Bioplastics production from agricultural crop residues

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Abstract: Bio-based plastics have a huge market and a wide range of applications and then have become increased in economy and research. Due to the environmental hazard on all organisms and the pollution that happens in all natural resources such as air, water, plants and soil pollution and the limitation of quantity of fossil resources on our planet, the future cannot depend on petro-plastics. All fossil products should be replaced by bio-based products. The petro-plastics are one of the fossil products which should be replaced by bio-based plastics. In this study, potato peels were used to produce bioplastics by the extraction of the starch from the peels and adding some ingredients such as water, glycerin, vinegar and industrial colors with different ratios and in biochemical reaction under heating. This process produced a wide range of bioplastics samples with different properties such as texture, hardness and coherence. It was found that when the glycerin ratio increases the produced bioplastic becomes more flexible which withstands compressive stress to 0.5 MP, and vice versa when the glycerin ratio decreases the produced bioplastic becomes hard which withstands compressive stress to 1.1 MP. It was concluded that the bio-based materials can be used effectively to process bioproducts such as bioplastics.

Keywords: bioplastics, bio-based plastics, biodegradable plastics, bioprocessing, bio-based materials, biopolymers, agricultural wastes

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1 Introduction

Plastics are used for so many things, such as water bottles, milk jags, plastic bag to carry groceries, forks, knives, coffee cups, shopping carts etc…, with so much plastics all around the world. Plastic products from petrochemical industries are not eco-friendly due to having the high carbon footprint. Until recently, bioplastics has been explored as alternative to substitute the fossil-based plastic. Bioplastics are polymers that are manufactured into the commercial products from natural sources or renewable resources, and they can also be biodegradable (Boonniteewanich et al., 2014). There are mainly three types of bioplastics in the commercial scale of production (Pei et al., 2011): (1) Plastics derived from fossil carbon source but biodegradable, (2) Plastics derived from polymers converted from biomass and biodegradable, and (3) Plastics derived from polymers converted from biomass but not biodegradable.

There are growing concerns about current petroleum based production, accumulation of waste in landfills and in natural habitats including the sea, physical problems for wildlife resulting from ingestion or entanglement in plastic, the leaching of chemicals from plastic products and the potential for plastics to transfer chemicals to wildlife and humans (Thompson et al., 2009). Bioplastics, derived from bio-based polymers, may provide a solution. Unlike the chemically synthesized polymers, the bio-based polymers are produced by living organisms, such as plants, fungi or bacteria. Some microorganisms are particularly capable in converting biomass into biopolymers while employing a set of catalytic enzymes. Attempts to transfer biomass to produce industrially useful polymers by traditional biotechnological approaches have obtained only very limited success,

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suggesting that an effective biomass-conversion requires the synergistic action of complex networks. As an interdisciplinary research field which is a unique combination of life science and engineering, synthetic biology can provide new approaches to redesign biosynthesis pathways for the synergistic actions of biomass conversion and may ultimately lead to cheap and effective processes for conversion of biomass into useful products such as biopolymers (Pei et al., 2011).

Starch-based bioplastic materials have been gaining interest for applications like packaging, food and beverage containers, carrier bags, and many others (Accinelli et al., 2012), because they can be composted or landfilled after use (Soroudi and Jakubowicz, 2013). The starchy matrices support the growth of a variety of microorganisms, especially fungi during the composting process. Mechanical recycling is theoretically possible, but difficulties and added costs in removing impurities (e.g., food residues, paper labels) and reduced thermoplastic properties of final recycled products have made this approach less attractive, particularly for manufacture of products such as carrier bags, mulching films, in which even small variations in mechanical properties cannot be tolerated technically (Accinelli et al., 2015a). On the other hand, several studies have shown that starch-based bioplastic granules can serve as an effective formulation for delivering biocontrol and bioremediation fungi (Accinelli et al., 2015b). Additionally, flax can be produced from bioplastic fibers and then used for medical purposes (Kulma et al., 2015).

The objective of this study is to use agricultural crop residues such as potato peels to produce bioplastics. The produced bioplastics were subjected to some tests regarding texture, hardness and coherence.

2 Materials and methods

In this study, potato peels were used as an example of starchy agricultural crop residues which can be processed for the production of bioplastics. In the experiments and the processing of waste to bioplastics, the following instruments were used: flasks, magnetic hot plate stirrer, thermometers, stopwatch, digital mass balance, glass spoons, foil papers, and graduated cylinders. On the other hand, the following materials were used: starch extracted from potato peels, glycerin, vinegar and water where the amounts of these materials are presented in Table 1.

Table 1 The used materials in each experiment and the required time and energy

Experiment number	Used Materials	Required Time	Consumed Energy (kJ)	Weight of Produced Bioplastic (g)	Properties of produced Bioplastic
1	20 g Starch 2.5 mL glycerin 2.5 mL vinegar 50 mL water	7 min	210	93.9	-Textures: hard -It's molecules coherent to some extent
2	10 g Starch 2.5 mL glycerin 2.5 mL vinegar 60 mL water	7 min 30 s	225	87.80	-Textures: flexible -It's molecules coherent to some extent -Thickness: superfine
3	20 g Starch 2.5 mL glycerin 2.5 mL vinegar 60 mL water	6 min 55 s	207	96.95	-Textures: very hard -Little coherence to some extent
4	10 g Starch 5 mL a mixture of vinegar and glycerin 1:1 60 mL water	8 min	240	89.20	-Textures: hard -It's molecules coherent extent
5	5 g Starch 2.5 mL glycerin 2.5 mL vinegar 60 mL water	10 min	300	82.30	-Textures: very flexible -Little coherence to some extent -Thickness: very superfine
6	10 g Starch 5 mL glycerin 2.5 mL vinegar 60 mL water	5 min 30 s	165	88.90	-Textures: semi-flexible -It's molecules coherent -Thickness: semi-superfine
7	10 g Starch 2.5 mL glycerin 5 mL vinegar 60 mL water	5 min 30 s	165	88.60	-Textures: semi-flexible -It's molecules coherent to some extent -Thickness: very superfine
8	4.2 g Starch 2 mL glycerin 2 mL vinegar 48 mL water	4 min	120	73.60	-Textures: flexible to some extent -It's molecules coherent -Thickness: semi-superfine

Potato peels were boiled and a milky white water was formed, where starch was extracted from that water by filtration. The processing steps of starch extracted from potato peels to produce bioplastics can be listed as following:

1- Weighing the starch and then poured into the flask.

2- Determining the required volume of water using the graduated cylinder and then pouring the water into the flask which contains the starch.

3- Using the magnetic hot plate stirrer to mix the water and the starch at 105^{o}C where the time was recorded using a stopwatch.

4- Adding the vinegar then the glycerin to the mixture.

5- Stirring the mixture until being cohesive then measuring the temperature of mixture.

6- Uplifting the flask from the hot plate stirrer then stopping the stopwatch and recording the time.

7- Pouring the mixture onto oil greased foil paper or oil greased Petri dish, where the oil will ease removing the bioplastic once it dries. At this stage the bioplastic can be shaped as required.

8- Keeping the Petri dish in an oven at 65^{o}C for one to two hours.

9- Removing the product from the Petri dish to get the bioplastic.

On the other hand, the produced bioplastics were tested at the laboratory for biodegradability. Amylase enzyme was added to water, where the mixture was stirred. Afterwards, the bioplastic was added to the mixture. The sample was left overnight along with the control sample which consists of water only. This test was conducted to ensure that the produced bioplastic is biodegradable.

3 Results and discussion

The required time and energy along with the used materials in each experiment are presented in Table 1. Additionally, the relationship between the processing time and the consumed energy is shown in Figure 1. The properties of bioplastics produced from each experiment are presented in Table 2. It was found that when the glycerin ratio increases the produced bioplastic becomes more flexible which withstands compressive stress to 0.5 megapascals, and vice versa when the glycerin ratio decreases the produced bioplastic becomes hard which withstands compressive stress to 1.1 megapascals as shown in Table 2. The results showed that it is possible to successfully produce bio-based plastics from potato peels starch. Bioplastics can be used in several applications besides their positive impact on the environment, economy, society and sustainability.

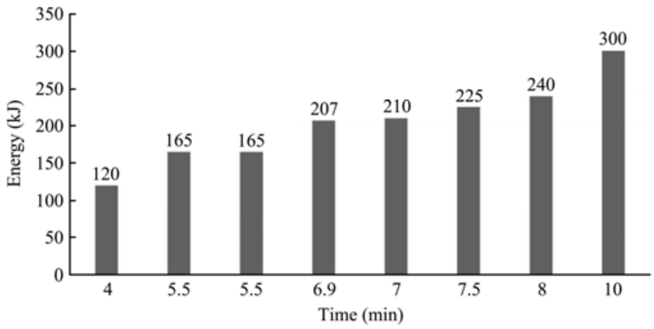
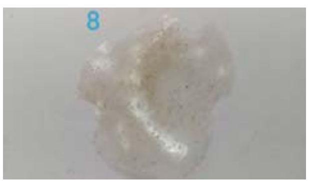


Figure 1 Relationship between processing time and consumed energy

Petro-plastic is a chain of polyethylene (polymer) of small units of ethylene (monomer), where petro-plastic takes 500 to 1000 years to break down. Therefore, it thought to engineer new materials that could break down easier. This results in developing biodegradable plastic, where natural organisms (e.g. bacteria) are capable of breaking the bio-based material into smaller parts. In this case, a starch polymer (amylose) is broken down into its monomer parts of simple sugars (i.e. glucose). Sugars are vital energy sources for all living organisms; as a result many organisms from bacteria to humans have enzymes that brake down starch into simple sugars. Starch polymer is made of chains of simple sugars monomers (glucose), where the bonds which connect them is called glycosidic bond or glycosidic linkage which is a type of covalent bond that joins a carbohydrate (sugar) molecule to another group. An enzyme called amylase breaks the sugars apart from each other, where water molecule is absorbed in order to break the glycosidic bond between 2 monomers through a process called hydrolysis.

Bioplastic is a chain (polymer) made up of simple sugars, i.e. glucose (monomer). Therefore, the bioplastic is a biopolymer synthesized from bio-based materials extracted from organisms (starch). On the other hand, starch is a bundle of polymers and, therefore, water was added to loosen up those bundles. Furthermore, starch has some bundles of branched polymer called amylopectin which make it difficult to synthesize a high-quality bioplastic. Hence, vinegar was added to the mixture to cut off those branches to make a linear polymer called amylose. If the bioplastic is just made from this amylose, then a very hard bioplastic will produced. Therefore, glycerin was added to make the bioplastic more flexible.

Table 2 Properties of bioplastics produced from each experiment

Experiment Number	Produced Bioplastic	Properties of Produced Bioplastic
1		- hard texture which withstands compressive stress to 0.9 megapascals - coherent molecules to some extent
2		- flexible textures which withstands compressive stress to 0.6 megapascals - coherent molecules to some extent - superfine thickness:
3		- very hard texture which withstands compressive stress to 1.1 megapascals - little coherence to some extent
4		- hard texture which withstands compressive stress to 1.0 megapascals - coherent molecules
5		- very flexible texture which withstands compressive stress to 0.5 megapascals - little coherence to some extent - very superfine thickness
6		- semi-flexible textures which withstands compressive stress to 0.8 megapascals - coherent molecules - semi-superfine thickness
7		- semi-flexible texture which withstands compressive stress to 0.8 megapascals - coherent molecules to some extent - very superfine thickness
8		- flexible textures to some extent which withstands compressive stress to 0.7 megapascals - coherent molecules - semi-superfine thickness

The produced bioplastics were tested at the laboratory for biodegradability. Amylase enzyme was added to water, where the mixture was stirred. Finally, the bioplastic was added to the mixture. The sample was left overnight along with the control sample which consists of water only. It was found that the bioplastic breaks up in the amylase and, therefore, it is biodegradable.

Future investigations will focus on the use of metal clusters, discussed by Attia and Samer (2017), in the production process of bioplastics from agricultural wastes.

4 Conclusions

According to the results of this study, it can be concluded that:

1. It is possible to produce bio-based plastics from starch extracted from potato peels.

2. Glycerin makes the chains of starch slip along each other which makes the bioplastic material more flexible. Therefore, the more glycerin is used the more flexible bioplastic is produced, and vice versa the less glycerin is used the harder bioplastic is produced.

3. Water mixes up all the ingredients and helps loosen up all long chain polymers.

4. Vinegar breaks the starch chains into smaller sizes which make them more manageable while creating the bioplastic.

5. The duration of heating and, therefore, the energy consumed increases when lower amounts of starch were used in the processing of bioplastics, due to the fact that the starch is responsible for the cohesion of bioplastic during heating and when low amounts of starch are used the process tends to evaporate more water while consuming more energy until reaching cohesion and stability.

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