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Production of Biodegradable Plastic from Biomass

*[1]Nora, A. Zidan, [1]Fatma, I. Barakat, [2]Manal, A. Sorour & [1]Shakinaz, T. El-Sheltawy

[1]Department of Chemical Engineering, Faculty of Engineering, Cairo University, Giza, Egypt

[2]Food Engineering and Packaging Department, Food Technology Research Institute, Agricultural Research Center, Giza, Egypt

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ABSTRACT

Plastic pollution is one of the most dangerous environmental problems that threaten the world. Conventional plastic doesn't degrade and tends to end up in seas and land, killing sea animals and polluting soils. Plastics obtained from agricultural wastes and have the ability to degrade, have appeared as possible solution to the conventional plastic problems. However, in order for the biodegradable plastic to substitute the conventional plastic, it must possess similar characteristics in addition to being economically and environmentally attractive. The aim of this paper is to produce durable and degradable plastic from potato peels. The effect of different operating conditions on the characteristics of the produced plastic, including biodegradation behavior, tensile strength and water absorption behavior, were studied. Acetic Acid with amounts of 4, 6 and 8 ml were used proving that the 8 ml acid concentration is the best from biodegradation point of view. Moreover, glycerol of amounts 2,4,6 ml were used, indicating a direct relation between degradation and glycerol amount, as well as, an inverse relation between water absorption and glycerol amount. Reaction temperature as well as drying temperatures were also tested showing that the low temperatures have good effect on enhancing the properties of the produced plastic.

1.Introduction

Plastic products are used in numerous of applications as in construction, electronics, medical devices and mainly in packaging due to its low cost, durability, versatility and ease of handling. However, plastic wastes are representing a huge environmental problem; since most of them are not degradable and can remain either in soil or water for decades without changing or degrading causing a lot of health problems as well as threatening the environment (Adamcova & Vaverkova, 2016).

Plastics are mainly disposed by three methods; incineration, landfilling or recycling, however, recycling is the least used method among the three methods. Incineration of plastics causes harmful emissions that affect the atmosphere and increase the greenhouse effect. Moreover, landfilling of plastics pollutes the soil and harms land creatures; since plastics contain chemicals that help in improving their properties (Ezeoha, 2013; Yaradoddi, et al., 2016). Table 1 illustrates the amount of plastic wastes produced in the world and the methods of disposing it. The table shows that the amount of plastic generated five years ago was around 7 billion tons at which more than 50% of it ended up landfilled or discarded. On the other hand, the plastic wastes that ended up incinerated or recycled were very small amount. Moreover, forecasts show that in 2050, the total plastic wastes expected to be produced would be 30 billion tons where landfilling will continue its dominance for the upcoming years together with incineration, while recycling will continue to be the least favorite method of disposals it is thought to be uneconomic option due to the presence of additives in the plastic which makes its recycling a difficult and less profitable process (Geyer, et al., 2017).

*Corresponding Author
Email: Norazidan@live.com

Table 1. Global Plastic Wastes production (billion tons)

Year	2000	2015	2050
Total Plastic Waste	2,500	7,000	30,000
Landfilled	2,500	5,000	11,000
Incinerated	0	1,000	12,000
Recycled	0	1,000	7,000

Geyer, et al., (2017)

Ritchie and Roser, have found that the wastes produced from packing only are the highest among all other plastic applications. In 2015, it was recorded that wastes produced from packaging application only, accounts 46 percent of the total plastic wastes generated in that year.

Taking about the countries that contributes highly in the plastic generation, it was found that China and Indonesia are the main producers of the global plastic wastes accounting for almost 40 percent of the total wastes generated in the world (Jambeck, et al., 2015; Ritchie & Roser, 2018). Table 2 shows the ranking of countries with the highest quantity of mismanaged wastes that ends up in water or soil. It also shows the consumption of plastic per person per year in those countries. Asia was found to be the continent with the highest amount of mismanaged wastes. It is though that the reason behind the massive increase in wastes in the countries with the highest wastes generation especially in Asia is due to huge population and fast growing economy. Another interesting fact is that most of those countries lies on coasts, oceans or rivers and have a very large population in coastal cities; this explains the reason behind the mismanaged wastes generated from those countries as almost third of the wastes produced by those countries ends up in water (Hotz, 2015; McCarthy, 2019).

Table 2. Top Ranked Countries with highest amount of Mismanaged Wastes

Country	Ranking	Total Mismanaged Wastes (Million tons)**	Plastic Wastes that ends up in water (Million tons)**	Waste Generation Per Capita (Kg/Year)[5]*
China	1st	8.8	3.53	44
Indonesia	2nd	3.2	1.29	22
Philippines	3rd	1.9	0.75	26
Vietnam	4th	1.8	0.73	37
Sri lank	5th	1.6	0.64	131
Egypt	6th	1.0	0.39	66
Thailand	7th	1.0	0.41	51
Malaysia	8th	0.9	0.37	73
Nigeria	9th	0.9	0.34	37
Bangladesh	10th	0.8	0.31	11

* Ritchie and Roser (2019)
** McCarthy (2019)

In Africa, it was found that Nigeria, South Africa together with Egypt and Algeria are the main countries responsible for wastes generation in Africa (Jambeck, et al., 2015) .Egypt has also been ranked as number six among the countries with highest mismanaged wastes. (HEPCA, 2013). According to the facts mentioned, the world started to find solutions to the plastic problem. People started to find substitutes as carton or paper. However, it was important to find a long term solution that can substitute the conventional plastic. It was important that this alternative material possesses same characteristics of the conventional plastic as mechanical properties, ease of handling and flexibility, and at the same time be profitable and environmentally friendly. Biodegradable plastic was thought to be the miracle alternative. Biodegradable plastic is the plastic produced from bio-based sources as starch obtained from fruit and vegetable wastes as well as cellulose and agricultural fibers. The term bio in biodegradable refers to the degradation process of the produced plastic where it can degrade easily in soil by the bacterial action. (Ezeoha, 2013). To produce biodegradable plastic from starch, an acid and a plasticizer must be mixed together with the starch as will be discussed later in this paper. (Wang, et al., 2003; Yang, et al.,2006).

Starch consists of two types molecules; Straight chain molecules called Amylose and branched chain molecules called Amylopectin (Nidoni et al., 2019). Using acid in the production process, break the branched chains and convert it to straight chain in order to facilitate the polymerization process. Moreover, plasticizer is used to enhance the mechanical properties as flexibility and durability (Fabunmi,et al., 2007).

Biodegradable plastic has many advantages as the rapid degradation since it can totally degrade in a month. It also produces less emission than the conventional plastic. On the other hand, it has important limitations as the poor thermal and mechanical properties and high water absorption compared to the conventional plastic (Pathak & Mathew, 2014; Chen, 2014; Arikan & Ozsoy, 2015).

That is why; in this research, the objective is to examine the effect of various operating conditions on the properties of the produced plastic and then select and justify the best operating conditions for the properties of biodegradable plastics. The effect of changing the amount of acid, plasticizer and starch on the produced plastic is studied in addition to the temperature and time factors. So, Glycerol is used as a plasticizer and Acetic Acid in the manufacturing process. On the other hand, starch obtained from potatoes peels is used.

2. Materials and Methods

Materials

The main materials used in this research are Potato peels, Acetic Acid and Glycerol. Potato Peels were purchased from local market in Cairo, Egypt. The peel specifications are tabulated in Table 3, keeping in mind that this amount of peels was extracted from 1 kilogram of potato.

Table 3. Potato Peels Specification per 1 kilogram of Potatoes

Property	Value	Unit
Mass	345	gm
Density	0.985	gm/cm^3
Moisture Content	42	%

Acetic Acid Properties

Acetic acid and glycerol were obtained from Elgomhoria Company for Trading Chemicals and Pharmaceuticals, Cairo, Egypt, with the characteristics shown in Table 4 and Table 5, respectively.

Table 4. Acetic Acid Properties

Property	Value	Unit
Density	1.05	gm/cm^3
Boiling Point	118	°C
Concentration	96	%

Table 5. Glycerol Properties

Property	Value	Unit
Density	1.26	gm/cm^3
Moisture Content	0.2	%
Glycerol Content	99.7	%

Equipment

Moulinex grinder was used for starch extraction, the specifications is listed in Table 5. Furthermore, for the production of biodegradable plastic film a 78 HW-1 stirrer and hot plate was used, together with Sartorius basic scale.

Table 5. Moulinex Grinder Specification

Property	Value	Unit
Type	Multi Moulinette	
Power	400	Watt
Capacity	500	ml

Methodology

The production process of biodegradable plastic is divided into two main processes; leaching of starch from potatoes peels and manufacturing of the biodegradable plastic as shown in Figure 1.

Leaching of Starch from Potato Peels

Potatoes are washed to remove any contaminants and then peeled, then peels were ground and soaked in hot water; in order to break bonds between starch and other molecules to facilitate the extraction process and achieve maximum extraction. To make sure that the maximum bond breakage has occurred, this mixture is left for fifteen minutes, and then filtered, where the ground peels are removed from the mixture, well squeezed to extract all solution and the starch solution is collected in a separate beaker. This process is repeated twice to make sure that all starch is extracted. The starch solution is left to settle where all the starch is settled and collected at the bottom of the beaker. The water is then removed letting beyond it a white layer of starch. The starch is collected and dried. Drying process usually takes 24 hours. After drying, the starch can be used in the second process. (Goswami, et al., 2015)

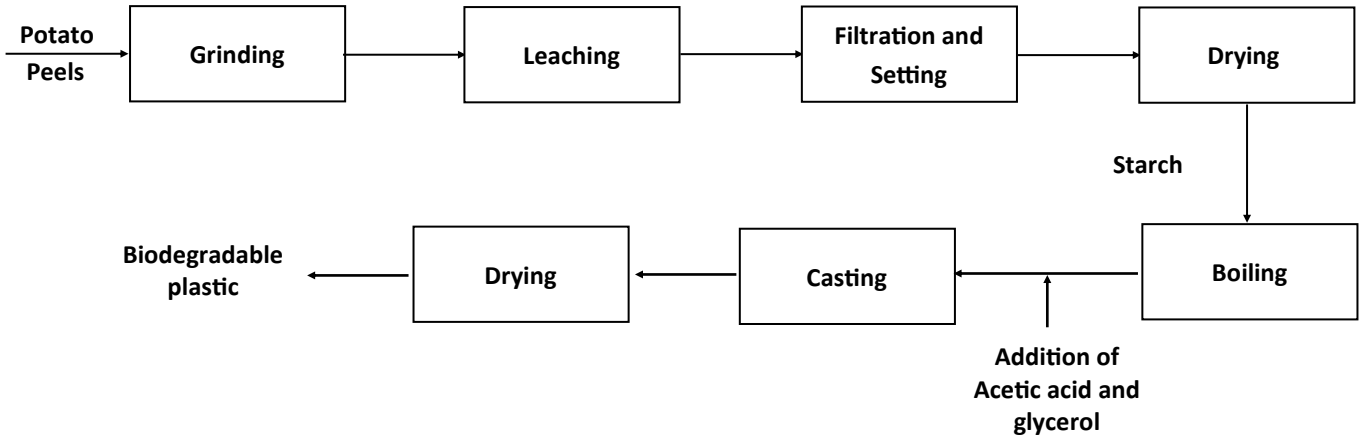

Figure 1. Production of biodegradable plastic from Potatoes Peels

Manufacturing of Biodegradable Plastic

For each 1 kg of potatoes, 345 gm of peels were produced and 17 gm of starch were extracted by the same procedures mentioned above. The extracted starch is mixed with water and is heated at 100°C using the hot plate and magnetic stirrer. Acetic acid and glycerol were then added to the starch solution and boiled at a reaction temperature of 100°C till the solution started to form gel like liquid. This gel is spread on petri dish for higher homogeneity, and is left to dry in the air at a temperature range of 25-30°C. The drying process takes almost 4-5 days till a constant weight.

Characterization of produced biodegradable Plastic: Biodegradation Test

Biodegradation test is performed in soil through bacterial action. The samples are weighted and buried in pots filled with muddy soil at a depth of 4-5 cm. The weight of samples is checked every three days till they fully degrade. The degradation behavior can be indicated from the percentage of weight loss that is calculated using Equation (1) (Arikan & Bilgen, 2019).

$$Weightloss(\%) = \frac{wi - wf}{wi} \times 100 \quad (1)$$

Where, w_i is the initial weight and w_f is the final weight of the sample

Water Absorption Test

Water absorption is an important property. Water resistance of plastic is important in application like packing especially in food industry to prevent food contamination or rotting. Samples are weighted and immersed in 50 ml of water for one day in order to check the amount of water that can be absorbed by the plastic sample. Water is then removed and samples are wiped with paper towel. Samples weight was determined once again to indicate the water absorption through calculating the percentage of weight gain using Equation (2), (Eterigho, et al., 2017)

$$Weight\ \ Grain\ \ (\%) = \frac{wf - wi}{wi} \times 100 \quad (2)$$

Where, w_i is the initial weight and w_f is the final weight of the sample

Tensile Strength

Tensile strength is measured using CT-3 Brookfield texture analyzer

Effect of Different operating conditions on the Properties of Biodegradable Plastic

Some experiments were applied with the aim of investigating both optimum drying conditions and reaction temperature. Other experiments were conducted with the objective of studying the effect of various operating conditions on the properties of the produced plastic as biodegradation, tensile strength and water absorption. These factors are as follows:

- Amount of starch
- Amount of acid
- Amount of plasticizer

Effect of Drying Temperature on the Produced Biodegradable Plastic

Two samples were prepared using 5 gm of starch, 8 ml of acid and 2 ml of glycerol. The reaction temperature in both experiments was 100°C. The first sample was spread in petri dish and left to dry in the air at 25°C while the second sample was poured in petri dish and is left to dry in a dryer at 40°C. The aim of these experiments is to check the effect of drying conditions on the produced biodegradable plastic and determine the most suitable drying temperature as well as the most adequate drying medium either air or electric dryer.

Effect of Reaction Temperature on the Produced Biodegradable Plastic

The effect of temperature on the hardness and physical appearance of the produced plastic was investigated by changing the reaction temperature between 100°C and 200°C.

Effect of Starch Pretreatment on the Produced Biodegradable Plastic.

In order to enhance the properties of the produced plastic, two experiments were made, one by adding starch pretreatment step in production procedures while the other without pretreating starch. The pretreatment step involves boiling starch and water together at the beginning at the same reaction temperature and then filtering this solution. The solution is mixed again with acid and glycerol and is heated till it forms a thick fluid. The objective of the filtration step is to remove any solid particles that did not suspend at the beginning in order to enhance the properties of the produced plastic as permeability which is very important for many applications specially packaging. The procedures of producing biodegradable plastic in both cases are shown in Figure 2.

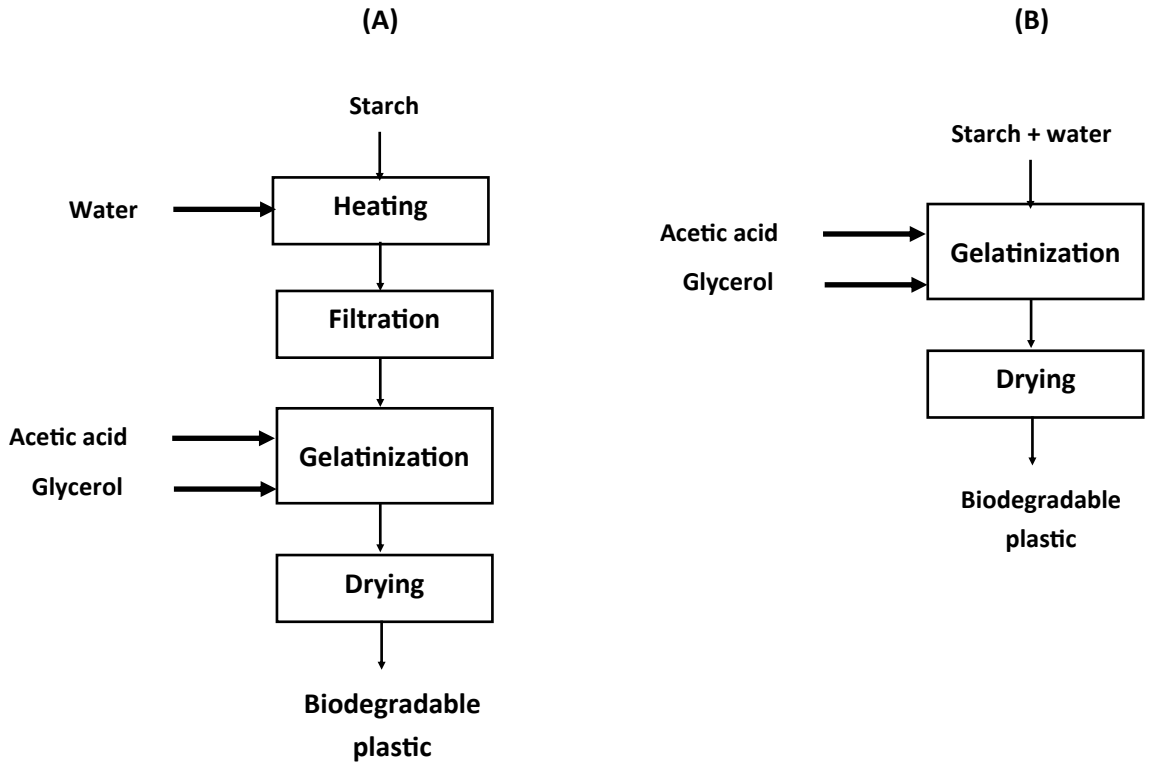

Figure 2. The effect of acid and glycerol on biodegradable plastic produced (a) with pretreatment (b) with treatment

Effect of Acid on properties of Biodegradable Plastic

Samples were prepared using different amount of acids while fixing the amount of starch and glycerol. Acetic acid amounts of 4 ml, 6 ml and 8 ml were used. The effect of different acid amounts on biodegradation, tensile strength and water absorption was studied.

Effect of Glycerol on Properties of Biodegradable Plastic.

The effect of glycerol amounts on biodegradation behavior, tensile strength and water absorption was studied. The glycerol concentrations used are 2 ml, 4 ml and 6 ml. The acid and starch concentrations used throughout the three experiments were fixed.

Effect of Starch on the Properties of Biodegradable Plastic.

Fixing the amounts of both acid and glycerol, the effect of using 5 gm, 7.5 gm and 10 gm of starch on properties of the produced biodegradable plastic was tested and relations between starch concentrations and water absorption, tensile strength and biodegradation behavior was concluded and graphed.

3. Results and Discussion

Effect of Drying Temperature on the Physical Properties Produced Biodegradable Plastic.

Drying conditions were varied to test its effect on the physical properties of the plastic. Two samples were prepared, where one of the samples was dried in a dryer at 40°Cand the other was dried in the air at 25 °C. It was found that some cracks have been developed on the surface of the dried samples using laboratory drier, these cracks did not exist in other experiments that were dried at room temperature of 25°C; indicating that the high drying temperatures cause deformations to the produced plastics and affect their mechanical properties.

Effect of Reaction Temperature on the Physical Properties Produced Biodegradable Plastic

For further studying of the effect of temperature on the produced plastics and their properties, two samples were prepared using a reaction temperature of 100°C and 200°C respectively. On the other hand, all operating conditions including amounts and drying conditions were the same throughout the experiments. It was found that the sample which was prepared at a reaction temperature 200°C has not only cracked but it was also completely deformed. The sample was really hard to the extent that it would break if it was pressed. On the other hand, the sample which was prepared at 100°C has not shown any change in structure. From this result, it can be concluded that not only the drying temperature affects the mechanical properties of the plastic but also the reaction temperature. High reaction temperatures affect the properties of the produced plastic greatly, making it hard, fragile and speeds up its mechanical failure. (Zakaria, et al., 2018)

Effect of Starch Pretreatment on Produced Biodegradable Plastic

Starch pretreatment involves heating the extracted starch with the appropriate amount of water and then filtering this solution to remove any starch particles that still exist in solution. It was obvious that unfiltered starch particles have appeared clearly on the surface of the sample that was produced without the addition of pretreatment step and hence affected the permeability and structure of the plastic. However, after adding this filtration step to the production procedures, the sample looked very pure without unsuspended particles and with enhanced properties that qualify it to be used in various applications as food packing.

Effect of Acid on properties of Biodegradable Plastic

Variation in amount of acetic acid was tested by preparing 3 samples with the same amount of glycerol and starch while using 4,6 and 8 ml of acid respectively. To test the effect of acid on the biodegradation behavior, the weight of samples was monitored regularly every three days. The results are illustrated in Figure 3. It is shown that there is a direct relation between the amount of acid and degradation of plastic. The plastic that was prepared using 8 ml of Acid has even fully degraded faster than the other samples which needed three extra days to fully degrade, This could be due to the low chemical resistance of the produced plastic. Acid is used to break branched chains in starch molecules to help in the formation of polymeric materials. However, the produced polymer can be a bad resistor to chemicals like acids, alkalis or salts. Also, with the increase in acid, hydrolysis reactions increase which in turns enhance the degradation behavior. This explains the reason behind the rapid degradation and deterioration of samples as acid increase (Pratiwi, et al., 2017).

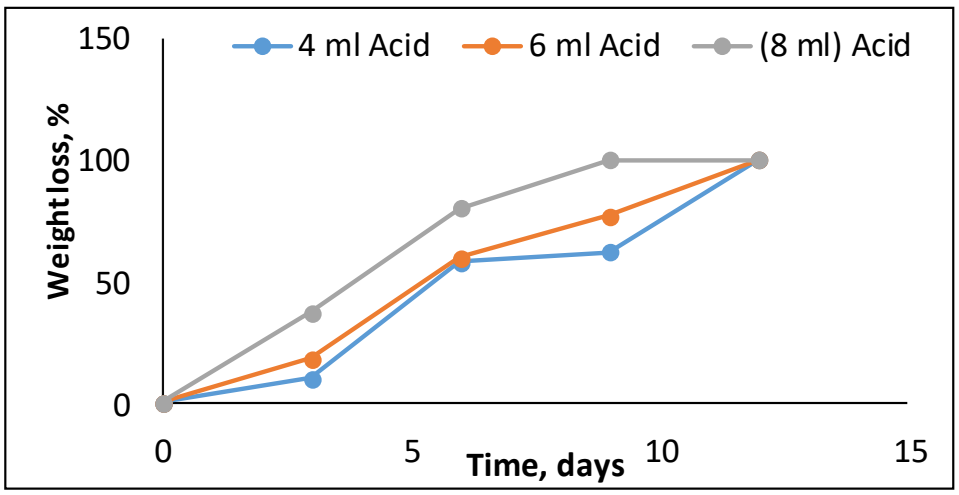

Figure 3. Effect of Acid Amount on Biodegradation Behavior

Although the aim is to produce biodegradable plastic to solve the environmental problems of the conventional plastics, it is still important that plastics do not degrade so fast and to have a good life time during its usage as in construction applications.

The effect of acid on water absorption was also tested and illustrated in Figure 4. The weight gains of samples firstly increased and then it decreased again with the increase in acid amount. The reason behind this increase at the beginning is the hydrophilic nature of both acetic acid and starch.

However, the reduction in percentage of weight gain could be due to the acetylation reaction that occurred between glycerol and acid and hence decreased the hydroxyl group in glycerol which leads to lower water absorption.

Tensile strength is a mechanical property that indicates the durability and toughness of the plastic It tests the mechanical stress that the plastic can bear before it deforms. The tensile strength was measured using texture analyzer device.

As illustrated in Figure 5 , using 6 ml of acid has achieved the highest tensile strength of 14.5 N/m2; since the acid is used to increase the cross linking between molecular chains and enhancing the polymerization reaction. Hence, the tensile strength has increased with the increase in the amount of acid. However, on increasing the acid amount to 8 ml, the tensile strength has decreased to 11 N/m2 due to the increase in molecular interactions which has led to decrease in the strength of the samples. Hence, the tensile strength has increased with the increase in the amount of acid. However, on increasing the acid amount to 8 ml, the tensile strength has decreased to 11 N/m2 due to the increase in molecular interactions which has led to decrease in the strength of the samples.

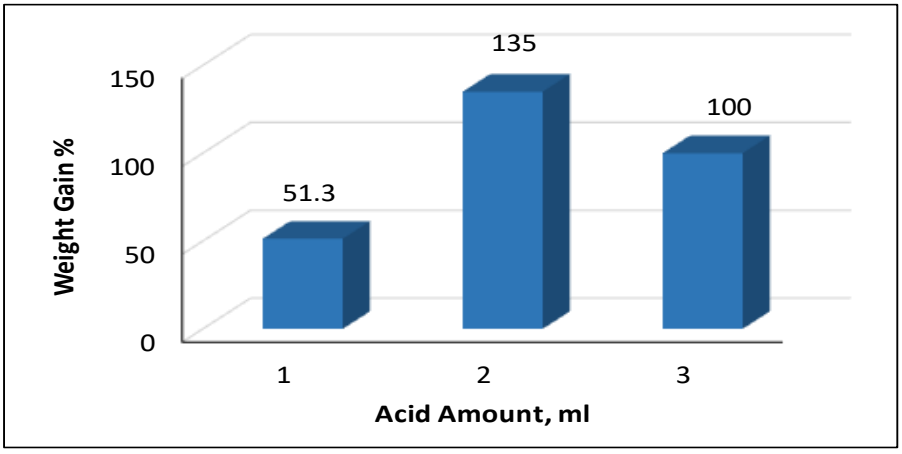

Figure 4. Effect of Amount of Acid on Water Absorption

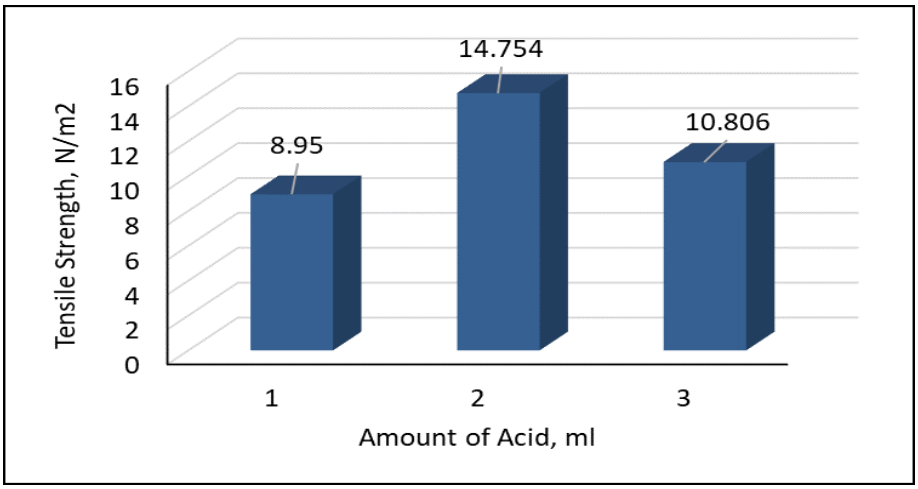

Figure 5. Effect of Amount of Acid on Tensile Strength

Effect of Glycerol on Properties of Biodegradable Plastic.

Glycerol amount was changed to 2,4 and 6 ml, respectively while keeping the starch and acid amounts fixed through the experiments. Glycerol was found to have the same effect of acid on biodegradation behavior; where increasing the amount of glycerol, increase the amount of weight loss as shown in Figure 6. The samples containing 4 ml and 6 ml of glycerol have degraded in 9 days, while that contains 2 ml of glycerol has degraded in 12 days. The glycerol is a plasticizer which aims to give the produced plastic its flexibility. As the glycerol increases, the flexibility of samples increase and hence its softness. This could explain the reason behind the inverse relation between glycerol amount and degradation time. Figure 7 and Figure 8 show the degradation of samples after 3 and 6 days, respectively. Decaying of samples appears clearly after 6 days.

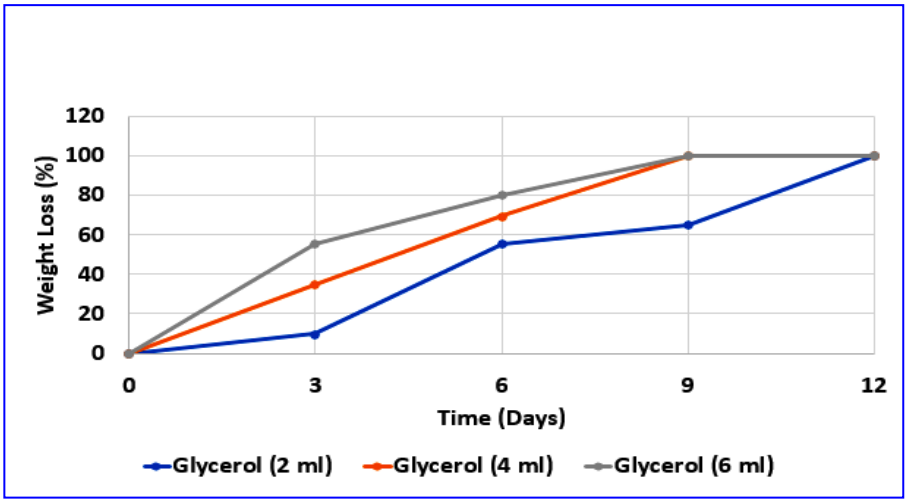

Figure 6. Effect of Glycerol Amount on Biodegradation of Plastic

Figure 7. Effect of Glycerol Amount on Biodegradation of Plastic After 3 Days

Figure 8: Effect of Glycerol Amount on Biodegradation of Plastic After 6 Days

On the other hand, increase in glycerol was found to decrease the water absorption and enhance the water resistance property. Figure 9 shows the percentage of weight gain of samples after absorbing water. The result was very surprising; as glycerol is hydrophilic and increases the water absorption. However, increase in glycerol amount could have increased the strength of the molecular bonds formed between glycerol and the produced polymer. The strong bonds therefore; prevented the water from penetrating this strong structure and hence weakens the reaction between both starch and water, and glycerol and water (Yu & Visakh, 2015).

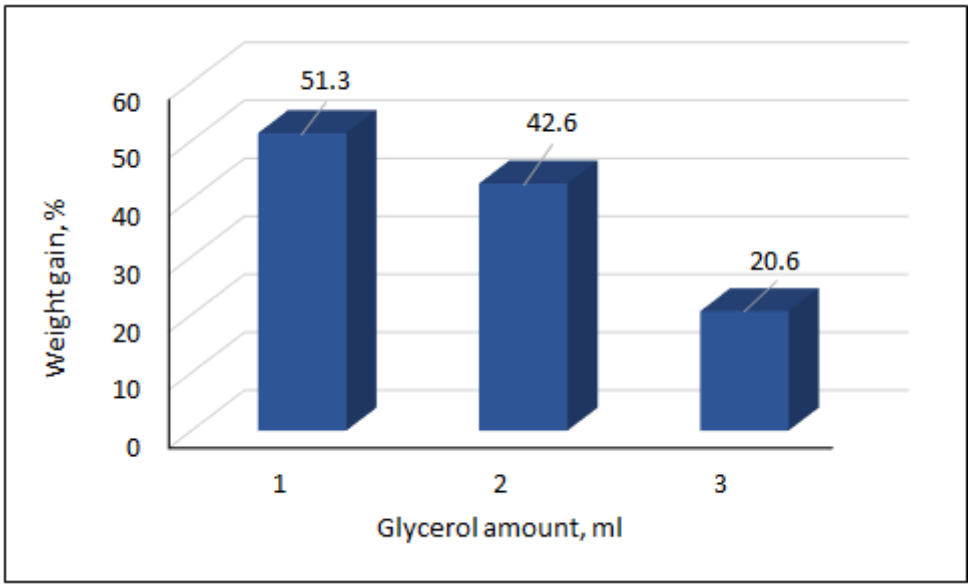

Figure 9. Effect of Glycerol Amount on Water Absorption

Moreover, as shown in Figure 10, an inverse relation between tensile strength and glycerol amount was found; due to the nature of glycerol whose objective is to give the sample its flexibility and softness. The tensile strength was 38 N/m^2 on using glycerol amount of 2 ml. On the other hand, the strength has decreased to 7 N/m^2 on using a higher amount of glycerol of 6 ml.

Effect of Starch on Properties of Biodegradable Plastic

Different weight of starch samples (5, 7, and 10 gm) were used to test the effect of starch concentration on the behavior of the produced plastic. It was found that the biodegradation behavior is inversely proportional to the amount of starch as shown in Figure 11. The figure shows that after 9 days, the sample containing 5 gm of starch has fully degraded, however, 75 percent of the sample containing 10 gm of starch has degraded by that time. This is due to the high amount of starch used which caused more molecular interactions and reduced degradation.

Water absorption results appear in Figure 12. The figure shows that water resistance decrease with the increase in starch concentration. This result was expected and is very logic since starch is hydrophilic and is known for its affinity for water. (M Sujuthi & Liew, 2016)

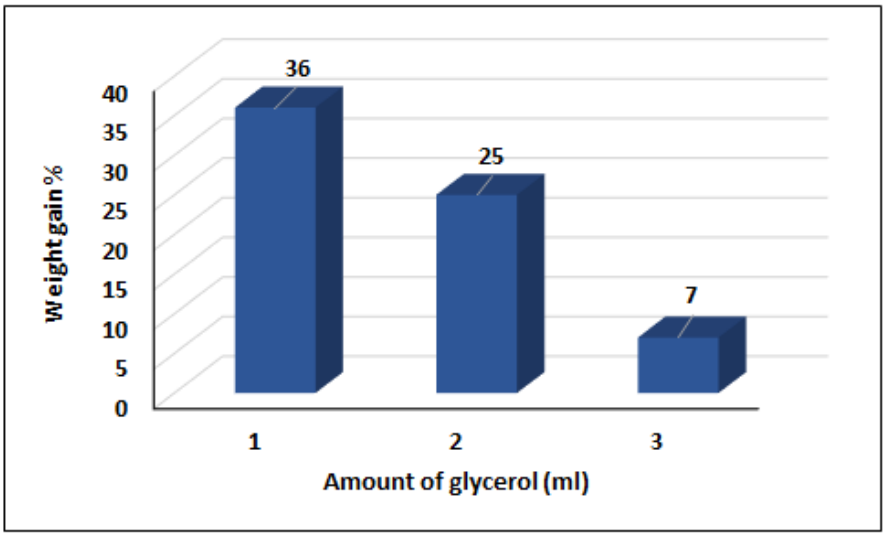

Figure 10: Effect of Amount of Glycerol on Tensile Strength

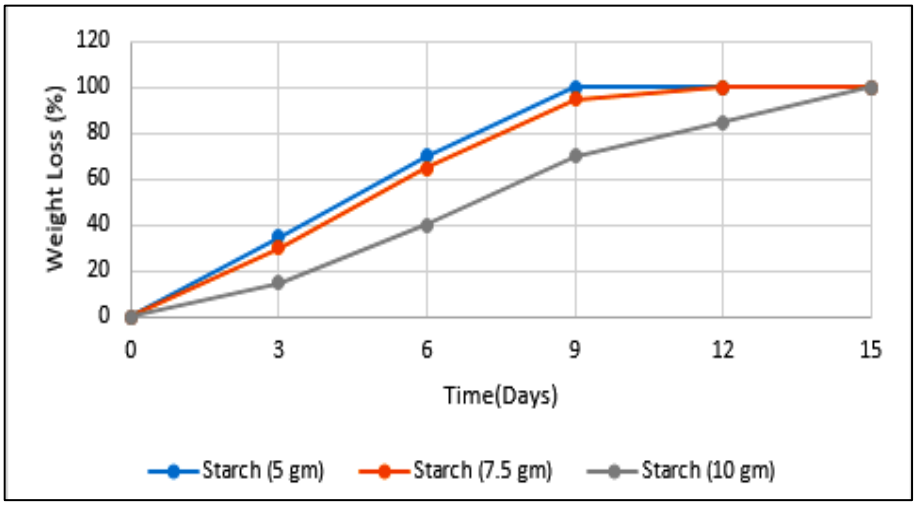

Figure 11. Effect of Starch Amount on Biodegradation Behavior

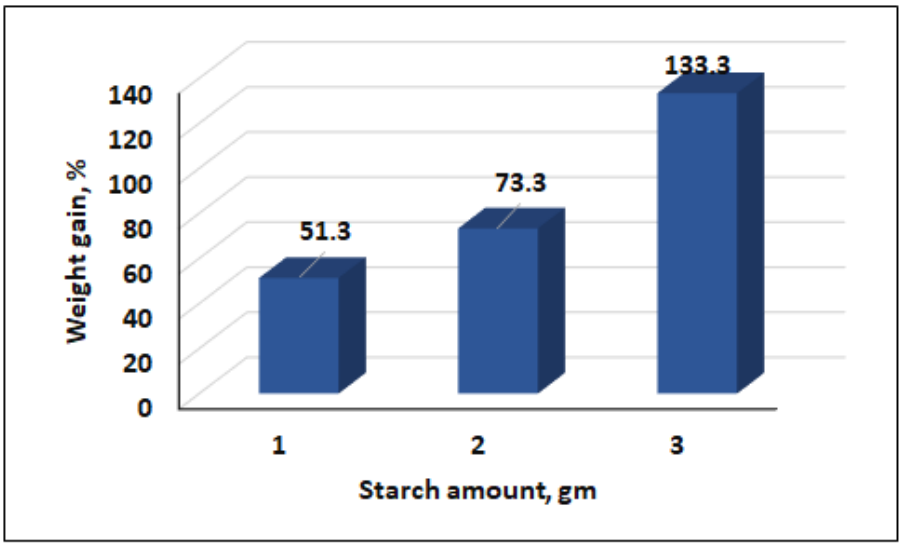

Figure 12: Effect of Amount of Starch on Water Absorption

Furthermore, using 7.5 gm of starch has given the highest tensile strength of 38 N/m^2 as illustrated in Figure 13. However, on using 10 gm of starch strength has decreased to 21 N/m^2, this is due to the excessive molecular interactions that are taking place with the increase in amount of starch.

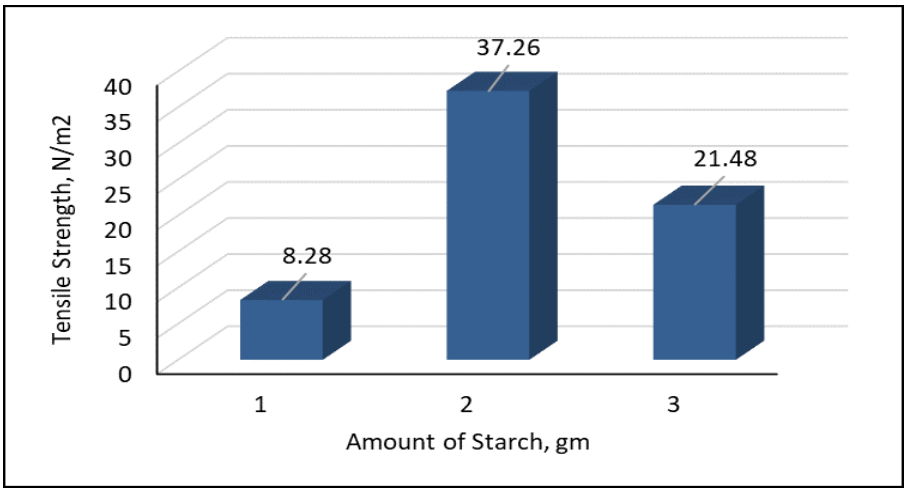

Figure 13. Effect of Amount of Starch on Tensile Strength

4. Conclusion

This paper summarized the environmental problem caused by plastic, shedding the light on the importance of finding an environmentally friendly alternative to the plastic which should possess same specifications. In this paper, potato peels together with acetic acid and glycerol were used to manufacture the biodegradable plastic.

In order to find the best operating conditions that makes this type of plastic economically worth studying, the paper highlights the effect of many factors as reaction temperature, drying conditions, acid amount, plasticizer amount and starch amount on the properties produced plastic as tensile strength, water absorption and biodegradation.

It was found that low reaction and drying temperatures are both beneficial to the produced plastic as they enhance the mechanical properties of the plastic and its hardness. Pretreatment of starch was also found to be an important and necessary step in manufacturing of plastics in order to be used in certain applications that require the high purity and permeability of plastics as food packing.

A direct relation was derived between both the amount of acid, glycerol and the amount of weight loss. Furthermore, water resistance was enhanced using glycerol. Yet, the absorption was found to increase with the increase in starch amount due to its hydrophilic nature.

Due to the numerous experiments that were made with the aim to find the most suitable operating conditions, many conclusions were drawn as follows:

- ♦Drying using air at a temperature range 25-30°C is better than using a dryer of temperature 40°C.
- ♦Lower reaction temperatures to 100°C are better than higher reaction temperatures to avoid cracking and plasticity of samples.
- ♦Pretreatment of starch is important step for achieving highly permeable samples that can be used in packing materials.
- ♦Lowering Acid amount is better to avoid fast degradation.
- ♦Lowering glycerol amount to 2 ml is better for the mechanical properties of the produced plastic to avoid softness and high elasticity of samples.

It could be concluded that Biodegradable plastic was found to be very promising substitute. However, it is recommended to study the natural additives that could be added to the plastic to in order to improve its properties furthermore to make it more comparable to the conventional plastics. As an example of these additives is the natural fibers that enhance the strength and hardness of plastic or cotton linters that increase the product life time.

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