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Biodegradable polymer synthesis from renewable sources

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Abstract:
In this study, pectin was extracted from fruit peels and used it for the synthesis of plant-based polymer. Pectin was extracted from fruit peels with acid boiling and washing with ethanol. The extracted pectin was used to produce the bioplastic samples. The bioplastic samples were produced by doing acid hydrolysis. 0.5M HCl, and 99% glycerol was used as a plasticizer during hydrolysis. The residence time for hydrolysis was 30minutes and NaOH was used for neutralization. The samples were dried in oven at 50^0 Celsius for 24 hours sample was produced with analysed with FTIR spectrometer and biodegradability test was done using home compost. The duration of biodegradation test was 30 days, and all the samples were more than 90% biodegraded.

Keywords:	Bio, bio-based, polymers, bioplastic, pectin, film, starch
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Table of Contents

List of abbreviations

ASTM- American Society for testing and materials
$BaSO_4$- Barium sulphate
BPA- Bisphenol A
$CaCO_3$- Calcium carbonate
FTIR- Fourier-Transform InfraRed
HCL- Hydrochloric acid
GM- Genetic modification
HNO_3- Nitric acid
H_2SO_4- Sulphuric acid
NaOH- Sodium Hydroxide
$Na_2S_2O_5$- Sodium meta-bisulphate
PA- Polyamide
PBAT- Polybutylene Adipate Terephthalate
PBS- Polybutylene succinate
PE- Polyethylene
PEF- Polyethylene furanoate
PET- Polyethylene terephthalate
PHA- Polyhydroxy alkanoates
PHB- Polyhydroxy butyrate
PLA- Polylactic acid
PP- Polypropylene
PVC- Polyvinyl chloride
PUR- Polyurethane

List of figures

List of tables

FOREWORD

I would like to thank and express my appreciation to my supervisor Stewart Makkonen-Craig for the supervision, guidance, constructive criticism throughout the research study. I would also like to thank my colleague Juha Linjala for his excellent support in the lab as well as with the biodegradability test. I am grateful to all the lecturers and staff for the guidance throughout my studies at Arcada University of Applied sciences.

Finally, I would like to thank my family and friends for their continuous support during my studies as well as special thanks to my parents for their encouragement to complete my studies and thesis.

1 INTRODUCTION

Polymers are materials which are formed by long, repeating chains of molecules. These materials have unique properties which is relatively based upon different types of molecules bonded and how they are bonded.

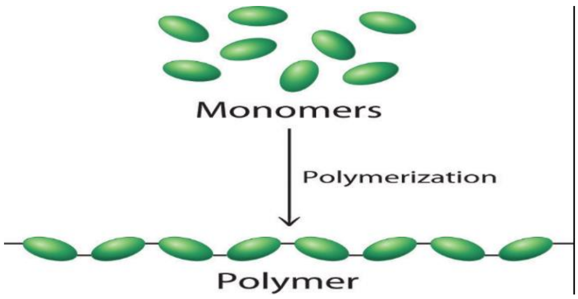


Figure 1 Monomers and polymers (College, 2020) (Image credit: LibreTexts)

Polymer is synthesized through process called polymerization and during this process many monomers are connected with covalent bonds. In today's modern world, our lifestyle depends upon polymers. Polymer's material which are used to make clothing, houses, cars, and aeroplanes to those with sophisticated applications of medicine, diagnostics, and electronics. (Yunqing Zhu1*, 2016)

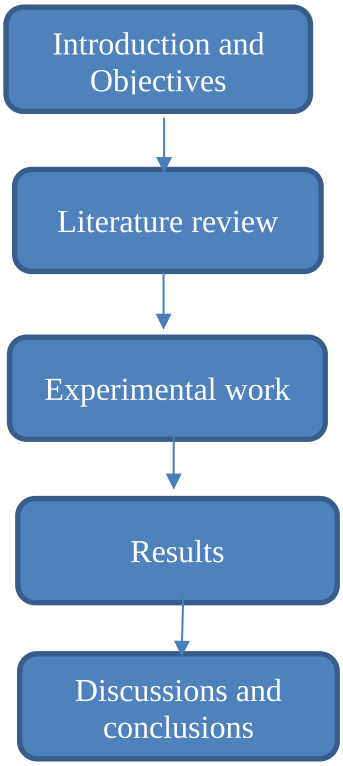
Most of the polymers and chemicals are derived from fossil resources. The population of world is increasing and so as the demands for energy, chemicals and materials continue to increase. Only about 6-8% of oil produced around the globe is used to produce plastic although there are environmental concerns when these product goes to landfill. This percentage of oil produced from oil is expected to go up by 20% in 2050 (ZhongkaiWanga, 2019). The polymers which are derived from non-renewable sources are associated with environmental concerns, i.e., raw material and their end-of-life options. Although some of the synthetic polymers derived from petrochemical sources are recyclable to some extent but the sustainable idea would be replacing the raw materials from fossil based to renewable sources. Research carried out in the recent days has been mainly focused on replacing synthetic polymers with renewable alternatives along with developing the end-of-life options that generates materials which are recyclable or biodegradable (Yunqing Zhu, 2016). So, one of the possible options is developing of more and more sustainable polymers by using biomass from plant as renewable raw material. These polymers derived from biomass of the plant are often termed as bioderived. It is very important for us know that some of the synthetic polymers derived from petrochemical source are biodegradable but not all bioderived polymer are biodegradable.

Polymers have contributed to our society with wide range of benefits and convenience but at the same time polymers have brought some undesirable consequences on climate change as well as environment, which the scientific world has not noticed since the very beginning days. So, its duty of present days students, educators, researchers, as well as scientists to develop the possible solutions to minimize the adverse effects on environment and to promote the use of sustainable material to achieve the goals of sustainable development. There is various research ongoing in sustainable chemistry with idea of transforming biomass into polymers. Likewise, the highly successful molecular engineering of petrochemicals the molecular biomass also can be utilized to biobased polymers by following a similar procedure. The key challenge while developing a material is improving the properties of material with respect to its sustainability and economics (ZhongkaiWanga, 2019).

1.1 Research objectives

Synthetic polymers make up to 20% by waste of the annual waste globally (Gironi, 2011)and due the presence of hydrocarbon chain they are not biodegradable or fully breakdown in landfill which can take up to 500 years. Corn starch is also one of food source so if waste is utilized as a raw material to produce bioplastics it will help to decrease the use of livestock. The main idea of the research project was to extract pectin from fruit skins (waste material) and utilize it to produce bioplastic samples in laboratory scales, also investigate the different characteristic of the produced film with FTIR and biodegradation test.

1.2 Thesis framework



The thesis deals with the topic “sustainable polymer from renewable resources”. As per the thesis framework, the first chapter gives a general description about polymers and as well as objectives of the research work carried out. The literature review covers all the information about different terms of bioplastics, types, advantages, disadvantages, application properties and biodegradability. It is followed by experimental work where the reporting of practical work is done as per the thesis plan. Results from the experimental work come out in the results part. The results will be discussed in the final chapter and conclusion and recommendation are drawn.

2 LITERATURE REVIEW

2.1 General information about biopolymers

Biopolymers are fully or partly derived from biological sources such as potato starch, sugarcane, or cellulose from trees. Bioplastics are not just a single material, but they consist of whole family of materials with various applications and properties (Chen, 2014). Generally, a biopolymer is derived from derivatives of sugar which includes cellulose, starch, and lactic acid whereas conventional polymer is derived from petrochemical sources.

2.2 History of bioplastics

Table 1 History of bioplastics (Rajendran, 2012)

Year	Development
1941	Plastics from soya was experimented by henry ford and made a car with plastic. The world war II played a significant role in the development of bioplastic. (Rajendran, 2012)
1992	A company named Metabolix, came up with their solution to need of chemicals, plastic, and energy. (Rajendran, 2012)
2000	The same company Metabolix initiated the research program to develop an engineered industrial crop to produce bioplastic. (Rajendran, 2012)
2005	A pilot plant at hirose was introduced by Japanese automaker Toyota to test the feasibility of bioplastics. (Rajendran, 2012)
2006	With a goal to reduce the environmental effects of mobile phone, a bioplastic material reinforce with fibre was developed using kenaf plant by Unitika Ltd and LONDON-NEC. (Rajendran, 2012)
2010	A company from Malaysia Cardia Bioplastic Malaysia Manufacturing (CBBM) started to develop bioplastic. (Rajendran, 2012)
2012	Bioplastic was developed from seaweed and expected to be one of the most eco-friendly products based on research published in journal of pharmacy. (Rajam, 2018)
2013	Bioplastic was synthesized from blood and crosslinking agent such as proteins, sugars etc. Examples are diodes, acrylamides, aldehyde etc. (Campbell, 2004)

2014	Bioplastic was made from blending vegetable waste such as parsley, spinach stems, hulls of rice with TFA solutions of pure cellulose according to a study published in 2014. (Bayer, 2014)
2016	An experiment was conducted which found out that car bumper which passes regulation can be made from nano-cellulose based biomaterials using peels of banana. (Sharif Hossain, 2016)
2017	Bioplastic from dry matter of plants; lignocellulose resources. (Brodin, 2017)
2019	Korea research institute of chemical technology stated that five different types of nanomaterials were extracted and synthesized with strong antibacterial effects and 100% biodegradable within 6 months. (Tran, 2019)
2020	VTTs new FDCA Technology is recently developed technology. Plastic bottle made from citrus peel. (Rautiainen, 2020)

The above table only describes some of the notable developments in the history of bioplastics until 2020. However, there has been extensive research and development in recent days which are discussed in sections 2.5 and 2.8 below. The use of plastics has long history of productions since it has been a vital asset for human beings which provides wide range of functions that are not easy to replace easily or economically by the other materials. Moreover, with research and development it can get more attention and market share.

2.3 Understanding the bio-based and biodegradable terms

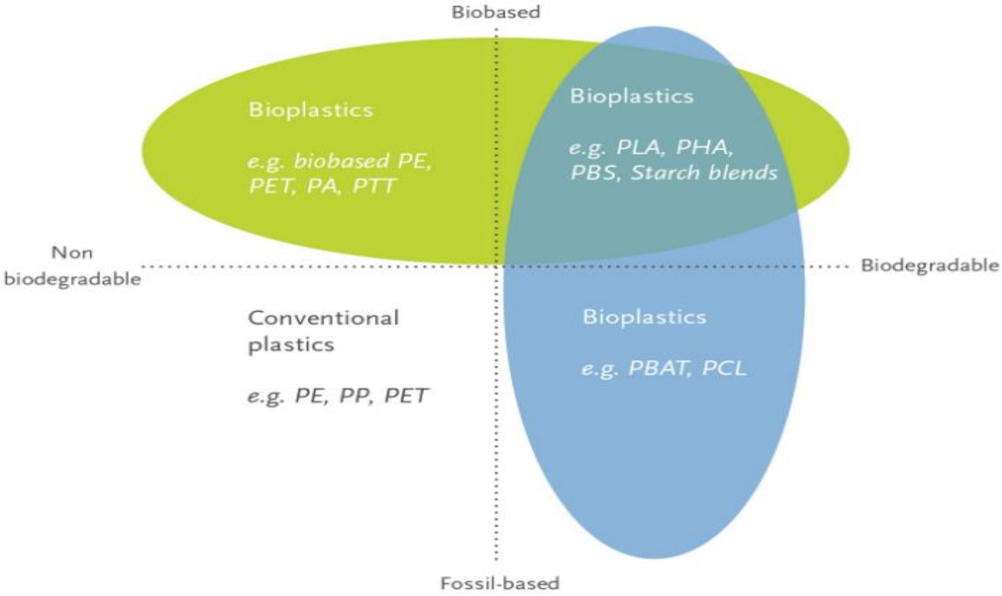


Figure 2 Types of polymer based on their source and their end-of-life options. (European bioplastics, 2020)

Polymers can be classified into two types in terms biodegradability i.e., biodegradable, and non-biodegradable. Similarly, based on raw materials, it can be classified into fossil based or biobased. However, the major categories for sustainable polymers are natural polymer and synthetic biobased polymers. Some of the examples of natural polymers are lignin, hemicellulose, starch, protein, and modified biopolymers which are widely used for preparing composites and bioplastics. Sustainable polymer does not necessarily need to biodegrade and in fact most of them do not, but they are an alternative to petroleum resources and reduce carbon footprint. (ZhongkaiWanga, 2019)
Depending upon the properties, polymer materials can be classified as follows:

- **Biodegradable and biobased:** The materials which are synthesized using renewable sources such as biomass from plant which biodegrades under different environmental conditions. These materials are suitable making products like disposable or single use cups, plates, packaging, containers as well as cutleries. These materials are sustainable alternative because it saves fossil fuel as well as supports plant growth. (Taddele, 2019)
- **Non-biodegradable and biobased:** These materials are specially designed to have a longer lifespan, durable properties and derived from sustainable and renewable sources. Some of the examples are fibres, carpets as well as present day car interior. Material in the automobile industry as a replacement of some metal components exhibit similar efficiencies but reduce the weight. (European bioplastics, 2020)
- **Petrochemical based:** Most of the petrochemical-based material are non-biodegradable but there is some material that biodegrades with the help of microbes in the compost, soil or in the oceans. (European bioplastics, 2020)

From the above definitions and Figure 2, we can make a statement that the property of biodegradation depends upon the chemical structure rather than source of the material.

2.4 Types of bioplastics

There are various types of bioplastic which are derived from different sources. They differ from each other depending upon the raw material used for their synthesis and development. Apart from raw materials and synthesis, it can be classified according to their mechanical and thermal characteristics as well as its biodegradability. Some of the commonly used bioplastics are described in the following subsections.

2.4.1 Starch-based plastics

The development of biodegradable polymers from renewable sources has been given particular attention in recent years. Starch is one of commonly available and cheap biopolymer which is totally degradable and used and natural food ingredient. Starch consists of amylopectin and amylase. It is one of the promising raw materials because of its availability, low cost, biodegradability, and renewability. Bio-plastic starch is either semi-crystalline or amorphous polymeric material which consists of gelatinized starch consisting of mixture of a plasticizer. (Mehta, 2014)

Starch is easily available raw material due to low cost, renewable and abundant. Starch-based plastics include wide variety of complex blends of starch including compostable plastics i.e., PBS, Polycaprolactone, PHA, PLA and PBAT. These complex blends improve mechanical properties as well as water resistance. (Luc Avérous, 2014)

The starch-based films are generally used for packaging purposes. It is mainly formed by starch blended with thermoplastic polyesters to make biodegradable polymer as well as compostable products. The most common use of this film has been used for packaging of fruit, vegetable, bakery items etc. This film can be used as composting bags which enhances selective collection of organic waste. (Luc Avérous, 2014)

There are many sources of starch which can be used for the synthesis of starched-based polymer. Some the examples are cassava, corn, avocado, rice, sugarcane, fruit peel etc. All of these are edible materials, and it is a source of food energy used by consumer which makes it economically difficult to use food sources. The alternative can be using of waste material which is rich in starch. Fruit peel is waste material which contains high sources of starch which is approximately 18,5%. (Pudji Astuti, 2014)

Pectin: Pectin is a type of starch, called heteropolysaccharide which occurs naturally in plant cells walls and gives them structure (Timberlake, 2020). It is complex macromolecule in nature which can be composed out of many as seventeen different monosaccharides containing more than twenty different linkages. It is one of the major plant cell wall components which plays a significant role information of higher plant cell walls. Generally, the polymeric composition of primary cell walls in dicotyledonous plants contains approximately 30% pectin, 30% cellulose, 30% hem-icellulose and 5% protein (Alphons G. J. Voragen, 2009)

Table 2 Pectin content in fruit waste (P.S. Panchami, 2017)

Source	Calcium pectate (%)	Pectin (%)
Citrus peel	24.5	25.5
Mango peel	7.5	8.8
Banana peel	2.5	2.8
Apple pomace	10.8	12.5

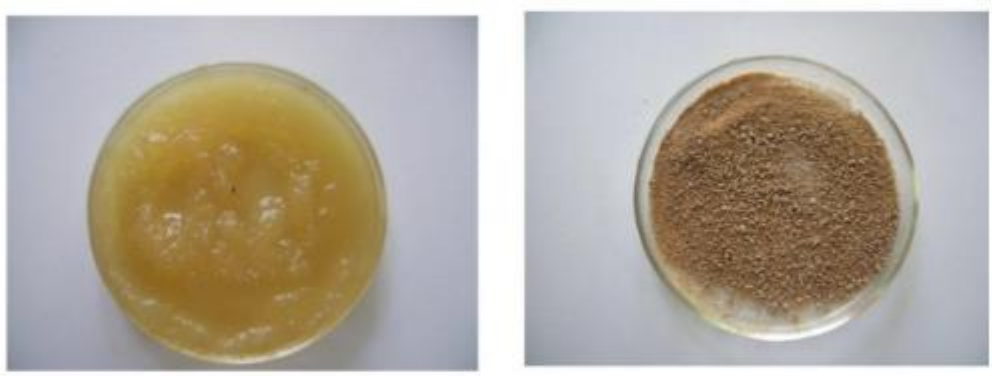


Figure 3 Citrus pectin before and after drying (P.S. Panchami, 2017)

2.4.2 **Cellulose-Based Plastic**

Cellulose is widely used to produce paper and paperboard also being the most abundant organic polymer. (Anon., ei pvm) Cellulose can be converted into a thermoplastic when it is extensively modified. Cellulose acetate is a thermoplastic used in packaging but due to its higher cost, it is rarely used. However, when cellulose fibres are added to starch, it improves the water resistance, gas permeability and mechanical properties because it is less hydrophilic than starch. (Luc Avérous, 2014)

2.4.3 **Protein-Based Plastic**

One of the sources for bioplastic is also protein which can be extracted from different sources. The plastics which are based on soy protein are one of the promising class of renewable and biodegradable materials. (B.Ralston, 2008) Casein is based on milk protein synthesized by acidification or enzymatic reaction followed by the addition of hardening agent for yielding commercial plastic. Soy and casein-protein based plastic have long history of production for over more than hundred years. Apart from casein, soy, wheat gluten as raw material exhibits properties for different biodegradable polymers. The water sensitivity and relatively high cost of soy protein-based has difficulties in use of it. So, it is readily available with mixtures of biodegradable polyesters which decreases the cost and improves water sensitivity.

2.4.4 **Some aliphatic polyesters**

Some of aliphatic polyesters are listed as follows:

- **Polylactic Acid PLA:** Polylactic acid is thermoplastic polymer which is melt-processible and totally based on renewable sources. It shows similar kind of properties to polystyrene and its amorphous state exhibits high stiffness and transparency which makes it suitable material for different applications such as plastic bottles, cups, stiff packages. It is completely non-toxic as well as biodegradable. Apart from being a compostable material, it is also used often in durable materials due to the sustainable image and biogenic origin. It is completely recyclable apart from being compostable and biodegradable. (Becker, 2016)
- **Polyhydroxyalkanoates:** Polyhydroalkanoates are water insoluble polyester which are a class of linear polyester consisting of hydroxy acid monomers (HA) connected by an ester bond. The ester bonds are produced by connecting carboxylic group of monomers with hydroxyl group which are close to each other. It is classified into two distinct groups i.e., short chained PHAs and medium chained PHAs which is determined by the number of carbon atoms. In recent years, PHAs has been able to get more attention because of its matching properties with conventional petrochemical polymers like polypropylene and polystyrene. (Justyna Możejko-Ciesielska, 2016)
- **Polyhydroxyurathenes:** It consists of group of biodegradable polyesters which are synthesized by microorganisms. It a natural polyester which has several disadvantages over traditional synthetic polymers which limits its application as an ideal biomaterial. Some of its features such as poor mechanical properties, high production, and inadequate compatibility with thermal processing techniques. (Zibiao Li, 2016)
- **Bio-derived Polyethylene:** PE is responsible for tons of plastics covering the world’s landfill despite of its recycling feasibility and melting for reuse. It often talked as material not being best at its biodegradability. Bio-derived PE is an alternative to synthetic PE in plastic industry which can reduce number of carbon emissions, lower overall energy consumption as well as to protect the environment. The most important part of understanding bio-based PE is that it has renewable carbon elements. This is one of the main reasons which pushes manufacturers to switch from fossil-fuel to bio-based plastics. (stanpac, 2019)

Some of the other examples of aliphatic polyesters are Poly-3-hydroxybutyrate, Polyamide 11, Genetically modified bioplastics, Lipid derived polymers.

- **Genetically modified bioplastic**: GM stands for genetic modification. Genes can be transferred within the same species, across species and across kingdoms. GM feedstock are not a requirement to produce bioplastics. Bioplastics can be synthesized from both GM and non-GM crops (BARRETT, 2020). None of the currently available bioplastic require the use of the GM although it is standard feedstock. But some of the second-generation bioplastics manufacturing technologies under development employ the "plant factory" model, using GM bacteria or crops to optimize the efficiency (Maximillian, 2015).

2.5 Recent development

2.5.1 VTT's new FDCA technology

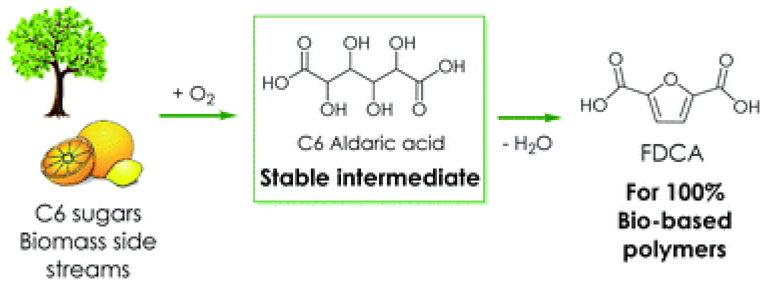


Figure 4 Aldaric acids as stable intermediates for the synthesis of furan dicarboxylic acid esters (Nicolaas van Strien, 2020)

A new FDCA technology from VTT could be new potential material to replace conventional PET polymers with PEF polymers which can also provide better shelf life for food. It is an indication that in the future we may be able to buy orange juice in a bottle which is made from orange peels (Rautiainen, 2020). The novel technology developed by VTT uses pectin containing agricultural waste i.e., sugar beet pulp, citrus peel, as a source of raw material. The annual production of PET products is estimated approximately 30 million tonnes, so it helps to lower the carbon footprint by 50% by replacing the fossil-based PET by plant-based PEF polymers. The utilization of pectin from waste streams offers boundless opportunities for the circular economy of plastic. (Rautiainen, 2020).

2.5.2 Bioplastic from soy residues: Pilot plant coming to Finland

A technology which can be used to manufacture multipurpose bioplastic from soy has been jointly developed by Finnfoam, Brightplus, VTT, Nordic Soya. The utilization of VTT's expertise in synthetic biology, a new pilot plant to produce bioplastic has been planned in Uusikaupunki for the first time in the world. The need of raw materials used for food are no longer needed to produce bioplastic which is done by soy molasses which is by product of soy feed. The technology utilizes the molasses from Nordic soya through a pipeline connecting the Nordic soya plant and new planned pilot which makes is easier and cost effective. Nordic soya has the largest and most modern built multistage plant in the EU in Uusikaupunki. The main idea of the project is to utilize the residue which is currently being burned due to its harmful nature to animal digestion. It will help to create sustainable growth, well-being, and jobs in the society according to **Tiina Nakari-Setälä**, Vice President, Strategy and Business Intelligence at VTT. (Seraste, 2021)

Figure 5 Jarkko Leivo, Rauna-Leena Kuvaja and Maiju Hietala from Brightplus holding biomaterial granulates derived from soy molasses, 3D printing filaments and pieces of injection moulded bioplastic. (Photo: Brightplus)

2.5.3 **Algae based materials**

Aquatic biomass "algae" which contains natural protein and carbohydrate-based polymers. One of the important advantages about algae is that it does not compete with food production as compared to corn (Kimberly-clark Corporations, n.d.). In recent years, manufacturers such as Solaplast, Cereplast, SPLASH have been researching and developing algal polymers. The algal feedstock is being used in different renewable plastic resin suitable for many applications (Solutions, 2018). Solaplast is a division of Algix that converts algae from catfish into plastics.

2.6 Advantages and disadvantages of bioplastic

2.6.1 Advantages of biodegradable plastics

Biodegradable plastics help to reduce the global environment problems resulted by unrecyclable and uncontrolled disposable plastic waste collected in landfill. It is suitable to recycle with organic waste if the plastics are compostable (Jane Gilbert, 2015). It can be the best alternative to conventional plastics which generates environmental problems either during the use or at their end of life. Some of the examples are improperly disposed shopping bags which can be harmful for sea life and the difficulty in recycling conventional plastics contaminated by food. (Jane Gilbert, 2015)

2.6.2 Advantages of bio-based biodegradable plastics

The most notable advantages of bio-based plastics over conventional plastics are that it reduces the use of fossils resources by replacing it with biomass. Biomass is one of key potential factors of carbon neutrality as well as contributes to a reduction of greenhouse gases.

The increasing use of bio-based polymers is an indication that it is attracting more interest in using renewable resources while manufacturing the products. However, there is no standard regulations which requires manufacturers to decide the presence of renewable resources within a product. (Jane Gilbert, 2015)

Nowadays, most of household are advised by the municipal services to sort the biowaste in a bio bag or bioplastic. All the student housing in Finland is given biobag for sorting of bio separately with bio bag. (HOAS, 2020)

In summary, the contribution of bioplastics towards improving environmental impact of products in summary are as follows:

- Production of monomers using renewable resources which decreases fossil fuels and GHGs.
- Due to the biodegradable nature, it allows reduction in amount of waste and offers additional options to end-of-life of products. (NaturePlast, n.d.)

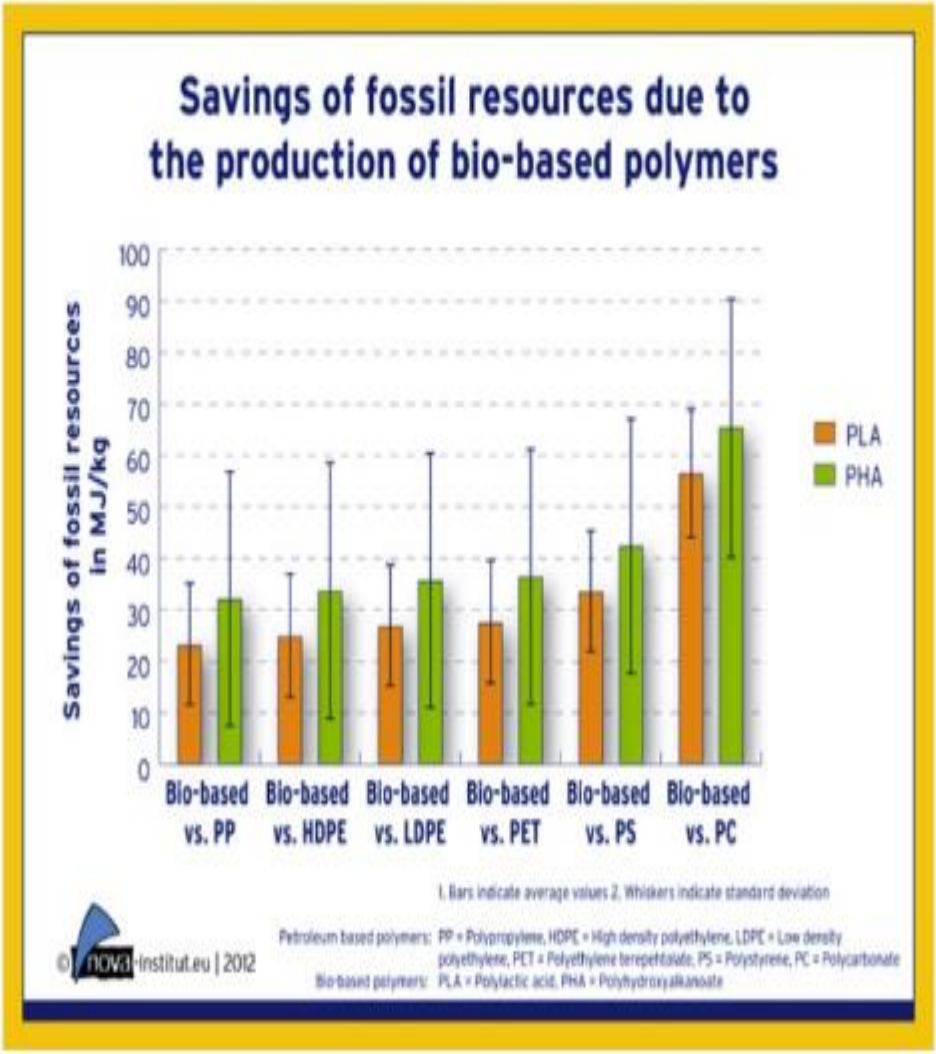


Figure 6 Saving of fossil resources due to production of bio-based polymers. (NaturePlast, n.d.)

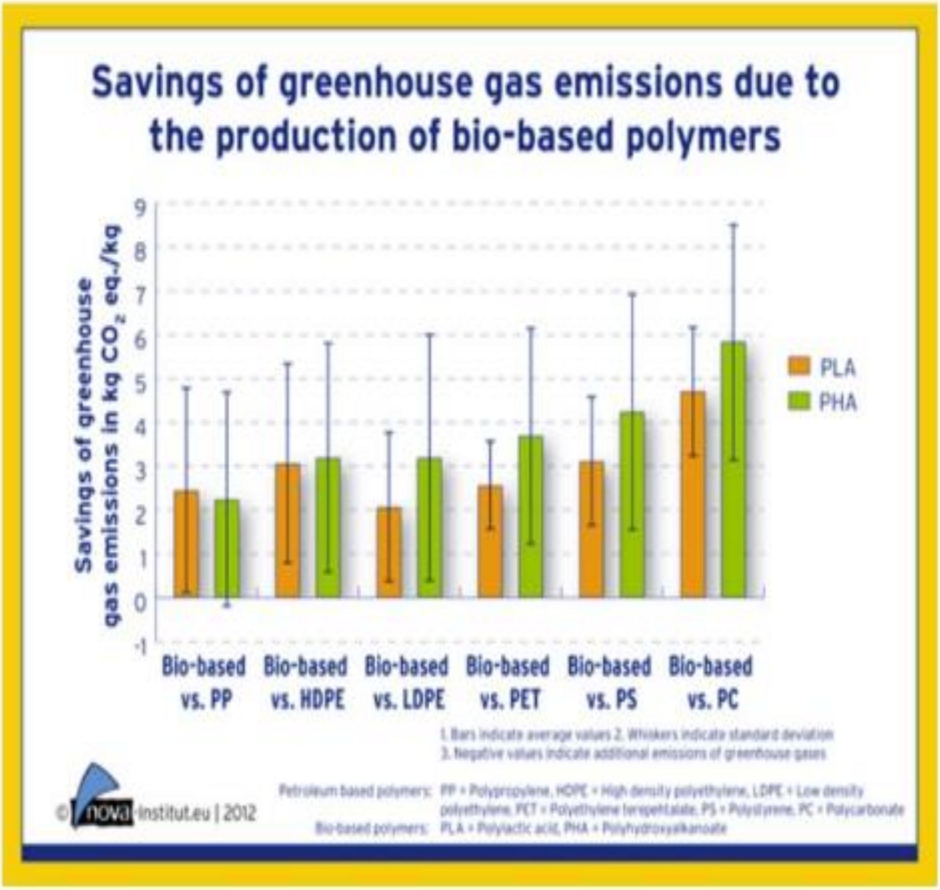


Figure 7 Savings of greenhouse gas emissions due to the productions of bio-based polymers. (NaturePlast, n.d.)

2.6.3 Disadvantages

There are many advantages of bioplastics but there are also numerous disadvantages. If the product is not disposed properly, it can lead to pollution of the water and soil. The waste of biodegradable polymers disposed in landfill can also contribute to biodegradability of land filled waste but at the same time, it accompanies methane generation and its potential release in the atmosphere. (Jane Gilbert, 2015) Furthermore, biodegradable polymers break down naturally but remains as a potential harm to wildlife when its discarded initially. (Jane Gilbert, 2015). It is not cost-competitive when compared to the conventional oil-based plastic. It twice expensive as much as the oil-based plastics. There is a growing concern that bioplastics based on terrestrial crops plants such as crop, potato could be harmful factors for food supplies: however, new innovations using food waste and biomass generated from others waste resources may address the growing concern over the terrestrial foods being the source of raw material (https://qualityinspection.org/, 2020). Humidity and temperature play a vital role in composting as it goes slower in colder conditions but during the times of high humidity, the process can almost come to complete stop. That means most of the advantages go unnoticed in equatorial and far-northern climates. (Anon., 2019)

Finally, we need to also consider about the possible impacts of recycling. The world needs be more economical in the use of plastics and its raw materials abiding the sustainable regulations. (Biome Bioplastics, 2011)

2.7 Market Size

Bioplastics represent approximately one percent of more than 368 million tonnes of plastics produces annually. The demand is also rising with more sophisticated biopolymers, applications and emerging products which is sign that it is growing and diversifying. According to European bioplastics, as of 5 January 2021, the global bioplastics production capacities are projected to increase from around 2.11 million tons in 2020 to 2.87 million tonnes. (Bioplsatics, 2021)

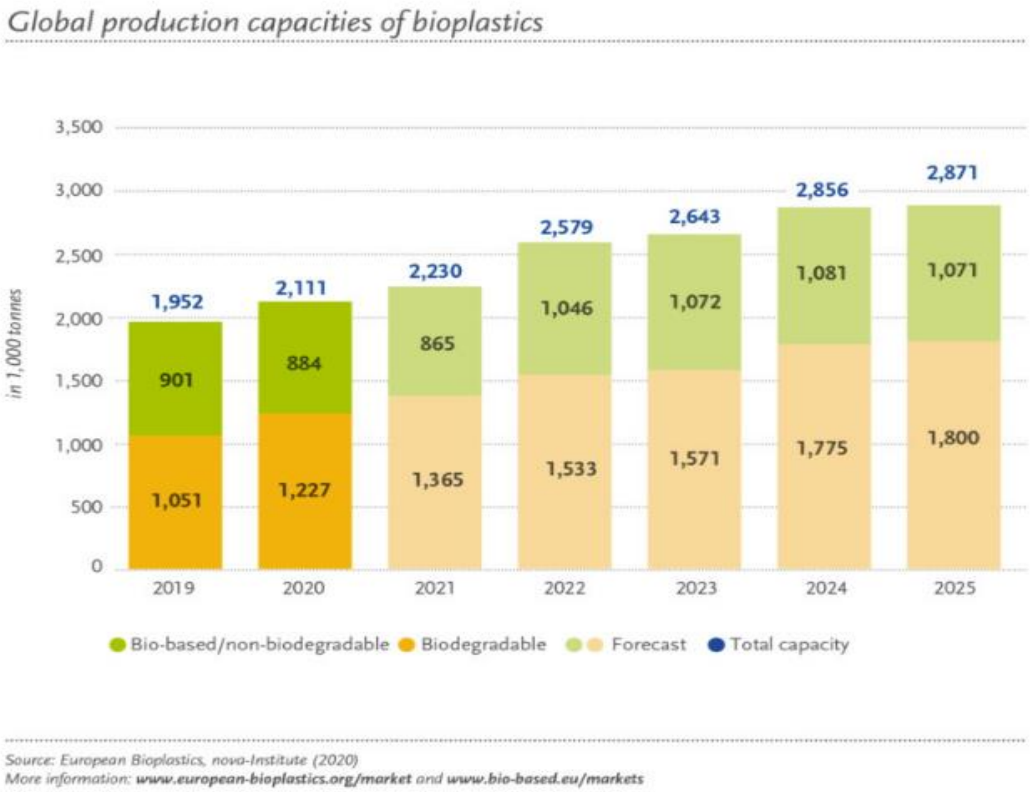


Figure 8 Global production capacities of bioplastics. (Bioplsatics, 2021)

There are different new polymers which have shown a continuous growth. Innovative polymers such as PLA, PHA, and bio-based PP. Bio-based PP has entered on a commercial market since 2019. It is projected to be increased by four times in 2025 because of its widespread application of PP in many sectors. Also, the production capacity of PHAs is expected to be tenfold by 2025. The production of overall biodegradable plastics is expected to reach to 1.8 million tons which currently 1.2 million due to high growth rate of PHA and new investments to produce PLA in US and Europe. (Bioplsatics, 2021)

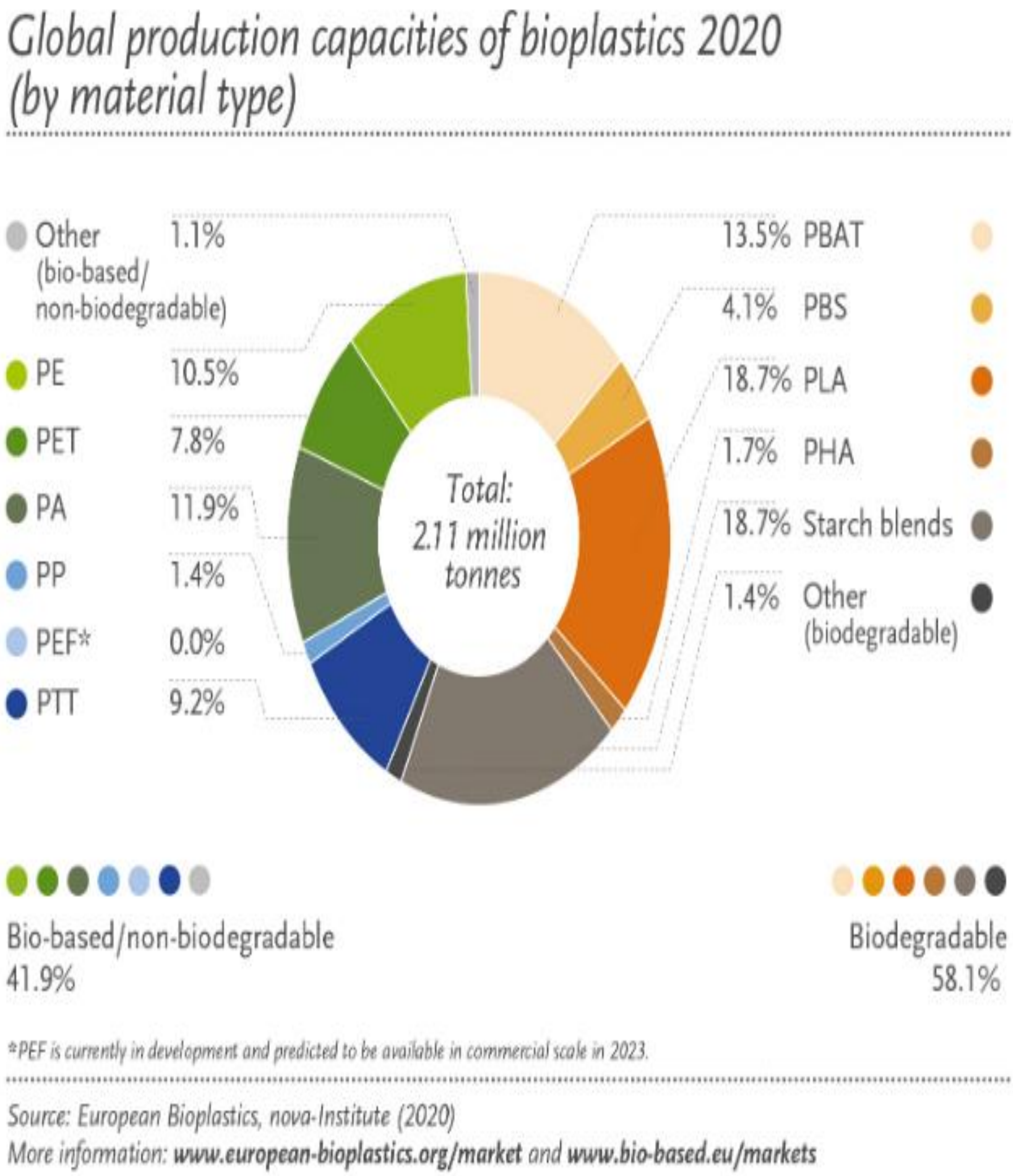


Figure 9 Global production of bioplastics by material types. (Bioplsatics, 2021)

Biobased, nondegradable plastic covers almost 40% (890 thousand tons) whereas biodegradable plastic covers about 60 (1.2million tons) percent of the global bioplastics production capacities. The share of bio-based, nonbiodegradable plastics is expected to decrease to 37 percent by 2025. Some of polymers that slowly in the drop-in rate are biobased PE, biobased PET, and biobased PA. A new polymer which is likely to get in the market in 2023 is PEF which can be an alternative to PET but PEF is 100 percent biodegradable. It has been expected as an ideal material for packaging of drinks, foods, and other products. (Bioplsatics, 2021)

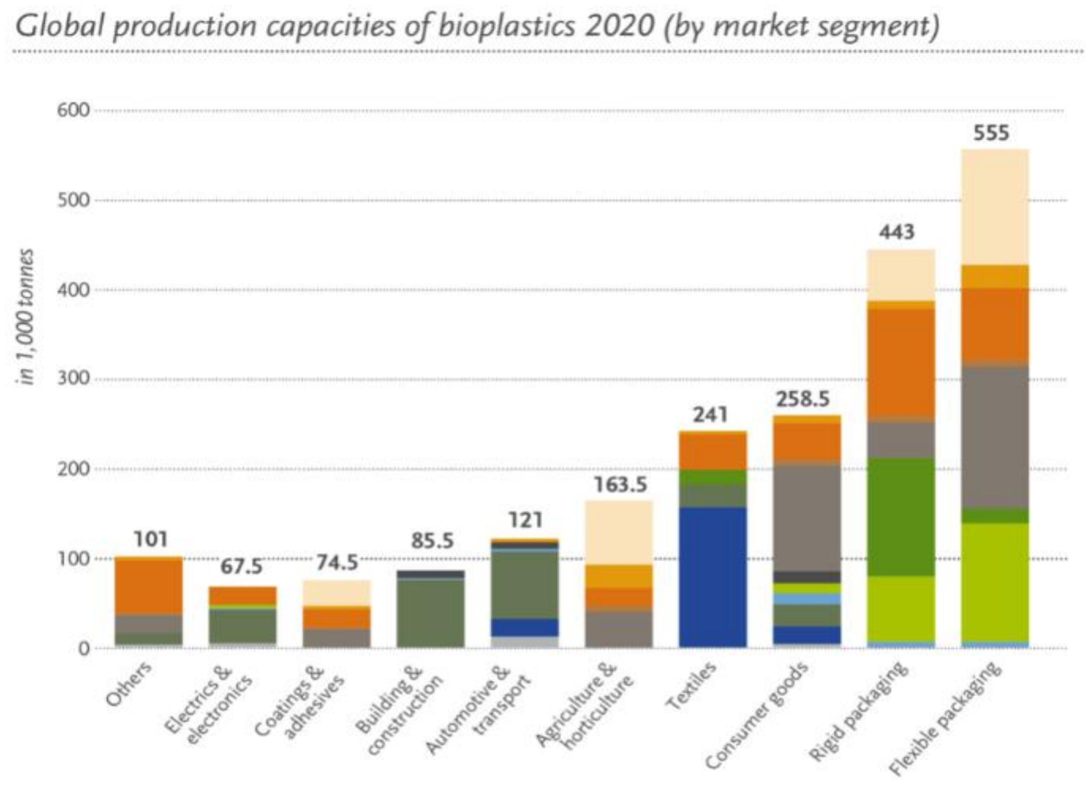


Figure 10 Global Production of bioplastic 2020(by market segment) (Bioplsatics, 2021)

Europe has been the vital player for the global bioplastics industry which ranks highest in the R&D and the largest market globally. As of now almost 25 percent of the global production capacity is in Europe, but Asia leads the actual production and regional capacity.

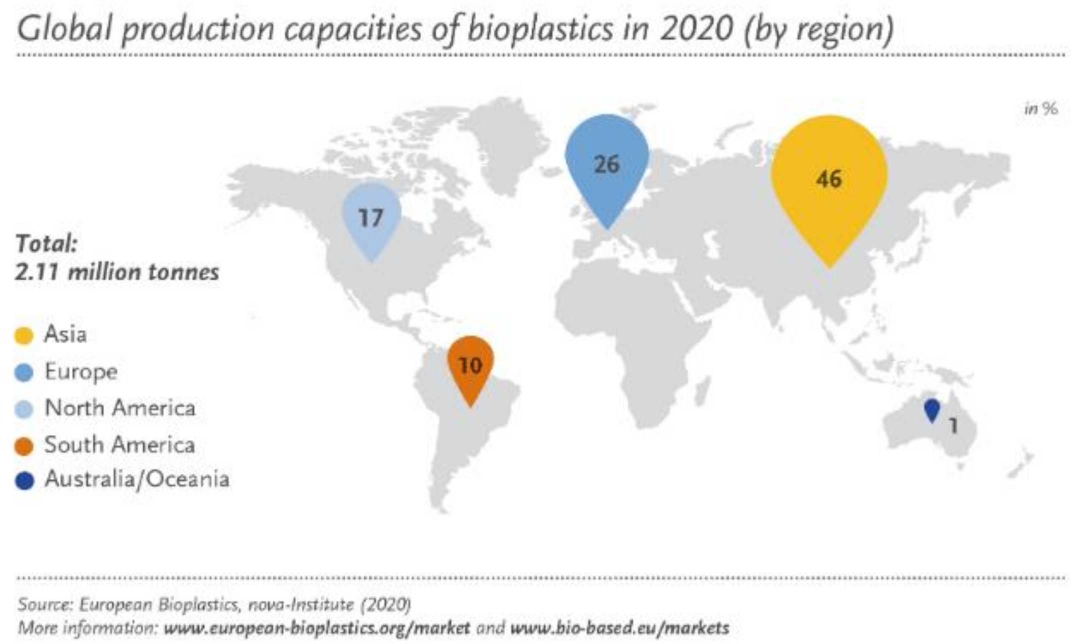


Figure 11Global production capacities of bioplastics in by region. (Bioplsatics, 2021)

Asia produced 46 percent of the total bioplastics in 2020 and it will remain as prime production over the upcoming years. The production share of North America is expected to be grown to 18 percent from 17 percent by 2025.

2.8 Applications of bioplastic

Many industrial sectors are in search of new materials for achieving the goal of sustainable consumption and production. Bioplastics is slowly becoming part of our day-to-day life. According to European bioplastics, the global production capacity of bioplastics was approximately 2.11 million tons. The biggest market share of the gross production was covered by packaging industry which accounted approximately 47 percent (0.99 million tons). (Bioplastics, 2021)

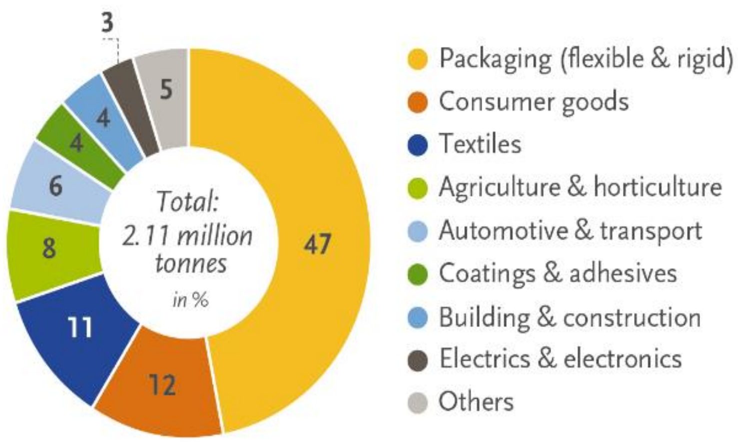


Figure 12 Applications of bioplastic in different areas (Bioplastics, 2021)

Bioplastics can be found in different market segments which are listed as follows:

- **Packaging:** There has been a significant rise in demand of packaging made from bioplastics used for premium, branded products having practical requirement as well as organic food products. Some of examples of bioplastics in packaging are shopping bag, compostable waste collection bag, trays for vegetable, meats, and eggs. It is used in packaging of short lived and fresh products like vegetable, fruits and meets which helps the products to get longer shelf life. Bioplastics are an alternative for single use packaging materials which ends up in the landfill without degrading for a long time. However, bioplastics should focus on improving properties like antimicrobial coating and different aspects which enables bioplastics industry to achieve better preservation food products than current packaging in near future. Bioplastics are feasible alternative to almost every conventional plastic material and application and has same properties with potentially additional advantages (Bioplastics, 2021). The two grades of Solaplast resins i.e., Solaplast1723 and Solaplast1223 are extensively used in the packaging industry which are derived from algae is developed by a company named “Algix”. It offers a various range of application and are bio-based, biodegradable and durable. (Ashter, 2016)

Figure 13 Solaplast resin used for manufacturing biodegradable packaging (Ashter, 2016)

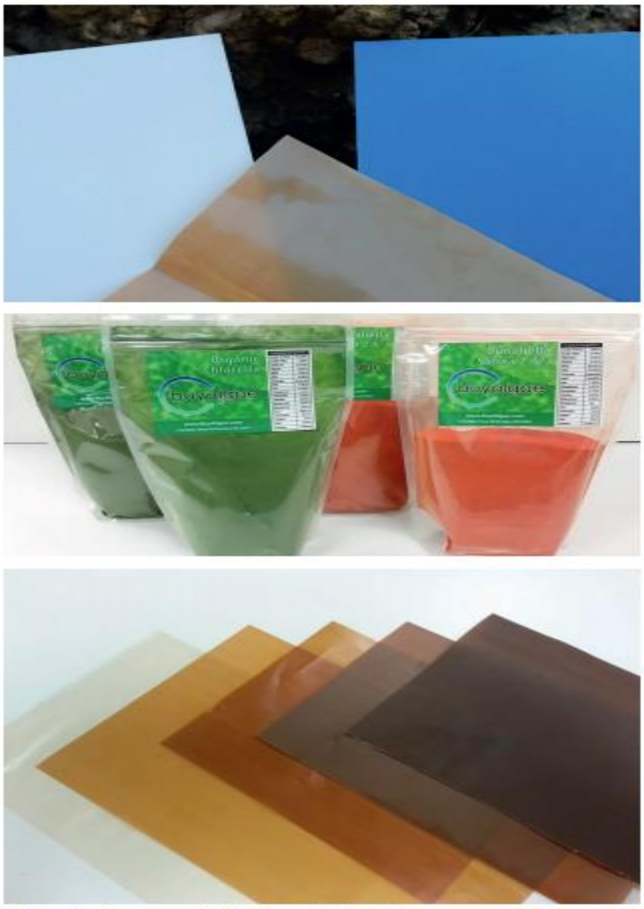


Figure 14 Solaplast compostable films. (Ashter, 2016)

- **Disposable houseware**: Disposable housewares are being marketable and have replaced traditional plastics such as polystyrene and polyolefin. Kitchen tools, bathroom accessories, washable containers and cups, hangers, hooks are now being manufactured using biodegradable plastics. There are few examples such as cutlery made from Cereplast, resin made corn and potato starch which biodegradable and qualifies as a compostable plastic marketed under Nat-Ur. NatureBag has products like Natur-ware cutlery which doth dual feature of being bio-based and compostable. The hangers from United Colors of Benetton are 100% recyclable and biodegradable. (Ashter, 2016)

Figure 9.4 Disposable housewares made from biodegradable plastics [21].

Figure 9.5 Natur-Ware bio-based and compostable cutlery [23].

Figure 9.6 Biodegradable hangers from United Colors of Benetton [24].

Figure 15 Biodegradable housewares (Ashter, 2016)

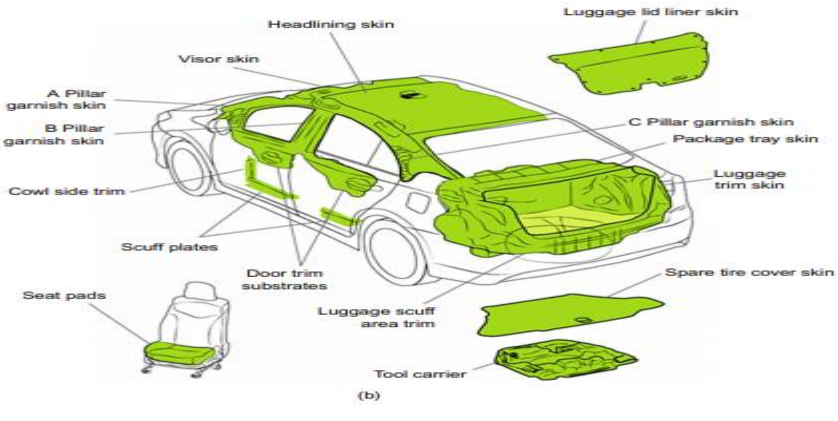
- **Agriculture and horticulture:** There are numerous advantages that bioplastic offers in agriculture and horticulture. One of the most important examples is Mulching films which aids the production of pure food by using minimum amounts of pesticide which is in fact a powerful sales argument among organic farming industry. The seeding strips and tapes used which biodegrades in the soil as the seeds germinate and takes root. (Bioplastics, 2021) There are different reasons for using mulch films which are, to give new seedlings a head start, and reduce the evaporation, conserve moisture, increase the soil temperature, as well keeping control of the weeds. Foils, yarns, and nets made from bioplastics help to prevent soil erosion until the roots of the plants have developed enough. It is also used in the farming of mushroom and coating od tree and bush roots. (Ashter, 2016)

Figure 16 Agricultural mulches, seeding strips and tapes made up of Biodegradable plastics. (Ashter, 2016)

- **Automotive Industry:** The focus of automotive industry these days is on reducing fuel consumption by reducing weight of vehicles. Plastic has been a major component for automakers and since there are a lot of issues with recycling of plastics, automotive industry is making a giant leap by using bioplastic components. (Ashter, 2016)

MODEL	PART
Prius	Seat cushions, scuff plate, cowl side trim, register blades
Corolla	Seat cushions
Matrix	Seat cushions
RAV4	Seat cushions
Lexus RX 350	Seat cushions
Lexus HS 250h	Luggage trim upholstery, cowl side trim, door scuff plate, tool box area, floor finish plate, seat cushions, package tray
Lexus CT 200h	Luggage compartment liner, carpeting
Camry	Radiator end-tank

(a)



(b)

Figure 17 Vehicles containing bio-based plastics (Ashter, 2016)

The manufacturers from the automotive industry are turning into biobased or partly biobased durable plastics to produce components with both exterior and interiors. The most common product made up of bioplastics are seat and airbag cover as well as steering wheels (Bioplastics, 2021). Toyota is very popular brand, and it has been on the driver's seat in adopting bioplastics which uses bio-based polyesters, bio-based PET, PLA blends in the manufacturing process. The company had set target of replacing 20 percent by weight of oil-based plastics for cars with bioplastics by 2015. (Ashter, 2016)

- **Consumer electronics:** A large share of electrical appliances made from plastic. It is used to make casing, circuit boards and data storage to make sure the electrical appliances are lightweight, durable, tough when necessary. There has been interesting development on increasing use of various bioplastics products in consumer electronics. Some of the examples are keyboard and mouse elements, mobile and computer casings, loudspeakers, vacuum cleaners. (Bioplastics, 2021)

Figure 18 Biodegradable plastics in Consumer electronics (Ashter, 2016)

A company called SUPLA has been able to develop optimized PLA compounds for the consumer electronics based on lactides from Corbion Purac. The first ever bioplastic touch screen computer which was developed in collaboration with a Taiwanese OEM/ODM, Kuender has been shown above in the figure (a). The PLA blends used in monitor screen also offer impact resistance, precise processing, excellent high gloss finish, and stable. Keyboards, mobile phones, consoles, earphones, laptops are other example of biodegradable consumer electronics. (Ashter, 2016)

- **Medical devices:** There are wide range of applications of bioplastics in medical fields. Surgeons use nontoxic biodegradable polymer sutures in life-saving heart operations and in various other procedures. The sutures easily dissolve and readily metabolized inside the body without any traces. Plastics sutures are mainly made using glycolic and lactic acids. The types of sutures required depend upon the type of surgery, tensile strength required, knots used and its potential for infection accounts 95 percent share of total market whereas rest 5 percent include pins, implants, and dental devices. Porous polymer is used to make biodegradable dental implants which are used to quickly fill the hole after the extraction of tooth. It helps to prevent scabbing and allows the growth of slower-growing connective and ligament.

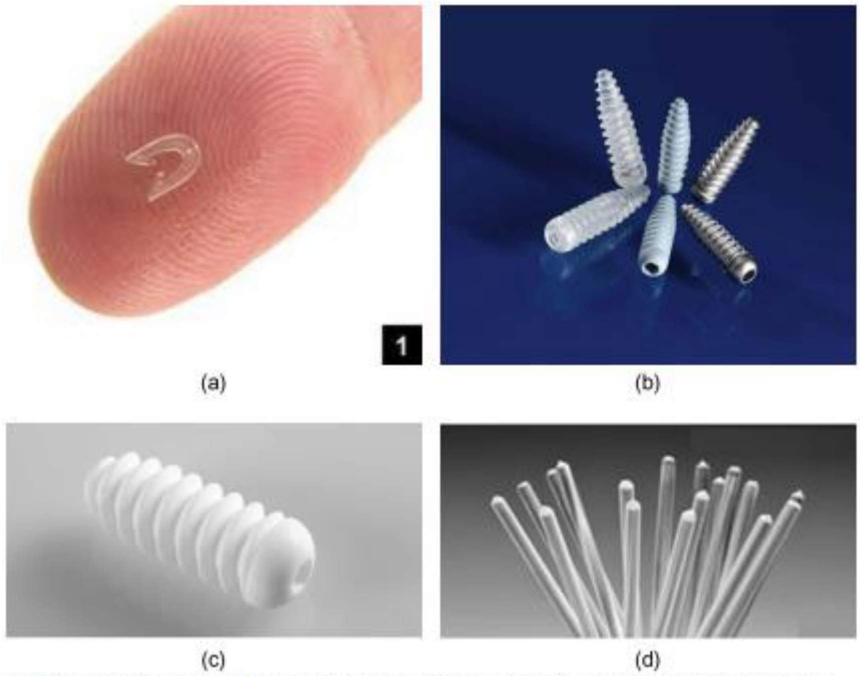


Figure 9.10 (a) Insorb absorbable skin stapler, (b) dissolvable medical screws promoting bone growth, (c) absorbable anterior and posterior cruciate ligament interference screw, and (d) absorbable orthopedic pin [32–34].

Figure 19 Biodegradable stapler, pins, and screws.

2.9 Properties

Bioplastic consists of diverse materials with different properties which can be divided into mainly three groups.

- Bio-based or partially bio-based: Durable plastics such as bio-based PE, PET, PET is also called drop in solution. Other bio-based technical performance polymers are PA and partly biobased PUR. Biobased PET and PE are identical to their conventional counterparts and exhibits similar properties. It is technically equivalent while comparing with fossil-based counterparts while it can be mechanically recycled in the current recycling streams. Moreover, it can help reduce the carbon footprint.
- Bio-based and biodegradable: Biobased and biodegradable plastics are compostable plastics such as PLA, PHA and PBS as well as starch blends. PLA and PHA are innovative materials which offers compostability and biodegradability as well as optimized barrier properties in some cases.
- Fossil-based biodegradable: PBAT and PCL are based fossil based but may be produced as partly bio-based in the upcoming years.
  There has been a significant growth in the variety of bioplastic material along with their properties such as flexibility, durability, printability, transparency, barrier, heat resistance, gloss, have also been enhanced properly (Anon., 2016).

  The physical and chemical nature of polymer used in manufacture determines the properties of plastics. Meanwhile, the properties of polymers also depend upon the molecular structure, degree of crystallinity, and chemical composition (Sina Ebnesajjad, 2012). So, these factors affect the temperature at they undergo physical transformations and density of the polymers. Polymer chains do have the ability to align themselves in ordered structures, and its ordered thermodynamics state determines different properties which are, melting point, glass transition temperature (T_g), electrical as well as mechanical properties. Polymer as a packaging material provides the protection to food. The degree of protection offered by polymer depends upon the chemical nature of the polymers which determines its stability to temperature, light, water, and solvents etc. (A.V. Orezzoli, 2018).

Table 3 Packaging properties with respect to their functions (周, 2016)

Properties of materials for packaging	Functions
Tear strength	Protection and containment., package operations and distribution
Burst strength	Avoids external contaminations, Protection, and containment.

Water vapor transmission	Protection against degradation by water
Tensile strength	Prevents external damage, Protection, and containment.
Oxygen transmission rate	Prevention against oxidation, avoids growth of microorganisms

3 PROCEDURE

The experiment procedure of the thesis project was initially based on research paper published by international journal for scientific research and development (Singh, 2015) which presents the experimental idea on how waste generated from banana peels can be utilized and developed into a biobag. This experimental procedure was developed with reference to (Taddele, 2019)as well.

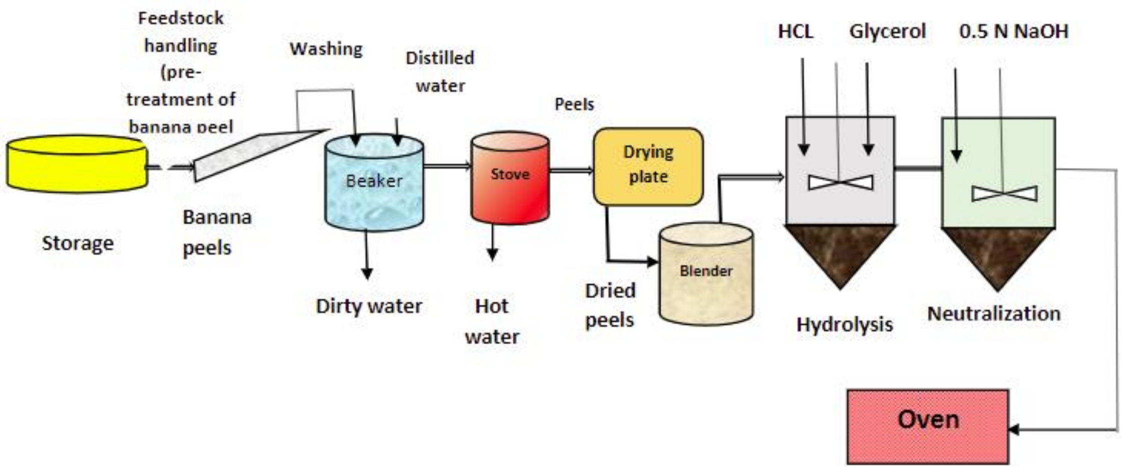


Figure 20 Initial Planning of experiment (Taddele, 2019)

After the initial planning of the experiment, it was conducted several times and there were few problems while forming the films, acid concentration and drying temperature for film formation during the experimental procedure. While doing literature review it was known that the banana peel contains two different chains of polymer i.e., amylose and amylopectin and HCL was used in hydrolysis of amylopectin which aided the pro-cess of formation of film. The H-bonding between then chains of glucose in starch determines the film formation. After the initial phase of experiment came with the idea of extracting pectin from banana peels and using it for film formation. The first experiment was done by extracting pectin from banana peel and since yield of pectin was less than as compared to citrus peel. So, the fruit peels which rich in pectin was used in the following experiment to achieve the higher yield percentage of pectin from fruit peels which were taken from my own kitchen that was waste from smoothies and juices. Finally, an experimental procedure was designed with difference to different articles (S. Chodijah, 2019) and prior experiments. The experimental procedure has been shown below in section 3.4.

3.1 Reaction Mechanism

Pectin was extracted from citrus peel. Pectin is a high molecular-weight carbohydrate polysaccharide starch found in the cell walls of fruits and vegetables (Luiz Trugo and Paul M. Finglas, 2003). Starch is long-chain polymer of glucose molecule which contains amylopectin and amylose. The intermolecular bonds of starch molecules are break down by heat. The hydrogen bonds with water dissolve the starch granules which makes starch exhibit gelatine form. Hydrochloric acid was used for the hydrolysis of pectin because H-bonding amongst the chains of glucose in starch restricts the formation of film. HCl aids the process by the formation of film.

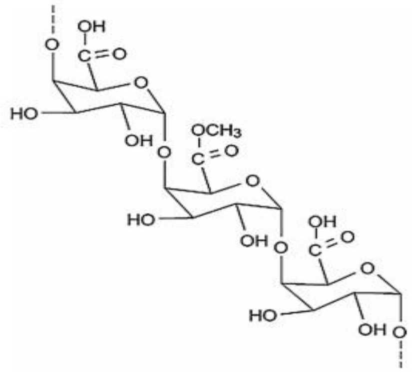


Figure 21 Chemical structure of pectin (J. Aburtoa, 2015)

3.2 Materials and equipment's

3.2.1 Fruit Peel

The fruit peels were collected from my own kitchen. The waste discarded while making smoothie has been used as raw materials for this project. The selected fruit peel was clementine, banana, and lemon. The fruit skins were selected based on their high pectin content. Citrus fruit are rich in pectin and banana being the most abundant fruit.

Figure 22 Peel of selected fruit as a raw material

3.2.2 **Plasticizer**

Glycerol was used as a plasticizer which determines the flexibility of the films. Plasticizers are generally added to make materials softer and more flexible. It is low molecular weight substance which promotes its plasticity and flexibility when added to polymer solution. It makes polymers suitable for the application of film coating. The changes in amount of plasticizer will affect the flexibility, tensile strength, and hardness. When the concentration of plasticizer is increased, flexibility of polymer increases while the hardness and tensile strength of the polymer material decreases. (Adrian P. Mouritz,, 2012) Plasticizer lowers the number of physical-cross links between starch chains which allows to retard the rate of retrograde. (Taddele, 2019)

3.2.3 **HCl**

It is a colourless inorganic acid which has distinctive pungent smell. It is classified as strongly acidic, so it is better to follow MSDS for safe use. It is a solution of hydrogen chloride and water with different other chemical species which includes hydronium and chloride ions. It is used in the production of PVC for plastic. It is used as food additive and used for production of gelatine in food industry. It is often used as descaling agent in most household. It is also used for leather production. (Favre, et al., 2014)
HCl was used in this research for the hydrolysis of pectin which is required to aid the process of film formation because the H-bonding among the chain of glucose in starch restricts the formation of film.

3.2.4 **NaOH**

NaOH is also known as caustic soda which is solid ionic compound. It consists of sodium cations Na^+ and OH^-. It highly soluble in water and it absorbs moisture and carbon dioxide from air. It is highly caustic base and alkali which decomposes proteins at ordinary ambient temperature and may cause several burns (Siemens, 1969). It must be handled according to MSDS. It is used in multiple industries. As it has numerous uses. It is used in the manufacture of pulp and paper, soaps and detergents, and textiles etc. it also used as a drain cleaner. It reacts with acids to form water and corresponding salt. For example, when NaOH reacts with HCl it forms NaCl which is salt.

$$NaOH(aq)+HCl(aq) \longrightarrow NaCl(aq)+H_2O$$

The use of NaOH in this experiment was to make sure the neutralize the acidity of the solution during hydrolysis. Acid hydrolysis changes the property of starch without changing its granule structure.

3.2.5 **Filler ($CaCO_3$)**

It is also known as chalk powder. It is odourless, white powder which has been used in the plastic industry since many years. It is widely used substance for different purposes such as filler and pigment material not only for paper, plastics, rubbers but also in construction, materials, cosmetics, nutrition supplement in animal foods (Y. Lin, 2012). The main cause of adding ground $CaCo_3$ as filler material for plastics was to reduce costs of material. In recent years, with development of precipitated $CaCo_3$, which are smaller and can be used not only as fillers but also to improve the mechanical properties of polymers (Y. Lin, 2012).

3.2.6 **Corn starch**

Corn starch was used as co-biopolymer. Corn starch is commercially available raw material to produce bioplastics. It has unique functional property, low cost, odourless due to which it is widely used in processed food, pharmaceuticals, textiles, and paper products. It is also used as stabilizer and thickener of fluid in foods in the food industry because of its high viscosity, bland taste. Corn starch is a semi-crystalline polymer consisting of a mixture of linear polysaccharide amylose, and highly branched polysaccharide amylopectin (Walid Abotbina, 2020).

3.2.7 **Acetic acid**

Acetic acid was used for the extraction of pectin. Acids are used in extraction of pectin because they facilitate extraction of insoluble pectin which is tightly bounded to the cell matrix of the plant materials which results in higher yield (Kulathunga, 2017).

3.2.8 **Chemlease**

Chemlease is a product widely used in composite moulding which offers operational efficiency with combination of advance technology (Chemlease, 2021). Chemlease was used while casting the film which made a lot easier to take out the film from petri dish. It forms a solvent resistant as base layer which avoids the film from tear and damage.

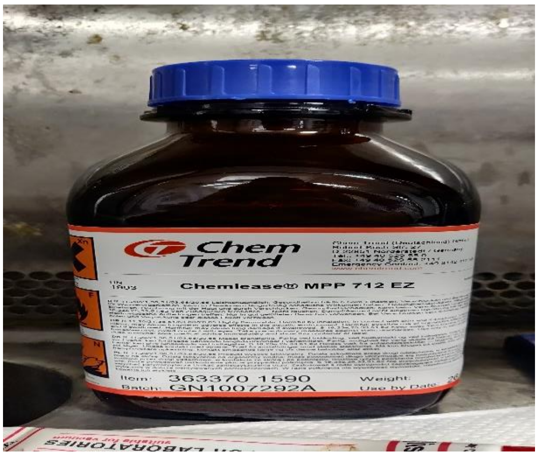


Figure 23 Chemlease

3.2.9 **Vacuum Filtration**

Vacuum filtration was used to separate the solid pectin content from the solution. It is a technique used to separate mixture of solid and liquid through a filter paper in a Buchner funnel. The solid remains in the filter and liquid is drawn through the funnel into the flask by a vacuum. (Chemistry glossary, n.d.)

Figure 24 Vaccubrand for filtration (Photo taken in lab)

3.2.10 **Ethanol**

Ethanol played a major role in the extraction of the pectin. Pectin is insoluble in ethanol, so it helped the pectin to precipitate. Other equipment's used the experiments are disposable pipettes, hot plate, magnetic stirrer, petri dish, drying oven, grinder etc. Hot plate was used as source of heat during pectin extraction and acid hydrolysis. Magnetic stirrer is used to mix the solution constantly and vigorously. Petri dish was used for casting the film and oven was used for drying film. Grinder was used for the grinding the dry pectin content to fine pectin powder.

3.3 Extraction of pectin and production of bioplastic film

Figure 25 Laboratory procedure of extraction of pectin and production of biodegradable films

First, the selected 247g of fruit peels were cut into pieces and washed using deionized water to remove impurities and they were put in a beaker of 800 ml. After that 600 ml 2% acetic acid was poured in the beaker and it was boiling for around 3 hours at a temperature of 100^0C. Magnetic stirrer was used in beaker to make sure that the peels were immersed in solution all the time. The main reason for boiling is that the cell walls of the peels get softer which aids the process of pectin extraction. The acidic solution was of acetic acid which was maintained by checking through litmus paper. When the solution of acetic acid is more than that of pH 2.8 the pectin solution gets dissolved and if its less acidic then the pectin precipitate will not form (Methodology of isolation of pectin from orange peel, 2020). To maintain the acidic pH any kinds organic or inorganic acid can be used such as tartaric acid or HCl. After boiling the solution was filtered and the filtered solution was mixed with solution (70% ethanol 30% water) and left it on the table for a while. The pectin started to separate from the solution as it is insoluble in alcohol. Then the solution was filtered with the help of vacuum filtration. Filtration was repeated several times to lower the water content from pectin as much as possible. The pectin filtered was used to produce biodegradable films.
Filtered pectin was left in the oven to dry for 8 hours at a temperature of 50^0C. After the drying time pectin did not dry out completely so it was left to dry at 18 hours at same temperature. The extracted pectin was ground into fine powder using a blender. Both of pectin i.e., dry powder and pectin wet paste were used for formation of thin film formation.

3.3.1 Dry pectin powder

2g of dry pectin was taken in a 50ml beaker and 0.1g of corn starch was added as co-biopolymer. 20ml of water was added and beaker was kept on a hot plate at a temperature of 100^0C with constant stirring with the help of magnetic stirrer. 3ml of 0.5M HCl was added to the solution followed by the addition 2.1ml of 99% Glycerol. 0.5M NaOH was added for neutralization of the reaction. Litmus paper was used to check the pH of the mixture. The hydrolysis time was 20 to 30 minutes until mixtures forms thick and gel like structure. The mixture was poured on petri dish and left in the oven for drying 50^0C for about 24 hours.

3.3.2 Pectin paste

25g of pectin paste was taken in a 50ml beaker and kept in a hot plate at a temperature of 100^0C. 3ml of 0,5MHCl was added to the pectin paste as well as 2.1ml of 99% Glycerol was also added. Magnetic stirrer was used for mixing and constant stirring. 0.5MHCl was added to neutralize the solution. Litmus paper was used to check the pH of the mixture. After the acid hydrolysis for about 30 minutes the mixture was poured in petri dish and left in the oven for drying for 50^0C for approximately 24 hours.

3.4 **FTIR**

FTIR spectroscopy has a wide range of chemical applications, especially for polymers and organic compound and polymers. It offers analytical opportunities in, QA/QC, analytical, academic, and forensic labs (Bradley, n.d.). In some cases, it is also used for the identification of inorganic materials. It uses the infra-red light to scan and examine samples which provide the band absorption spectra from which we can do analysis of the chemical and functional properties. FTIR instrument sends infrared radiation between 10000 to 100 cm-1 through a sample. The sample absorbs some radiation which is converted to rotational (vibrational) energy by molecules of samples. The resulting signal at the detector presents a spectrum normally ranging from 400cm-1 to 4000cm-1, which represents a molecular fingerprint of a sample (RTI laboratories, n.d.)

The FTIR spectra was obtained by using FTIR instrument. The four sample which were to be tested were cut into small pieces. After blue light stopped flashing which is an indicated that the instrument has warmed up. The iD7 ATR accessory was cleaned and positioned correctly. Omnic software was opened in the desktop which generates spectrum of the measured sample. The time taken to generate the spectra was about 16 seconds. First, the background spectra were collected which followed by sample.

3.5 **Biodegradability**

Biodegradability of polymers was tested by using free standard with the help of composting. The waste is mainly broken down by bacteria fungi, ray fungi and earthworms, with aid of large number of microorganisms. The work of microorganisms to release the nutrients, thermal energy, carbon dioxide, water, and water vapor from the waste which allows to generate heat about 70-80 degrees Celsius in the compost. It helps in the formation of high-quality compost soil for degradation of different products (Biolan, n.d.). A product’s ability to biodegrade is directly proportional to the amount of carbon available for microbial consumption. The main challenges in biodegradation test are the complexity of the biochemical interactions, the composition of material tested as well as the specific requirements of each biodegradation test. The recommended standard for biodegradation of solid materials is ISO 16929, while OECD 301for liquid and ASTM D5864 for lubricants (Situ Biosciences LLC, n.d.).

The biodegradability test was done using a home compost facility. The compost included waste products generated from household works which consist of wooden chips, bio waste kitchen scraps etc. The home compost was used to test the biodegradation properties of the films. The samples were marked with for different colours of tape which made easy for the visual inspection.

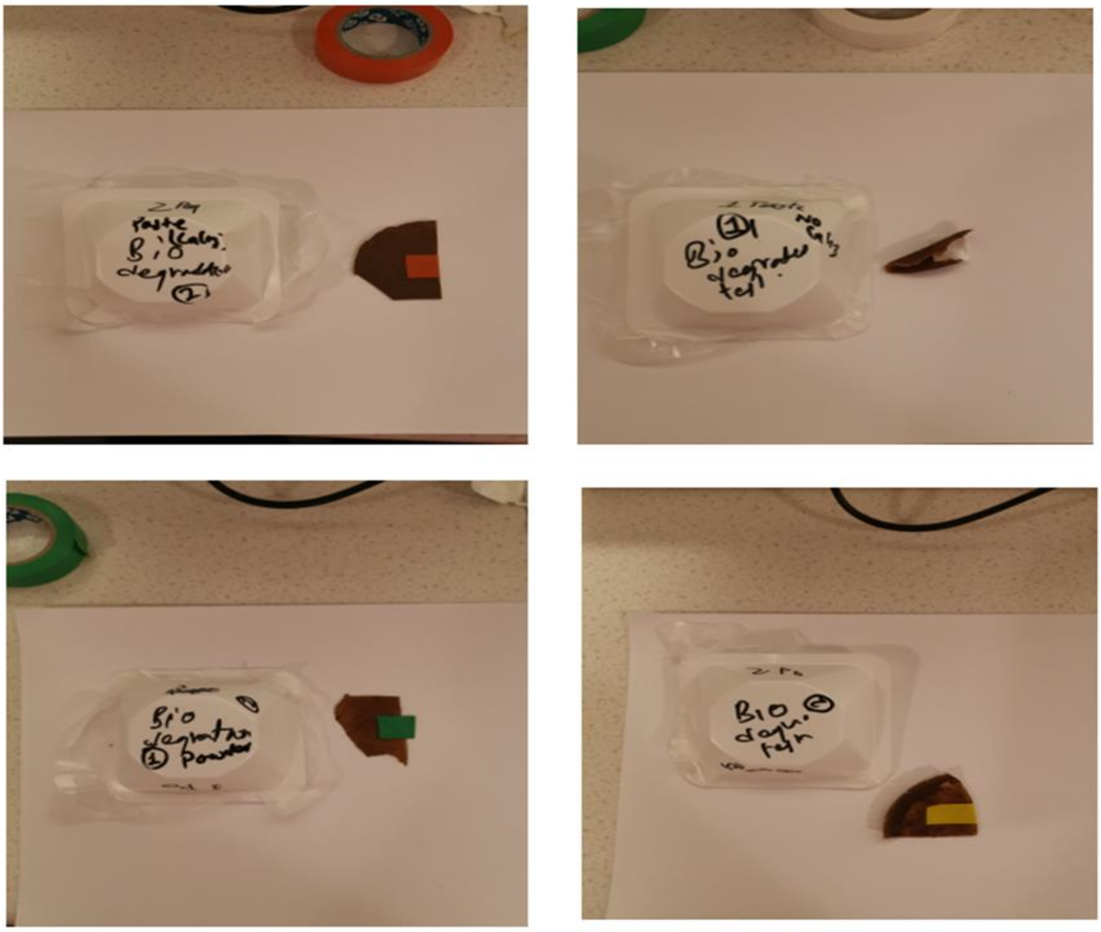


Figure 26 Biodegradation test initial preparation with labels

4 RESULTS AND ANALYSIS

After the pectin was dried it was very difficult to separate as it was solid particle attached to drying plate. The total mass of dry pectin extracted was 8g which means the yield was approximately 5%. The pectin was used for production of bioplastic film and it has been shown below.

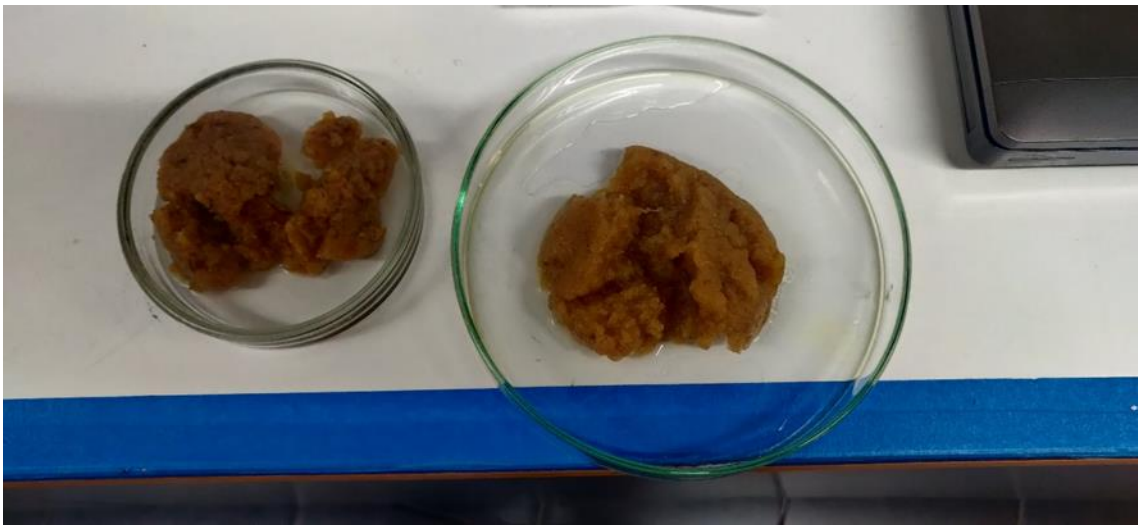


Figure 27 Pectin after filtration and ready for drying

Figure 28 Dried pectin after milling

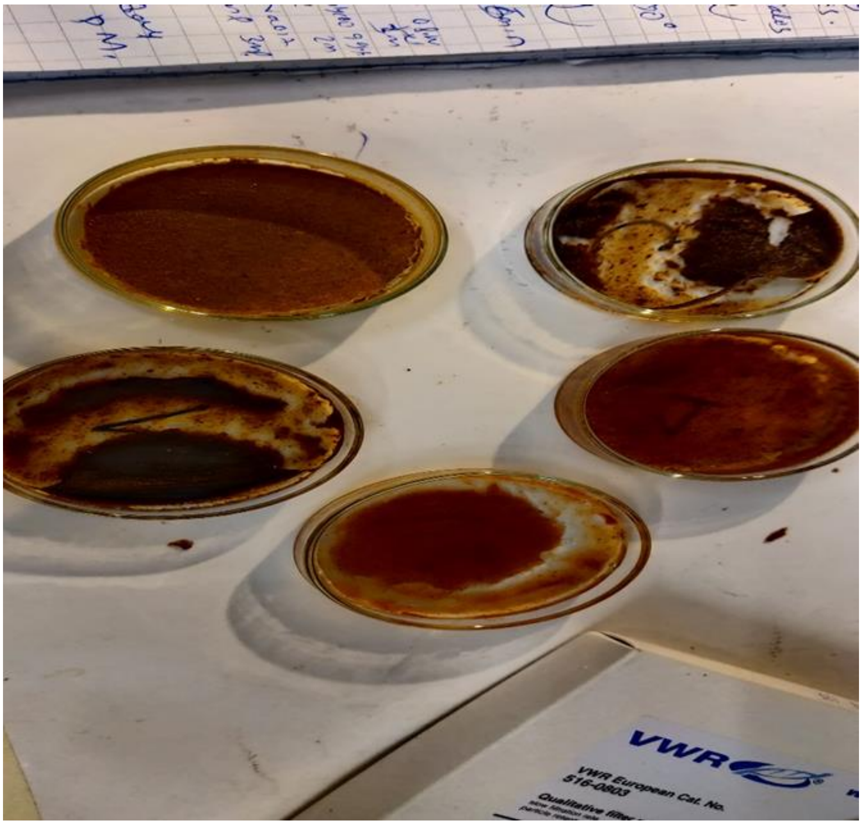


Figure 29 Results with some failed casting

The bioplastic films were finally taken out of the oven to see the results. There was some obstacle in film formation. There was some problem with oven at the end of the project while doing this drying. The temperature of the oven was eventually falling after some time after the drying started. The thickness of the four samples were measured. The samples were found to have uneven thickness which is a result of uneven particle size because of inappropriate milling as well as due to impurities. The films were flexible and opaque. The films were cut into pieces for FTIR analysis and biodegradation test. Among the samples two were produced pectin paste which did not remain intact for the film formation, they were noticed to be thicker than the ones made from pectin powder. The two samples produced using pectin powder remain more intact than the samples from the pectin paste. The films produced from pectin paste was showed less strength than the films from dry pectin powder. At least five intact films are needed to do the tensile analysis. The color of the films was similar although the pectin paste films were little light-colored. In the earlier days of the project film synthesized using more volume of cornstarch (20%) did show satisfactory tensile properties but since our goal of the project was to use mainly waste materials, so the use of cornstarch was decreased down to 5%.

The thickness of the films was uneven, so it was measured ten times to calculate the average thickness of each film. The thickness of the films is listed in the table below.

Table 4 Samples and its thickness

Sample	Thickness(mm)
1. Pectin paste	0.82
2. Pectin Paste	0.83
3. Pectin powder	0.40
4. Pectin powder	0.56

4.1 **FTIR**

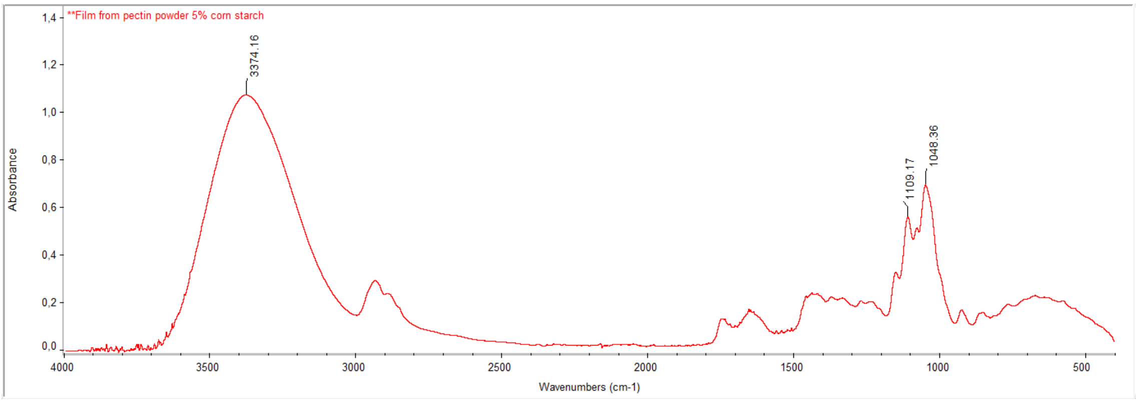


Figure 30 FT-IR Spectra of Film

The main idea of obtaining a spectrum of biofilm was to identify its functional groups which makes it easier to know the interaction of ingredients during the formation of film. The above figure shows the absorption peaks of OH group around 3374.14 cm^{-1}. It represents hydrogen bonded-OH stretch for functional hydroxyl group (O-H) which is because of the complex vibrational stretching naturally occurring in carbohydrate structures. The peaks obtained below the region of 800 cm^{-1} is attributed to the pyranose ring skeletal vibrations in the glucose unit of starches (Ramazan Kizil, 2002) . The small peak around 2900 cm^{-1} shows the aliphatic C-H vibration, the absorption of pectin can be seen in small peak around 1600 cm^{-1} and 1700 cm^{-1} which is C-O bond vibration. The absorption of band of 1109.17 cm^{-1} and 1048.36 cm^{-1} shows the vibration of C-O and the bending vibration of C-H in the FT-IR spectrum which shows that pectin contains O-H, C-H aliphatic groups and C-O (S. Chodijah, 2019).

From the above spectra, the shift from right of O-H stretch and C-H stretch is caused by plasticizer, which supports the fact that bond holding the starch molecules together are weakened. The hydrogen bond formed between plasticizer and starch during plasticization replaces the molecules of strong hydroxyl group which are broken. This statement agrees with Xiao, (Xiao FM, 2004) plasticizers could form hydrogen bonds with starch which takes place of the strong action between hydroxyl groups of starch molecules and make starch plasticizing.

4.2 Biodegradability Test

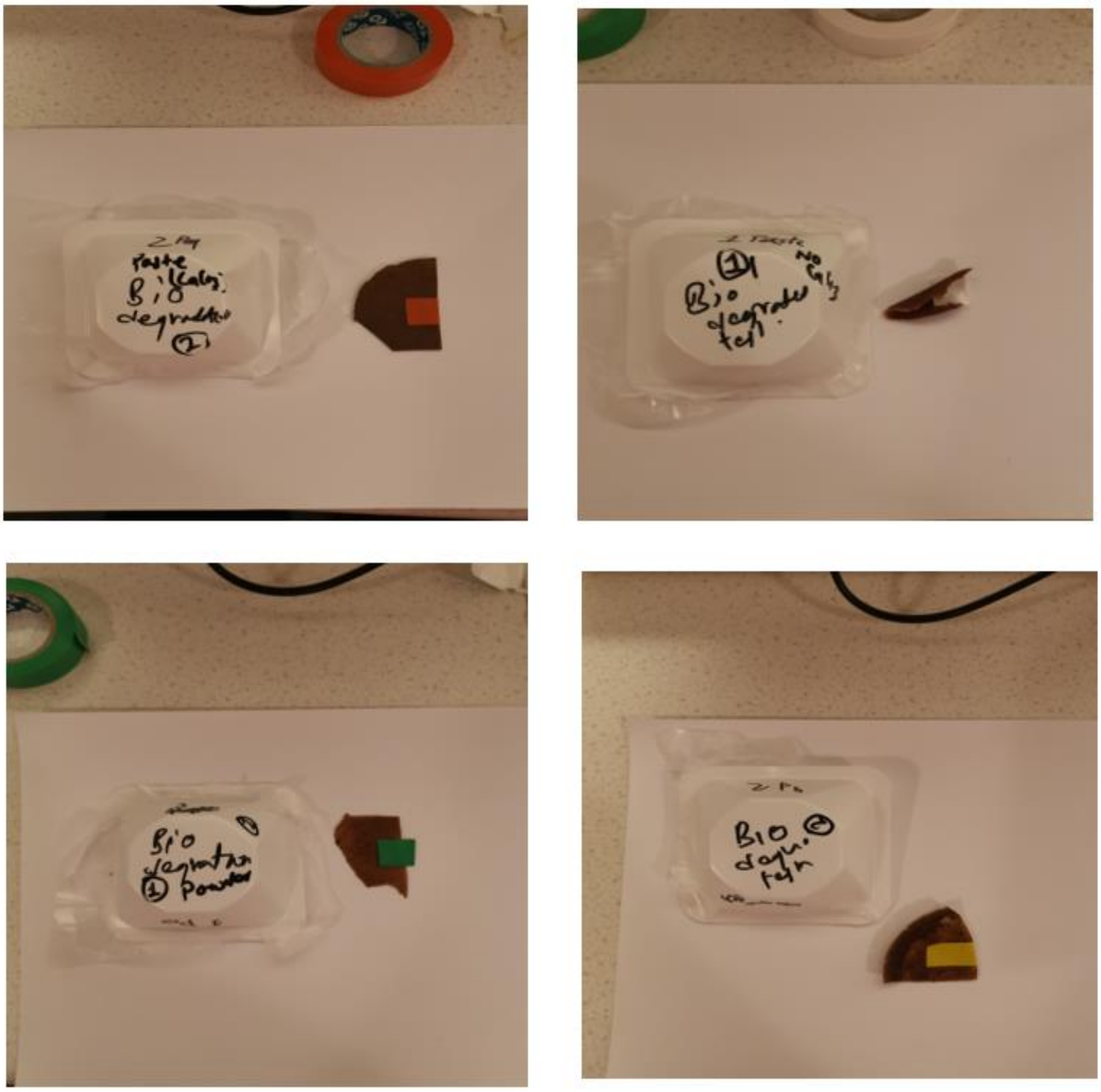


Figure 31 Biodegradation test initial preparation with labels

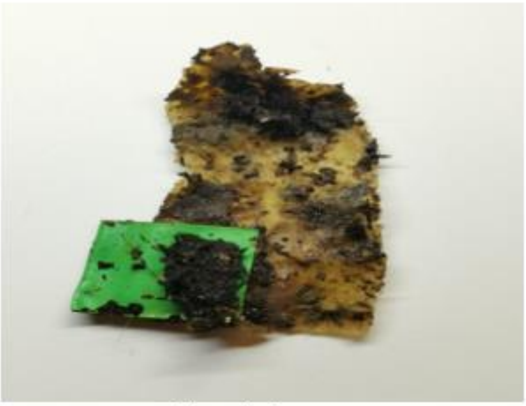
Table 5 samples with compositions and labels with different color of tape

Sample	Colour of tape	Composition
1	Red	Pectin paste (25g)
2	White	Pectin paste (25g)
3	Green	Pectin powder (2g)
4	Yellow	Pectin Powder (2g)

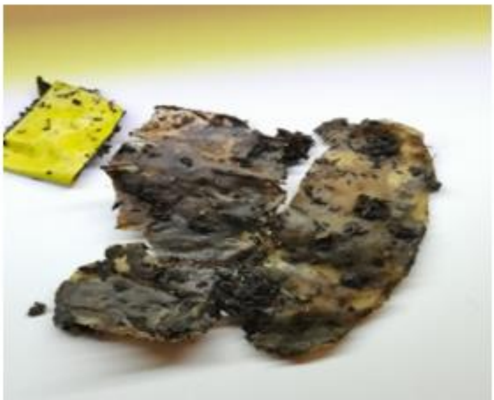
The following samples was placed on the compost on 26/12/2020 and the first visual inspection was done in 06/01/2021 which was 11 days. During the visual inspection, photos were taken in order see the degradation on different pieces of samples.

Sample 1

Sample 2



Sample 3



Sample 4

Figure 32 Biodegradability test initial inspection

In the first visual inspection slight weight reduction has been noticed and thickness has been reduced. The sample were only taken out for taking photos for visual inspection. The film was not weighed in that inspection though the biodegradation was happening at higher rate because of the temperature during the first and second week was ranging from 23^0-32^0 Celsius. As we can see the samples do not remain intact and it has loosened its size and weight.

The next visual inspection was done in 26/01/2021 and was taken out to weigh it to calculate the biodegradability of the films. Photos from the second inspection are as follows:

Figure 33 Biodegradability test results

We can easily notice that the films have degraded more and lost its shape. The second visual inspection was done after 20 days of the first inspection and the biodegradation rate has been slower this time than the first inspection. The maximum temperature of the compost was 32^0 Celsius in the first inspection though the compost temperature fell to 5^0 Celsius because the outdoor temperature range was -7^0 to -20^0 Celsius which supports the argument that the biodegradation process went slower than expected during the second inspection. The samples were too fragile as compared to its state before the biodegradation test. The samples have become thinner, and it has lost its opacity to some extent.

The biodegradability test was carried out in a compost and the percentage of biodegradation was calculated. The initial weight of film was measured prior to composting and the weight of film was again measured after one month of composting. The microbial resistance was calculated using free standard and has been calculated using the formula given below.

Microbial resistance (%): $\frac{Initial\ weight - Final\ weight}{Initial\ weight}$, The microbial resistance (%) for all the sample are calculated below:

Table 6 Microbial resistance

Sample	Initial Weight (g)	Final Weight (g)	Microbial Resistance(%)
1	1,01	0,02	98,09
2	1,53	0,07	95,46
3	0,36	0,03	91,83
4	1,06	0,07	93,45

There are numerous factors that affect biodegradability which are redox environment, temperature, substrate concentration, the adaptive response of the microorganism, availability of inorganic nutrients (John W. Davis, 1996). The decomposition process primarily depends upon the bacteria, fungi, and microorganisms. During the decomposition process the carbon dioxide, heat, water, and other nutrients are released and the heat generated by microorganisms increases the temperature of the compost which can exceed up to 70-80^{0}C. The decomposition process is affected by the outdoor temperature and compost masses freeze when the temperature is close to -5^{0}C (Biolan, n.d.). The temperature during the biodegradation period was found to be 32^{0}C which ranged from 23-32^{0}C during the first two weeks while the outdoor temperature range was 4 to -2^0 C degrees Celsius. The temperature dropped and varied from -7 to -20^0 C as the temperature of the compost also slightly reduced to 5^0 C. The temperature did rise to same range as in the first week, but the temperature of the compost remained 5^{0}C. Furthermore, we can make a statement that the decomposing process is slower in a colder weather and stops completely when the compost masses freeze. The percentage of biodegradability increases with temperature and vice versa but the when the temperature reaches the optimum point, the biodegradability decreases because temperature increases the cross-link and intermolecular force between starch molecules of fruit peel. Both samples which were produced from pectin paste tend to have higher biodegradation than the samples with pectin powder. This is due to the more water content on the films with pectin paste. The sample 1 from pectin paste had a higher weight as compared to pectin powder films though it has lost more weight.

5 DISCUSSIONS AND CONCLUSIONS

In this study, a polymer film was synthesized from fruit peels by extracting the pectin from the fruit peels. Pectin was extracted using 2 percent acetic acid solution by boiling for three hours at 100^0C temperature. The extracted pectin was used for synthesizing films by varying the operating conditions such as drying temperature, concentration of HCl, glycerol, and residence time for hydrolysis to obtain good quality films with optimum biodegradability and functional properties. FTIR was used to analyse the functional properties and biodegradability of the samples were measured for 30 days using a compost.

The main idea of the research was to study that the fair quality bioplastic can be produced from discarded or waste material. The main objective of the research was to extract pectin from waste material and use it for production of biodegradable films has been met. However, the study suggests that it still needs an additional filler like chitin, chitosan, and deep eutectic solvents as a plasticizer for better quality and wide range and of application. So, more research needs to be done to improve tensile properties, water absorption, elongation at break, oxygen, and water vapor transmission rate so that it can be possibly used for food and beverage packaging. The selected fruit skins could have dipped into $Na_2S_2O_5$ solution to prevent the growth of fungi and bacteria. Other different natural and chemical fillers which can be used to improve the properties of bioplastic are $CaCO_3$, $BaSO_4$, quartz and kaolin. To improve the properties of the bioplastic, further research should be carried out and other sustainable sources of starches can also be used as a raw material. Food wastes such as kernel seeds, mango seeds, avocado seeds also have high starch content. Other different types of acid such as HCL, HNO_3, H_2SO_4 shows high yield during the extraction of pectin so it can be considered with extensive research (Sandarani, 2017). The different variation in the reagents used may differ the properties of the polymeric films obtained. Fine quality pectin can be obtained, and it can be more precisely milled to dry powder to improve the properties of bioplastic especially the thickness could be evenly maintained. There were difficulties while milling the dry pectin powder to obtain even particle size which could be overcome by following the above procedure. In addition, visual observation of the films showed shrinkage, loosing shape in the films obtained from pectin paste.

Finally, we can conclude that films produced from pectin extracted from fruit peels is highly (approx. 90%) biodegradable. Further studies and continued research are required to improve the properties and qualities of bioplastics, this raw material can be an ideal sustainable synthesis in the future. The use of waste material as a source of raw material is part of circular economy as well as renewable energy.

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