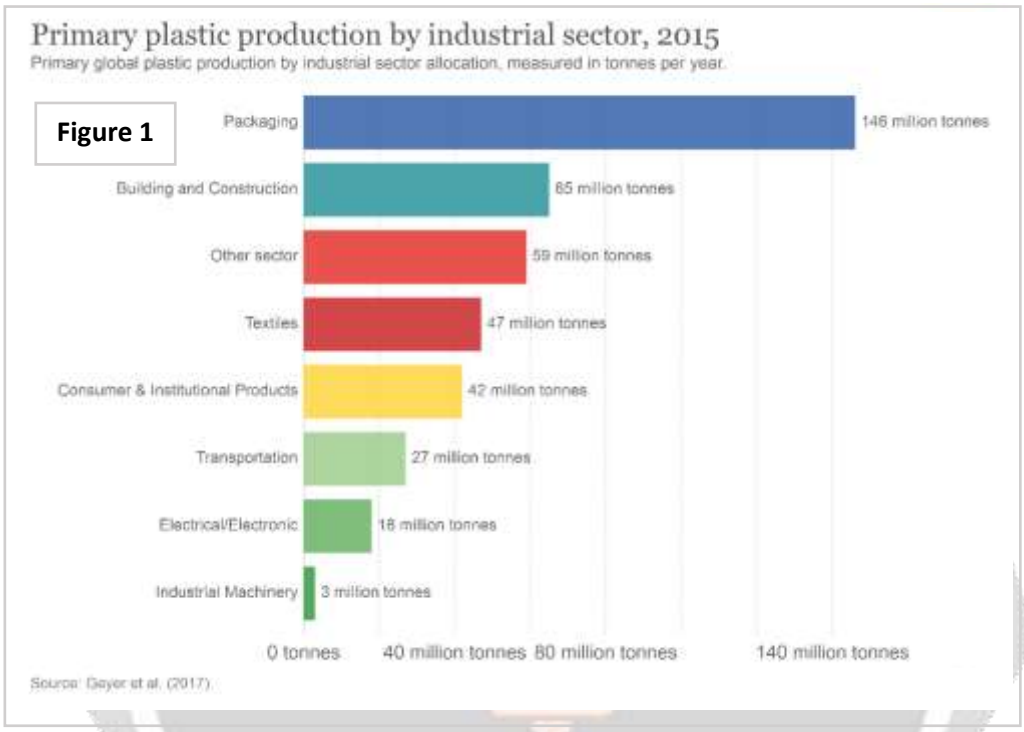
- **High-density polyethylene** (HDPE) – Used in packaging of water, juice containers, detergent and shampoo bottles, garbage bags, yogurt, and margarine tubs.
- **Polyethylene terephthalate** (PET) – Used in packaging of juice, water, soft drinks, beer, mouthwash, and other commercial products.
- **Polyvinyl chloride** (PVC) – Being the third most used plastic in the world cause asthma, allergic symptoms in children and certain type of cancers. Is generally used in making toys, blister packaging of medicines, food packaging, pipes etc. (6)
- **Low-density polyethylene** (LDPE) –Is safer than PVC. Is used for dry cleaning and as frozen food bags (6).
- **Polypropylene** (PP) – Used in bottles for ketchup, yogurt, medicine, syrups, straws, and baby bottles. Considered a safer plastic (6).
- **Polystyrene** (PS) – Develops reproductive and developmental problems. Brain and brain and nervous system damage notice in case of long-term use. Utilized for making plastic cutlery, disposable containers (6).

All over the over, about 8.30 billion tons of Plastic has already been generated since 1950s which is way more than the global population. Out of all the plastic generated, half of them is designed to be used once (3).

The CAGR of plastic industry is expected to grow at the rate of 6.2 % from 2019 to 2026 and the value projected for 2026 is 56.9 billion (4).

China produces the largest quantity of plastic which accounts for approximately 60 million tons. The United States produces 38 million tons of plastic annually followed by Germany at 14.5 million with Brazil at 12 million tones (6).

The Plastics are primarily used in packaging, building and construction work, textiles, consumers and institutional products, transportation, electronics, industrial machineries and in other areas. Out of all areas of its application, packaging has the highest share which accounts for 146 million tones as per 2015 published data and provides employment to almost 10 lakh people (figure 1). (7,8)



In FY 2018, India exported plastic bottle to 172 countries globally with the total export value of 120.86 USD million.

The top countries that import plastic bottles from India are United Arab Emirates (15.25 USD Million), USA (12.18 USD Million), Nepal (7.88 USD Million), Saudi Arabia (6.91 USD Million) and Kenya (6.09 USD Million). In March 2019, total export from India was of 12.08 USD million out of which 1.64 USD million was exported to United Arab Emirates.

The major ports through which generally exports occur are- Nhava Sheva sea (54%), Thar Dry Port-Ahmedabad (43.2%), Petrapole road- Kolkata, Raxaul- Bihar and Bombay air cargo (9). With increasing plastic production, there is high amount of plastic waste produced globally which is not managed properly.

India being world's seventh largest country produces 18,80,559 tons of plastic waste (Figure. 2). Due to inappropriate handling of plastics; micro-plastics enter rivers, sea and oceans which then interferes with our natural habitat. Chang Jiang river followed by river Indus contains highest amount of plastic waste around the globe which accounts for 14,69,481 tons and 1,64,332 tons respectively (Figure 3) (3). More than 100,000 marine mammals get killed every year due to this plastic waste and about 1.5 million albatrosses that inhabit at the Midway Islands have plastic in their digestive system (10).

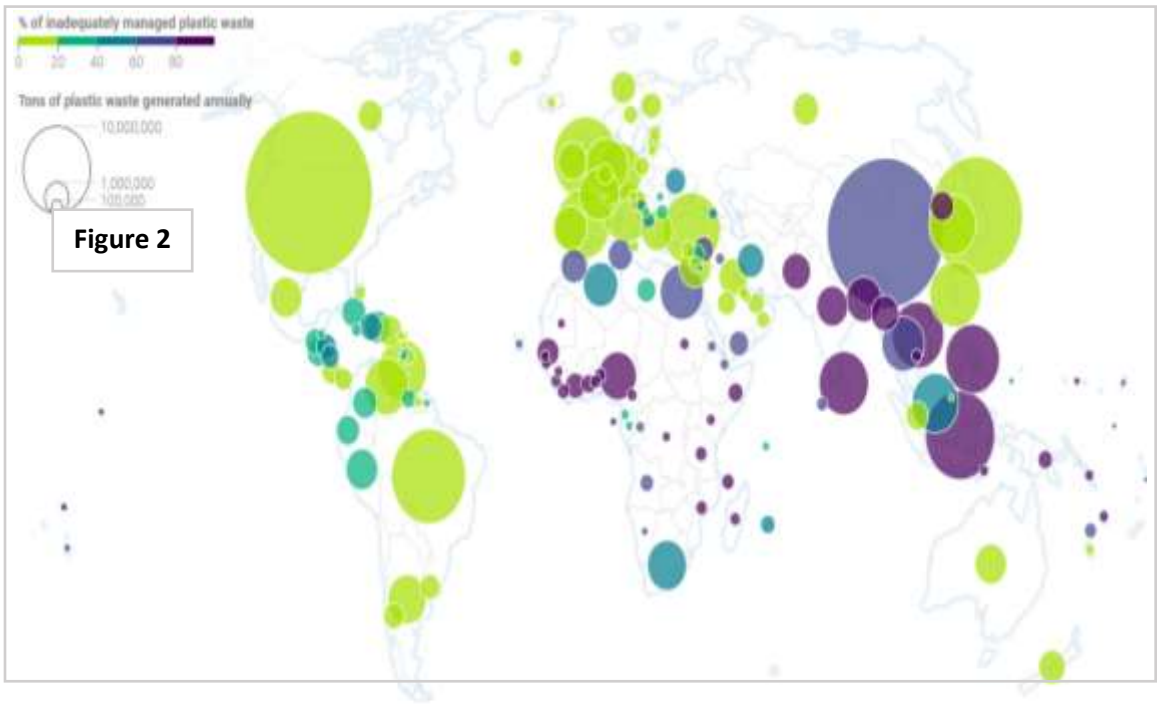
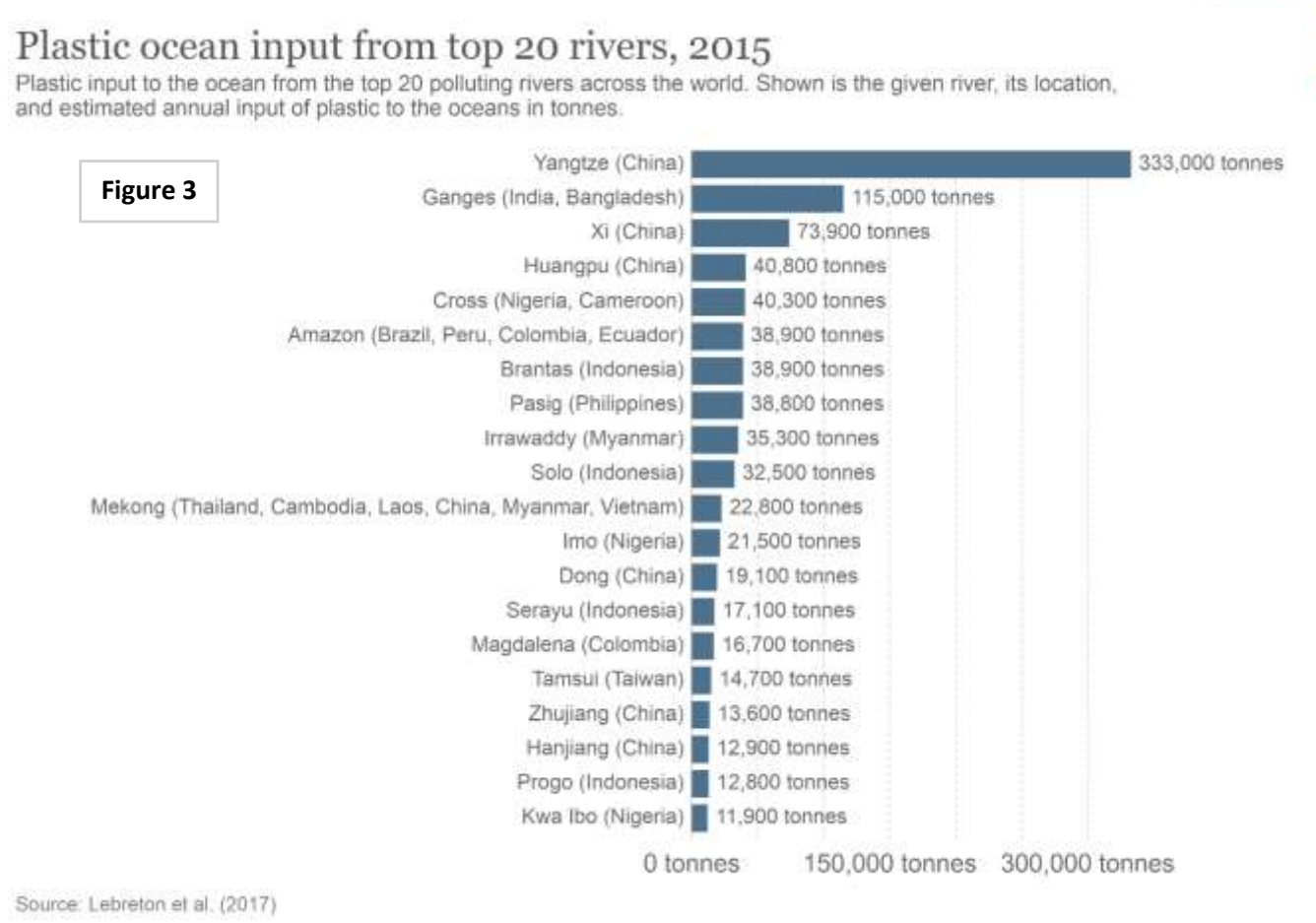


Figure 2

Data from "Plastic waste inputs from land into the ocean" by Jenna Jambeck and others, published in Science (2015)

Figure 3



The Great Pacific Garbage Patch (GPGP) is in the North Pacific Ocean having area of 1.6 million square Km, contains largest accumulation of plastic. It consists of 1.8 trillion pieces of plastics and having 79,000 tons of mass (10). Plastic being non-renewable in nature is causing devastating damage to our environment. As per a published report, 6.3 billion metric tons plastic was generated in 2015 out of which 9% was recyclable, 12% incarnated and 79% was discarded in landfills. If this continues, by the year 2050, there will be generation of 1200 Crore tons of plastic which may end up in landfills (Figure. 4) (3).

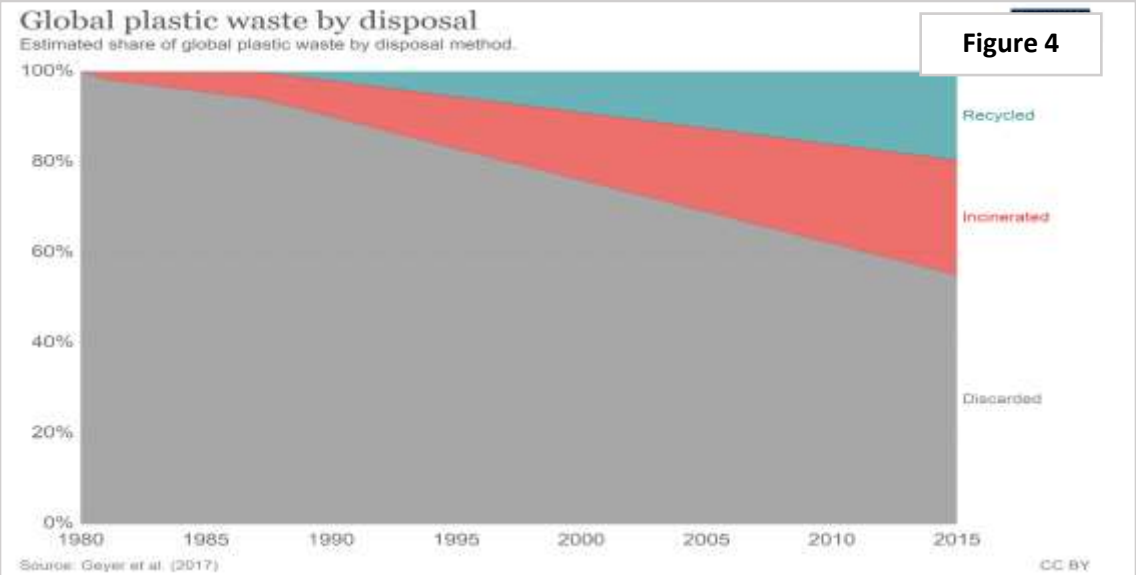


Figure 4

China have applied stringent environmental laws in July 2017 and entirely banned plastic waste import on January 1, 2018, which impacted the world due to various countries not prepared for the same.

As per a study conducted by University of Georgia, if this law persists, there will be 11 million metric tons of plastic waste be left unaccounted forever.

Later India imposed plastic waste ban in 2019. Now the waste has begun to redirect, to Hong Kong and other Southeast Asia countries (12,13). Indian government in 2018 pledged on world environmental day and banned the use of six different types of single-use plastics (polythene bags, bottles, plates, straws, and certain sachets) by keeping in mind that this ban could reduce the plastic consumption to approximately 14 million tons.

After this order by government, the Uttar Pradesh State Road Transportation corporation (UPSRTC) discontinued selling plastic bottles in bus and station (14, 15). Approximately 253 million passengers travel annually through UPSRTC busses and stopping the use of plastic does not provide a solution for our majorly plastic dependent society (16).

There are 50,000 plastic manufacturing units in India and about 10,000 manufacturing units have shut down causing more than 4.5 lakh people to lose their job before November 2019 (17). There is lack of alternative in India especially for plastic bottles due to which Indian economy might face catastrophic damage hence, alternatives need to be figured out soon.

Myriad materials could be used which are either biodegradable, degradable or compostable in nature having similar function as that of oil-based polymers (plastics).

Figure 4

	Non-Biodegradable	Biodegradable
Bio-based	BIOPLASTIC	BIOPLASTIC
Fossil Based	PLASTIC	BIOPLASTIC

Figure 4: Type of materials available. Biodegradables are bioplastics which are either biobased or are fossil based.

There are certain bio-based materials which has the potential to replace plastic bottles are -

Chitin and Chitosan- Insects, Invertebrates and fungi are main source of both chitin and Chitosan which possesses antimicrobial activity and is widely used in packaging industry.

Shrimps and lobster shells contain chitin which is biopolymer in nature. Lobsters are washed, dried under sun and crushed followed by which it is placed in hydrochloric acid and sodium hydroxide to obtain chitin from it. Chitosan has excellent strength and elongation property; however, has poor barrier to moisture. Blending chitosan with synthetic polymer improves mechanical properties of chitosan film. Adding glycerol/ sorbitol (plasticizers) improves plasticity of chitin (18,19). Around more than 1.5 lakhs tons of shrimps' head and cell waste generated annually in India before packing them which could be used in making bioplastic bottles (38).

Chitin and chitosan are used in treatment of obesity, cholesterol, and arthritis. Demand for them is around 2,000 tons per month (38).

Casein plastic- Milk constitutes around 3 % of casein. When casein is extracted with the help of rennet followed by being cured in dilute solution of formaldehyde for several days that leads to formation of Galalith (casein plastic). Galalith which was first introduced in Germany is used in manufacturing buttons, imitation jewelry, buckles, and hair clips.

Casein has great resistance to oxygen and aroma; however, is sensitive to water but to improve the mechanical property (by cross-linking), a plasticizer like formaldehyde is added. The formed Galalith is biodegradable, extremely hard, non-flammable and has good compressive strength (20,21).

Starch- Energy is preserved in plants in the form of starch example in corn, potatoes, pea, oat, wheat, banana etc. Potatoes and cassava have high starch content and low protein level as compared to wheat. Sweet potatoes contain about 58-76% of starch which has two components amylose and amylopectin (polymers) (22).

To retrieve starch through potatoes, first step starts with weighed them (before and after wash) followed by which the potatoes are hand peeled carefully to avoid wastage and then are diced into small symmetrical pieces. Blending and slurring is done with addition of water having ratio of tuber to water as 1:10 This is done on heater pate and ice is added to avoid heat induced damage. Slight amount of metal could be added to improve tensile strength. Next step is filtration, done using cheesecloth, water is added repeatedly to dilute. Process of centrifuge is done to remove unwanted components, then acid and water is added after drying the constituents, which leads to hydrolysis. Synthetic Polymer like glycerol can be added to improve the mechanical property. This extracted starch polymer is biodegradable and is of white color. Almost 50 % of the all the bioplastic available are made up of starch. (Figure 5) (23)

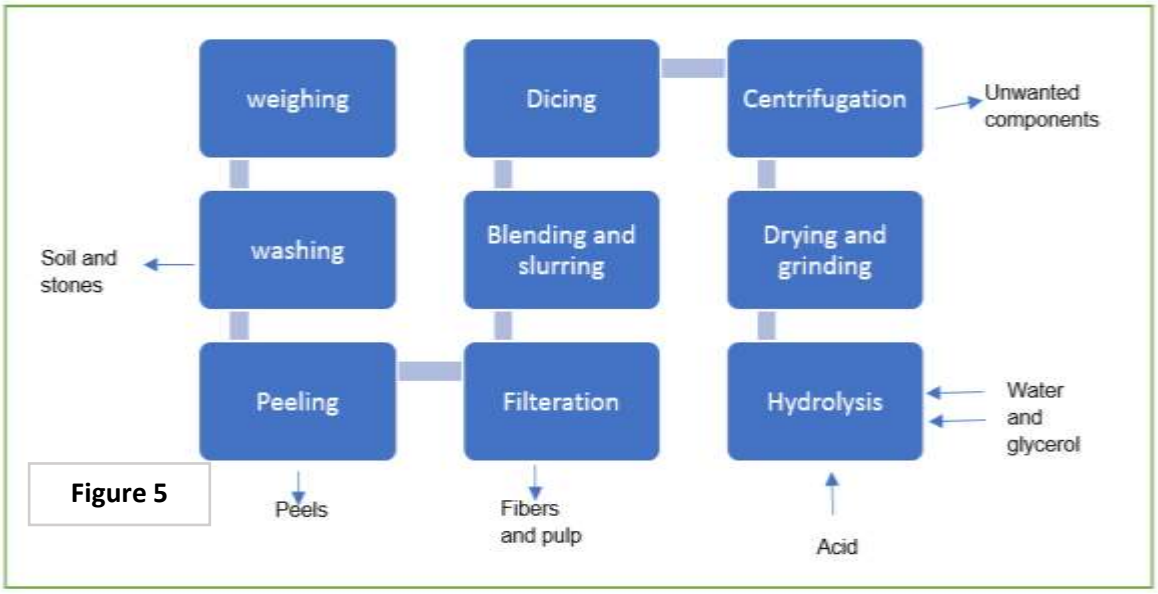


Figure 5

The plastic produced through starch is biodegradable only when the starch content is more than 60% (24).

Polylactic Acid or polylactide (PLA) is derived through starch from crops like corn and sugarcane. It is formed by converting lactic acid, which is biodegradable, thermoplastic. Polymerization of lactide with the help of a catalyst (like stannous octate) leads to formation of thermoplastic film which has good moisture resistance. There are three types of PLA (PLLA, PDLA and PDLLA) based upon the presence of location of lactic acid in the molecular structure. PLA when mixed with nanoclay or cellulose could help to reduce cost (25).
PLA can be produced by either chemical synthesis or through bacterial fermentation of carbohydrates. Bacterial fermentation is cost effective and can be classified as heterofermentative or homofermentative. Through heterofermentation, acetic acid, glycerol, ethanol, carbon dioxide with low quantity of lactic acid is produced, whereas, in homofermentation high amount of lactic acid is produced with minimal number of other metabolites. Melting point of PLA is 130-180 degree Celsius (26,27,28).
PLA degradation is a two steps process- hydrolytic degradation i.e., by diffusing in water and anaerobic degradation which is an enzymatic degradation. The complete degradation happens in 6 months (29).

Algae- Algae are of types microalgae or macroalgae. Microalgae are microscopically size organisms which can grow rapidly to produce biomass. Calothrix Scytonemicola, Almeriensis and Neochloris Oleoabundans are certain microalgae which can be used to produce bioplastic. On the other hand, seaweeds are macroalgae which are of types- Red seaweeds, Green seaweeds and Brown seaweeds. Seaweeds are cost effective, less brittle, and durable in nature (30).

Seaweeds are abundantly found on the coast of Gujarat, Tamil Nadu, Lakshadweep and near Andaman and Nicobar Islands which has great potential to be used widely as per central marine fisheries research institute (CMFRI). Algae produces starch by photosynthesis (30,31).

To prepare bioplastic, microalgae is weighed and is kept dipped in acetone for 24 hours to remove pigment and lipids. Then, magnetic stirring and centrifugation is performed. The solution is dried and kept in frozen bath (of dry ice) called lyophilization. Now to separate solid and liquid part, sublimation process is performed to evaporate liquid. Next glycerol or sorbitol is added to increase the mechanical property of the material (31).

Polyhydroxyalkanoates (PHA)- PHA is produced during bacterial fermentation of lipids and sugar which gets accumulated in the bacterial cell wall as a source of energy under unbalanced growth condition (example dryness, lack of nutrients) and excessive carbon. PHA is ductile, is UV stable, soluble in halogenated solvents (like

Chloform) and has melting point between 40-180 degree Celsius; however, is less elastic in nature as compared to conventional plastics so to improve the properties of PHA, fillers are added (32,33).
Organic waste or sludge can be used as feedstock for microorganism. The sludge from the water waste treatment process is found to be cheapest source of PHA (34).
To prepare PHA, bacterial strains are grown in a medium containing Sodium hypochloride which helps in lysis of the bacterial cell wall. Bacterial culture is then centrifuged with addition of NaCl solution and then freeze dried. The solution is then treated with halogenated solution like chloroform such that PHA gets dissolved and then it is dried (34)

OBJECTIVE

To review the plastic industry and determine various alternatives to plastic bottles which can create a bridge for the future growth of India and facilitate the preservation of the environment.

METHODOLOGY

Literature review of 15-20 research papers and 20-30 articles from year 2014 to 2019 and some important articles prior to 2014 reviewed with respect to plastic industry and various materials which could be used as alternative to plastic bottles.

RESULTS

Biodegradable plastic bottles in India are first time introduced in Lucknow-Delhi Tejas Express in October 2019, which is manufactured by The Indian Railway Catering and Tourism Corporation (IRCTC) which is on trial stage. These biodegradable bottles cost 15 paisa extra in manufacturing as compared to the plastic non-biodegradable bottles (35).

Urthpact the first completely compostable bottle manufacturing organization provides bottles, labels, and caps. The bottles are made from plants mainly made up of PLA hence the bottle degrades within 3 months of manufacturing (39).

Ooho is the first edible water bottle which is a blob like water container prepared using brown algae. Is extremely safe and easy to prepare. Sodium alginate (the algae) is mixed with calcium lactate leads to formation of Ooho (40).

Another brand-named Biota sells spring water in their bottles made from corn starch.

Cove bottle manufacturing company present in California, is the world's first reusable plastic bottles manufacturing organization which prepares bottle using PHA (37).

Lyspackaging a French packaging company prepared first biodegradable bottle in the world by using PLA from bagasse of sugarcane and has named their bottles as Vegan bottle. The label and bottle caps are also fully biodegradable in nature (41).

DISCUSSION

Eco-friendly bottles market has CAGR of 7.3% and is projected to grow to $ 1.7 billion by 2025 with PLA bottles have the highest share in the growth. In 2015, the biodegradable market was less than 1% but now is growing rapidly due to certain steps taken by various countries to fight against plastic destroying the health of environment as well as living organisms. The plastic eaten by fish and other animals enter food chain which is then consumed by the end user in the food chain i.e., humans. Bioplastics have the capability to save the planet and reduce the carbon dioxide emission by 30-70% as compared to conventional plastics (36). Many organizations have developed bottles which can be easily broken down and can be used as fertilizers. India has started taking initiative to participate in the preservation of our ecosystem.

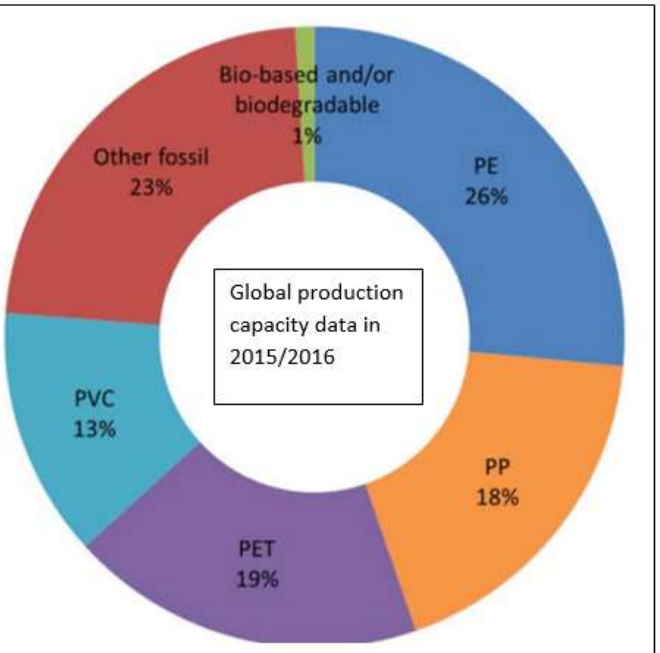


Figure 6: Source: Oeven D.M, Molenveld K. et. Al. Biobased and biodegradable plastic- Facts and Figures. April 2017.

CONCLUSION

The use of biodegradable plastic bottles reveals positive impact on the preservation of the environment; however, the market is growing at a slow speed. India being at a budding stage is providing bottles at super niche level at present but has potential to replace the plastic industry in future. Support from the government can aid in upbringing the use of biodegradables which is especially bio-based in nature.

RECOMMENDATIONS

Feasibility of different material for manufacturing of bio-based bottles could be considered.

More money for research and development in the field of preservation of ecosystem could be considered to reduce the cost of production and check feasibility of various materials. Awareness regarding the environmental health and what share we people must preserve the environment be could be explained. Different disposal bin could be allocated for the bio-based bottles for proper disposal and reusing them for crop harvesting. Volume based pricing could be considered to reduce the cost of manufacturing bio- based bottles. The organic waste or wastewater produced through water treatment plant could be considered for PHA bottles.

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