© AUG 2025 | IRE Journals | Volume 9 Issue 2 | ISSN: 2456-8880

Production of Ecofriendly Bioplastic Using Orange Peels: Towards the Greener Environment

NUSRAT FATEMA MOMIN[1], DR KINJAL UPADHYAY[2]
[1, 2]*Department of Biotechnology and Biochemistry, St. Xavier's College (Autonomous), Ahmedabad*

Abstract- Now a days the use of and need of conventional petroleum based plastics have increased globally. Petroleum based plastics globally is mainly used for food packaging material as it has good barrier properties, tensile strength etc. Along with the application it has one of the disadvantage is it affects the environment by causing land pollution and is threat to marine and human life. To overcome the environmental challenges production of bioplastics has been introduced. Bioplastics are the biodegradable plastics which can be degraded under certain conditions to overcome the environmental damage caused by plastic. Bioplastics are majorly made from the renewable biological sources like corn starch, carboxy methyl starch (CMS), cellulose, pectin etc. Bioplastic synthesis shows the utilization of agricultural waste like orange peels, banana peels, corn starch and other organic biodegradable waste. Bioplastics can be categorized into various types, based on the source that is been used, including cellulose-based, starch-based, protein-based, aliphatic and aromatic co-polyesters. Orange peels is used due to its high pectin content along with cellulose and hemicellulose for making biofilms. Using orange peels as source for bioplastic formation contribute to reduce environmental waste and production of eco-friendly products. Various methods and research has been carried for the production of biofilms from orange peels. To increase the flexibility and various chemicals are used such as glycerol, citric acid, acetic acid, carboxymethyl starch etc. various properties of bioplastics has been studied such as degradation rate, water solubility test, physiochemical properties of biofilm etc. Bioplastic from orange peels has various applications in industries such as molding, food packaging and production of carry bags. So, this review includes the production of bioplastic from orange peels and to overcome the environmental concerns.

Indexed Terms- Bioplastic, Orange Peel, Glycerol, Physiochemical Properties, Biodegradability Studies, Food Packaging Material

I. INTRODUCTION

The environment consists of all the biotic (living) and abiotic (non-living) things which are naturally present on earth and make up the natural environment. All the biotic and abiotic surroundings influence the survival, development and evolution of living population and organisms.

Biotic elements consists of animals, forests, birds, fisheries, plants and all living populations whereas abiotic elements such as water, land, sunlight, rocks and air affects the life of the living organisms. Every living things adapt certain changes for their survival in the environment according to the surroundings.

Environmental pollution is one of the most serious and pervasive problems that humanity and other life face today, and it affects both developed and developing countries. Three dimensional cross-linked networks, often known as thermoset polymers, male up the plastic we use today. They are non-biodegradable and are very much dangerous when burned, as they release a range of lung irritants (Fathima et al., 2020).

Plastics are the massive threat to all the biotic things like plants, animals and living population. Excessive use of plastics, cause severe implications, as it takes more than 500 years to decompose as a result it releases toxic compounds into the environment. Pollution can cause serious difficulties in geochemical cycles, as well as the long term viability of human and other creatures. Despite the fact that other organisms are affected by natural changes, humans are the primary perpetrator. Because it disrupts the thyroid hormone axis or hormone levels, It also affect humans. Natural bacteria are unable to breakdown the manmade compounds when they are discarded into the environment. As a result the plastics are there for many years which increases the land pollution.

1.1 Global Plastic Production

Plastics has become an integral part of our day to day life .The global plastic production in 2022 was noted about 436.66 million tons. China was the largest plastic producing country (32%), next comes the Asia (15%), Eu28 (14%), USA (14%), Row (8%), Middle east(5%), India(5%) and Japan (3%). The polymer which is highly used for plastic production is Polyethylene (PE) which is about 26% of global plastic production. Other polymers used worldwide are PP (19%), PVC (13%), PET(2%), PUR (5%) and PS (5%) simultaneously.(Houssini et. al.2025)

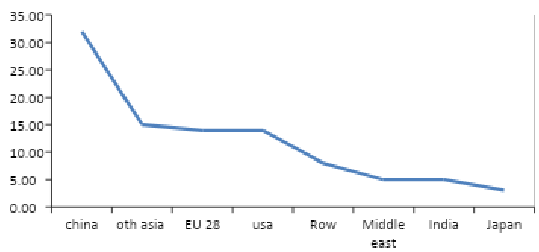

Figure 1. Countries involved in plastics production globally (in percentage)

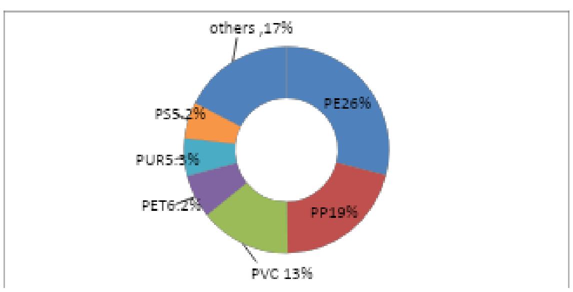

Figure 2. polymers used for plastic production globally

1.Plastic: An Eco-Terror

Natural bacteria are unable to breakdown the manmade compounds when they are discarded in the environment . As a result , these non-biodegradable plastics endure a long time in the environment, increasing the amount of solid waste generated. (Khanna, et.al., 2019)

Due to the continuous production of plastic, by 2050 it will lead to global warming due to green house effect and more rise in water pollution due to plastic waste in aquatic system which will lead to reduction of marine organisms.

Plastic bags create numerous environmental problems. They accumulate on streets and roads ,clogging the drainage which results to overflowing. Incineration leads to release of harmful gases like carbon monoxide, carbon dioxide, chorines, dioxins etc. which degrades the air quality and increases the chances of global warming . (Yaradoddi et al., 2022). It can take up to 1000 years for a single plastic bag to decompose fully. This allows the bags to linger in the environment for longer, resulting in a large build-up on the natural landscape (much more than degradable materials like paper). To put it another way, the more plastic bags you use, the more likely you are to harm the environment.

According to the Marrickville Council of Australia, up to 100,000 whales, turtles, and birds die each year as a result of plastic in their habitat. Plastic bags have not only negative effects on our natural surroundings, but they have also been linked to the deaths of countless animals, primarily due to the suffocation encountered on eating them.

Not only animals, but also infants and small children have been reported to have died as a result of plastic bags. Because plastic bags are thin and airtight, they frequently obstruct children's mouths and nostrils. Suffocation and, in some situations, death can result if they are not being watched by an adult. Incineration and burning of plastics release harming gases which affect the lungs of humans and cause serious breathing problems like asthma and cardiovascular health diseases

Figure 4. plastic pollution
https://unsplash.com/s/photos/environmental-pollution

II. ALTERNATIVE TO SYNTHETIC PLASTICS

With the increasing problems due to use of conventional plastics, an alternative of plastics that is biodegradable plastics were introduced. Because of these many environmental havocs by synthetic plastic there was a need of green alternatives. Food waste is supposed to be an undesirable matter, except to be used as compost. A significant trend that is being followed these days, is utilizing this food derived waste like shrimp peels, orange peels and used ground coffee etc. into bioplastic. These bioplastics are usually derived from renewable source of energy like potato, sugar cane bagasse, corn starch and algae. They are either or fully biodegradable by their properties. In addition, they require various co-binders and plasticizers to increase their strength and flexibility (Yaradoddi et al., 2022). Bioplastics contributes to lowering the dependence on fossil fuels and carbon dioxide emissions. Thus, we can say that bioplastic is the non-fossilized and biodegradable organic material from plants, animals and micro-organisms.

2.1 Bioplastics

Bioplastics are the plastics made from either bio-based material or biodegradable or possess both the properties.(Shamsuddin, et.al., 2017) According to International Union of Pure and Applied Chemistry (IUPAC) has defined bioplastic in the following way, "a bioplastic is derived from biomass or monomers derived from biomass and which, at some stage in its processing into finished products, can be shaped by flow"(Vert et.al., 2012). Bioplastics are generally made from the renewable sources such as vegetable fats and oils, maize, starch, wood chips, food waste, agricultural byproducts, microorganisms, recycled plastics bottles and other containers. Bioplastic is transparent, flexible, durable, heat resistant, and effective as a barrier. Bioplastics can be classified into three types: starch-based, cellulose-based and protein-based. Bioplastics are used in disposable items like packaging, tableware, cutlery, pots, bowls and straws. (Thomas S, et.al., 2013)

The use of bioplastics was started centuries ago. In 1500 BCE, Mesoamerican cultures (Maya, Aztecs) made containers using natural rubber and latex to waterproof their clothes. The first bioplastic was produced in 1862 by Alexander Parkes which was made using cellulose (known as parkesine). In 1962, Maurice Lemoigne developed Polyhydroxybutyrate (PHB) using bacterium *Bacillus megatarium.* It was the first bioplastics known made from the bacteria. The principle was based on the sugars, when bacteria absorb sugars, they produce polymers. The first company to produce bioplastics in higher amount was the Marlborough Biopolymers which was started in 1983. The company produced certain things like strips, filaments, chips, panel, and powders of bacteria known as Biopol. Recently, in 2018 an project was launched which focused on replacing nylon with bio-nylon, and the result was the invention of first bioplastic from fruit waste.(costa, et. al., 2023)

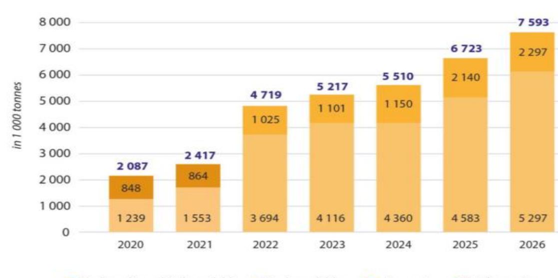

Figure 5 Global production capacities of bioplastics 2021–2026. Adapted from European Bioplastics, "Bioplastics Market Development Update 2021".
https://docs.european-bioplastics.org/publications/market_data/Report_Bioplastics_Market_Data_2021_short_versionpdf

2.2 Bioplastics in India

Bioplastics currently account for only approximately 1% of the 360 million tons of plastic materials produced globally each year. The global bioplastics production capacity is expected to increase from around 2.11 million tons in 2019 to around 2.43 million tons in 2024, owing to a growing sensitivity to the implementation of a "green and circular economy" reliant policy (Facts Figures, et.al., 2020). 13 Bioplastics market in India is in infant stage. Very few companies are operating in the bioplastic segment in India. Environmental awareness programs, easy availability of feedstock and government backing giving major support to Bioplastics manufacturers in India. More initiative needed for production, raw materials and technology development. Environmental awareness and promoting the long-term benefits of bio-plastics is an initial step that needs to take toward bringing this change. The National Green Tribunal's state-level committee has set August 31, 2019 deadline for the government to enforce the ban on plastic (M Sinan, et.al., 2020) Scientists across the India working for the development of bioplastics. Very recent development15 came from IIT-Guwahati and the new bioplastic is under commercial production (Kanika K. et.al., 2019). Bio-green India's 1st Biotechnology Company for Biodegradable Products. True green, Plastobags, Ecolife, Envigreen these companies are already producing bioplastics in India.

Figure 6. global bioplastic production Bioplastics Market will showcase neutral impact during 2020-2024 | Size, Share, Trends, Analysis, and Forecast | Research Report by Technavio

III. CLASSIFICATION OF BIOPLASTICS

Bioplastic materials can have a wide range of biodegradability percentages and can be obtained from a wide range of renewable or non-renewable sources, hence numerous classification systems based on different criteria have been developed to separate them (S. Kumar, et.al., 2017). Bioplastics can be generally classified into categories based on their biodegradability and bio-based content: bio-based (or partially bio-based) which are non biodegradable plastics (drop-in bioplastics); biodegradable (easily degraded) and bio-based plastics; and biodegradable polymers derived from fossil sources used for bioplastics

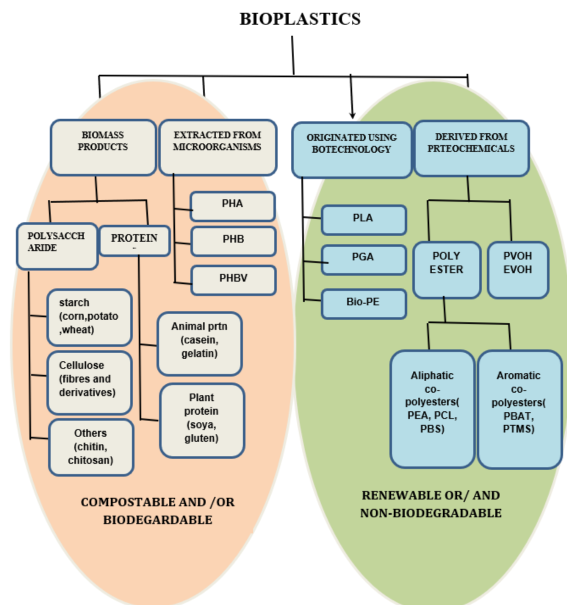

Figure 7. Classification of bioplastic

Biodegradable bio-based or fossil-based materials are alternative materials that are typically used in niche industries, such as food services, agriculture, or biomedical applications; as a result, their trade has only recently emerged. can be divided into four groups based on their origin: (i) agro-polymers, (ii) polymers derived from microorganisms, (iii) polymers derived from biotechnology, and (iv) a blend of biopolymer and commercial polyesters. As well as starch, cellulose, and pectin (S. Kumar, et.al., 2017).

Both starch and cellulose are not plastic by origination but they can be transformed into plastics by polymer technology or fermentation or other techniques like casting, mixing, extrusion, injection molding etc. Bio-polyethylene have prefix 'Bio' indicating that they are derived from renewable materials and have similar properties to that derived from petroleum-based plastics (Shah et al., 2021).

3.1 Agricultural waste as Feed Stock of Bioplastic

Agro waste such as (brewer's spent grain, olive pomace, residual remaining of pulp from obtained from fruit juice etc.) are produced in large quantity per year which can lead to certain environmental and economic problems. Agricultural feedstock such as potatoes, corn starch, banana peels, sugarcane bagasse etc. and other materials which contain starch, cellulosic and lignocellulosic compounds are used to make the bioplastics (Chan, et. al., 2021). The use of the agro-waste materials has replaced the use of the costly raw materials which were used to make the bioplastics. Due to use of the agricultural waste to make an eco-friendly bioplastics which is the alternative of plastics it is said that the production of bioplastics will increase up to 27.9 billion by 2026.(Chan J, Wong J, et. al., 2021)

3.2 Bioplastic from Orange peels

Orange peels are used for the production of bioplastic as they are rich in starch, cellulose, hemicellulose, pectin and lignin. Cellulose and hemicellulose which are an important component of plant cell walls provide strength to the bioplastic. Pectin play an important role in providing rigidity to the biofilm. Starch found in orange peels which consist of two different types of polymer chains called amylose and amylopectin, made up of adjoined glucose molecules that are bonded together to form bioplastic.

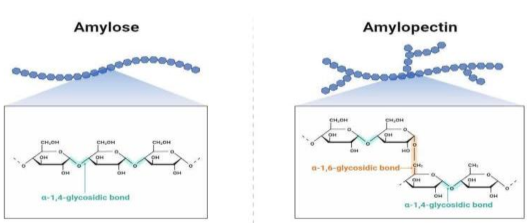

Figure 8. Structure of starch
https://microbenotes.com/starch/

IV. PROPERTIES OF BIOPLASTIC

Bioplastics selected by packaging industries are based on their physical and mechanical properties, which meets the industry needs. These properties determine not only their suitability but also their cost to a significant degree.

4.1 Barrier Properties

Poor barrier properties of both conventional and bio-based plastics are well-known thus they need to ne mixed with synthetic polymers (co-binders and plasticizers) to achieve desirable barrier properties foe packaging food stuffs. Bioplastics can show poor barriers properties under humid conditions but at low humidity they can have good barrier properties. Bioplastics with inadequate barrier properties can lead to short shelf life. (Chiellini, 2008b)

4.2 Mechanical and Physical Properties

These properties of bioplastic are determined by the molecular weight of the polymer chain structure, the degree of crystallization etc. Addition of co-binders and plasticizers increases mechanical properties such that it decreases the level of crystallization and melting temperature resulting in an increase or decrease in hardness and resistance to impact (Jain et al., 2019).

An evaluation of a biomaterial's mechanical-physical qualities is required in order to determine its suitability for a specific industry and the estimated service life. The ultimate tensile strength, Young's Modulus, and elongation at break are the key mechanical parameters that are routinely measured after the manufacturing of a bioplastic. The ultimate tensile strength, or simply tensile strength, represents the maximum stress that a material can sustain before breaking, whereas the Young's Modulus, commonly known as elastic modulus, specifies a material's stiffness: the higher its number, the stiffer it is (L.A. et.al., 2016).

All of these qualities are clearly influenced by the chemical structure, the degree of polymer orientation, and the crystallinity of the material, as well as the presence of reinforcing fibers or plasticizers.

4.3. Life cycle of Bioplastics

Life cycles of bioplastics are determined using life cycle assessments (LCA) and biodegradation studies of bioplastics (Roijen , Miller, 2022). The biodegradable plastics at the end when discarded undergo 3 step processes which generally releases carbon dioxide, water and new biomass. First step consists bio-deterioration , which allows microorganisms to grow inside and on the material which results in the changes in polymers physical, chemical and mechanical properties (Emadian, Onay and Demirel, 2017). The polymers used to make bioplastics are then broken down into simple forms such as oligomers and monomers, it happens during occurrence of the second step known as bio-fragmentation, which is also known as growth phase of microorganisms(Emadian, Onay and Demirel, 2017). The final stage shows that the nutrients obtained from degradation of bioplastics are used up by the microorganisms resulting in the release of CO_2 , water and biomass along with the energy. (Emadian, Onay and Demirel, 2017).

4.4. Biodegradability and Compostability

Due to cleaner life cycle, bioplastics are considered a alternative and replacement to traditional plastics. They are generally made from renewable resources and are treated with organic waste to form compost, which allows them to join the food and agriculture supply chain. As a result, they are held up as a shining example of circular economy (Bhosale, S. 2018). Compostable bioplastics, is defined as materials that can be treated in both aerobic and anaerobic biological processes, should be always collected with organic trash and given to aerobic composting, which can then be followed by anaerobic digestion. However, in recent years, several concerns about bioplastic waste management in industrial organic waste treatment have surfaced (Ruggero, F. et.al , 2020).

Biodegradation of bioplastics consist of different of steps like Bio- deterioration, De-polymerization, Recognition, Assimilation and Mineralization. Certain bioplastics have poor mechanical and thermal characteristics which can make the bioplastic rigid, dry and inflexible , also can have poor performance when it comes to humidity. In order to remove such challenges in their properties, before commercially using it as a food packaging material, biodegradable plasticizers can be added (Jain et al., 2019). Plasticizers consist of glycerol, citric acid and acetic acid and various low molecular weight polyhydroxyl component polyether and urea compounds. Poly hydroxyl components include PHA and PHB can help to enhance elasticity and degree of crystallinity. PHA can be used for making films, bottles and food containers and it is also has application in biomedical industries. Conversely, PHBs can be used to manufacture implants, bone plates, surgical instruments which need to be non-toxic, biocompatible to humans and also be able to endure higher temperatures. Biodegradation of films can vary accordingly, taking days, weeks and even months (Singh & Sharma, 2016).

Composting is a process used for degrading the organic matter by using the activity microbes under warm, moist and aerobic environment under controlled conditions (shaikh et. al., 2021). The compost material breaks down into the simpler compounds in the presence of microorganisms when provided with specific conditions. A degraded compost is non-toxic compost and can enhance the characteristics of soil and supports plant life (Dominguez-Soberanes and Berger, 2022). Biodegradation of such organic matter result majorly to compost along with water and carbon dioxide. As carbon dioxide is already component of carbon cycle, will not be part to greenhouse gases (Song et al., 2009). With the advantage of biodegradability and compostability properties environmental pollution caused due to the plastic can be decreased.

V. APPLICATIONS OF BIOPLASTICS

There are several different forms of food packaging materials made using bioplastics. It consists of biodegradable gels, films, bags, boxes with lids and trays etc.

BIODEGRADABLE GELS: They are used as hydrogels which helps in prevention of microbial contamination (Farris et. al., 2009).

BIODEGRDABLE FILMS: Its main purpose is to replace the polyethylene films which can be used in different industries for certain purposes (Muratore et. al., 2005). It consists of certain characteristics such as good barrier property, maintain structural integrity, enable controlled respiration, prevent food form microbial spoilage and also resists moisture for several weeks to months (Muratore et.al., 2005).

BIODEGRADABLE BAGS: They are strong, flexible, resistant to damage and breakage and retains moisture and temperature changes because of its raw material composition (shaikh et. al., 2021). Addition of certain additives such as plasticizers and co-binders enhance the properties of bag (Ivankovic et al., 2017). BIODEGRADABLE BOXES: Boxes with a cover are made using polystyrene, produced from corn. They are biodegradable under certain conditions and do not release any harmful gases into environment. They are resistant to oil and withstand higher temperatures (Almenar et al., 2008).

TRAYS FOR FRUITS AND VEGETABLES: These materials are resistant to moisture and are brittle. On freezing the product do not show any change in the structural properties (Makino and Hirata, 1997).

CONCLUSION

The review shows the utilization of orange peels to synthesis bioplastic as an alternative to conventional plastics used in day-to-day life. The presence of naturally available polymers in orange peels makes it suitable for bioplastic production. By using orange peels the pectin and cellulose content present in peels provides flexibility and strength to the biofilms. On addition utilizing orange peels helps in waste management and making bioplastic suitable for environment. Addition of plasticizers and co-plasticizers affected the mechanical strength positively . bioplastics made using agro-waste shows potential to be used in several industries as food packaging material, bio-sheets , biomedical packaging etc. and lowering the environmental pollution caused due to plastic waste.

ACKNOWLEDGEMENTS

The authors are thankful to the HOD, Dr. Sudeshna Menon, Senior faculty, Dr. Sebastian Vadakan and all the teaching and non-teaching staff. The authors are thankful to St. Xavier’s College (Autonomous), Ahmedabad, India for providing a financial assistance under the scheme of Research Project Seed Grant having award number SXCA/2021-2022/PR-01.

REFERENCES

[1] Almenar, E., Samsudin, H., Auras, R., Harte, B., & Rubino, M. (2008). Postharvest shelf life extension of blueberries using a biodegradable package. *Food Chemistry*, *110*(1), 120-127.

[2] Bioplastics Market will showcase neutral impact during 2020–2024 | Size, Share, Trends, Analysis, and Forecast | Research Report by Technavio. (2020, 15 December). Business Wire. Geraadpleegd op 23 april 2025, https://www.businesswire.com/news/home/20201215005831/en/Bioplastics-Market-will showcase-neutral-impact-during-2020-2024-Size-Share-Trends-Analysis-and-Forecast-Research-Report-by Technavio Bioplasticsnews

[3] Chan, J. X., Wong, J. F., Hassan, A., & Zakaria, Z. (2021). Bioplastics from agricultural waste. In *Biopolymers and biocomposites from agro-waste for packaging applications* (pp. 141-169). Woodhead Publishing.

[4] Chiellini, E. (Ed.). (2008). *Environmentally compatible food packaging*. Elsevier.

[5] Costa, A., Encarnação, T., Tavares, R., Todo Bom, T., & Mateus, A. (2023). Bioplastics: innovation for green transition. *Polymers*, *15*(3), 517.

[6] Domínguez-Soberanes, J., Berger, P., Hernández-Lozano, L. C., Ortega-Fraustro, D., Macías-Ochoa, M. F., & Cachutt-Alvarado, C. (2022). Bioplástico elaborado de cáscaras de naranja. *DYNA*, *97*(2), 203-209.

[7] Emadian, S. M., Onay, T. T., & Demirel, B. (2017). Biodegradation of bioplastics in natural environments. *Waste management*, *59*, 526-536.

[8] European Bioplastics. Bioplastics Market Development Update 2021. Available online: https://docs.europeanbioplastics.org/publications/market_data/Report_Bioplastics_Market_Data_2021_short_version.pdf (accessed on 22 april 2025).

[9] Farris, S., Schaich, K. M., Liu, L., Piergiovanni, L., & Yam, K. L. (2009). Development of polyion-complex hydrogels as an alternative approach for the production of bio-based polymers for food packaging applications: a

review. *Trends in food science & technology*, *20*(8), 316-332.

[10] Houssini, K., Li, J., & Tan, Q. (2025). Complexities of the global plastics supply chain revealed in a trade-linked material flow analysis. *Communications Earth & Environment*, *6*(1), 257.

[11] Ivonkovic, A., Zeljko, K., Talic, S., & Lasic, M. (2017). Biodegradable packaging in the food industry. *J. Food Saf. Food Qual*, *68*(2), 26-38.

[12] Jain, N., Mani, A., Bahadur, V., & Roy, D. (2019). Biodegradable packaging. ResearchGate. https://www.researchgate.net/publication/351305622_Biodegradable_Packaging

[13] Kumar, S., & Thakur, K. S. (2017). Bioplastics-classification, production and their potential food applications. *J. Hill Agric*, *8*(2), 118.

[14] Makino, Y., & Hirata, T. (1997). Modified atmosphere packaging of fresh produce with a biodegradable laminate of chitosan-cellulose and polycaprolactone. *Postharvest Biology and Technology*, *10*(3), 247-254.

[15] Muratore, G., Nobile, D., Buonocore, G. G., Lanza, C. M., & Asmundo, N. (2005). The influence of using biodegradable packaging films on the quality decay kinetic of plum tomato (PomodorinoDatterino®). *Journal of food engineering*, *67*(4), 393-399.

[16] Pollution Pictures | Download Free Images on Unsplash. Retrieved April 24, 2025, from Unsplash. (n.d.). Environmental pollution pictures: Download free images on unsplash. Environmental https://unsplash.com/s/photos/environmental-pollution

[17] Shah, M., Rajhans, S., Pandya, H. A., & Mankad, A. U. (2021). Bioplastic for future: A review then and now. *World journal of advanced research and reviews*, *9*(2), 056-067.

[18] Shaikh, S., Yaqoob, M., & Aggarwal, P. (2021). An overview of biodegradable packaging in food industry. *Current research in food science*, *4*, 503-520.

[19] Shamsuddin, I. M., Jafar, J. A., Shawai, A. S. A., Yusuf, S., Lateefah, M., & Aminu, I. (2017). Bioplastics as better alternative to petroplastics and their role in national sustainability: a review. *Adv. Biosci. Bioeng*, *5*(4), 63.

[20] Sinan, M. (2020). Bioplastics for sustainable development: general scenario in India. *Current World Environment*, *15*(1), 24.

[21] Singh, P., & Sharma, V. P. (2016). Integrated plastic waste management: environmental and improved health approaches. *Procedia Environmental Sciences*, *35*, 692-700.

[22] Song, J. H., Murphy, R. J., Narayan, R., & Davies, G. B. H. (2009). Biodegradable and compostable alternatives to conventional plastics. *Philosophical transactions of the royal society B: Biological sciences*, *364*(1526), 2127-2139.

[23] Structure of starch Available online: https://microbenotes.com/starch/ (accessed on 22 april 2025)

[24] Vert, M., Doi, Y., Hellwich, K. H., Hess, M., Hodge, P., Kubisa, P., ... & Schué, F. (2012). Terminology for biorelated polymers and applications (IUPAC Recommendations 2012). *Pure and Applied Chemistry*, *84*(2), 377-410.

[25] Yaradoddi, J. S., Banapurmath, N. R., Ganachari, S. V., Soudagar, M. E. M., Sajjan, A. M., Kamat, S., ... & Ali, M. A. (2022). Bio-based material from fruit waste of orange peel for industrial applications. *Journal of Materials Research and Technology*, *17*, 3186-3197.