PECTIN EXTRACTED FROM *Citrus sinensis (*SWEET ORANGE) PEELS AS POTENTIAL SOURCE IN MAKING BIOPLASTIC FILMS

A Research Paper

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ABSTRACT

RESEARCH PAPER: Pectin Extracted from *Citrus Sinensis* (Sweet Orange) Peels as Potential Source in Making Bioplastic Films

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Synthetic plastics have been a problem for a very long time. Many alternatives such as starch-based bioplastics were already proposed, however, studies have found that starch bioplastic production competes with the global food production. Thus, this study aims to use citrus wastes, since they are abundant and underutilized, to produce an alternative environmental-friendly bioplastic. Furthermore, this study focuses only on extracting pectin and producing bioplastics using pectin as the main source. The extraction of orange peels was carried out through hydrochloric acid extraction method. Subsequently, formation of biodegradable films was done by adding plasticizer, solvent and acid to the pectin. The pectin-based biodegradable film was later compared to the starch-based biodegradable film. The best sample was analyzed by testing and comparing their solubility and biodegradability. Sample C, which was a mixture of 75% pectin and 25% starch, produced the best results in terms of solubility. Moreover, Sample D, which consists of 100% pectin and 0% starch was the fastest to degrade among the samples. With its properties, pectin-based bioplastic films can be a potential substitute to starch-based bioplastic films and synthetic plastics as a whole.

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INTRODUCTION

Background of the Study

Plastic is a cheap, lightweight, and versatile material that has an extensive range of uses. Everyone has become very dependent on plastics because of its convenience. In fact, 300 million tons of plastic is produced each year – where 50% of which is for single-use purposes only (Plastic Oceans International, 2019).

Moreover, the bulk of the world's waste consists of hard-to-break-down products such as plastic bags, synthetics, plastic bottles, and tin cans. Their chemical structure makes them resistant to many natural processes of degradation (Wolchover, 2011). If not disposed of properly, these wastes could end up in landfills and most especially in bodies of water, which could pose a danger to aquatic life. According to Reddy (2018), each year about 13 million metric tons end up in our ocean – affecting at least 800 species worldwide. This marine debris can be very dangerous as they can be ingested by marine animals and can possibly entangle them causing suffocation and drowning.

Therefore, the usage of plastics should be discouraged because otherwise, these environmental impacts will become irreversible. Today, many are utilizing biodegradable plastics, believing it is a safe and ideal solution to the rampant problem of plastic pollution. However, biodegradable plastics are petroleum-based which means that additives and chemicals are strategically added to make their degradation process quicker than usual; these chemicals can be toxic and harmful to the environment when decomposed in the soil (Borhauer, 2019). In addition, the said plastics fragment and breaks down into microplastics rather than biodegrade. These can be ingested by marine animals, especially when it reaches the oceans and other bodies of water hence, pose a threat to the marine ecosystem. Since biodegradable plastics are also made from non-renewable, scarce resources such as fossil fuels, they release carbon dioxide and other greenhouse gases, which in turn, trap heat in our atmosphere, making them the primary contributors to global warming and climate change (Nunez, 2019).

Thus, another alternative solution was introduced, that is, the use of bioplastics consisting of natural polymers that are starch-based and cellulosed-based, which are primarily synthesized from agricultural plants such as grains, beans, potatoes and corn as various sources of starch and cellulose. (Acciona, 2019).

Additionally, a study in 2017 inferred that if traditional plastics were to be produced using renewable energy sources, greenhouse gas emissions could be reduced for about 50 to 75 percent (Posen, Jaramillo, Landis, & Griffin, 2017). Thus, this indicates that bioplastics could be a sustainable solution to the problem in plastics since it produces a smaller carbon footprint than biodegradable plastics; hence, it utilizes renewable resources in the environment. Nevertheless, Plastic Pollution Coalition claims that to meet the growing global demand for bioplastics, more than 3.4 million acres of land — an area larger than Belgium, the Netherlands, and Denmark combined — will be needed to grow the crops by 2019 (Cho, 2017). This land, however, can also be used to feed people, thus competing with the food production.

Essentially, this study proposes the utilization of orange wastes as a source in producing bioplastic, since citrus wastes are globally abundant, and underutilized (Boukroufa et al., 2015).

Pectin, the main constituent found in citrus fruits, is widely used as the main constituent in the bioplastics market due to its biodegradability, availability, and eco-friendly nature (Putra, Thamrin, & Saputra, 2019). Thus, pectin is widely used as a gelling, thickening, and emulsifying agent in a wide range of applications from food to pharmaceutical products (Kaya et al., 2014).

Furthermore, the study aims to determine the feasibility of making bioplastic films from orange peels, which are plant-based and biodegradable that represent competitive mechanical properties with some of the commodity plastics.

Therefore, with further improvements, the bioplastic films could potentially be used as sustainable packaging material for commercial goods such as soap and food products (Bátori et al., 2017).

Objectives of the Study

The main objective of the study is to determine the feasibility of producing bioplastic films from pectin. Specifically, the study aims to:

a.) extract pectin through acid extraction method using hydrochloric acid (HCl) as a reagent,

b.) develop bioplastic films having varying concentrations of pectin and starch, and

c.) determine the appropriate ratio of pectin and starch suitable in forming the bioplastic films in terms of its (a) biodegradability and (b) solubility through testing the bioplastic films.

Significance of the Study

The success in the utilization of orange peels can lead to further studies of other citrus wastes as sustainable packaging material in the bioplastic production most especially for the food industry (Bátori et al., 2017). Moreover, the production of bioplastic films could potentially open up opportunities for the development of environmental-friendly biomass materials.

Focusing on the ecological concern, the success of the study would aid in safeguarding aquatic life by minimizing the plastic remains and residues, especially in various bodies of water such as oceans. Thus, further development of bioplastic films would significantly reduce the accumulation of synthetic wastes as well as the emission of harmful greenhouse gases in the environment.

Scope and Limitations of the Study

This study mainly focuses on the extraction of pectin from orange waste and the production of biodegradable films.

Isolation of the pectin from orange peels is performed using the hydrochloric acid extraction method. This study is delimited to obtaining pectin and the pectin yield of the said method only. The properties of the pectin will not be tested furthermore. The method that is used in the production of bioplastic will simply be the addition of solvent (distilled water), plasticizer (glycerine) and acid (vinegar) to the main component (pectin). There are four samples: Sample A (100% Starch), Sample B (75%Starch, 25% Pectin), Sample C (50%Starch, 50% Pectin), Sample A (100% Pectin). The major concern of the study is determining whether pectin can enhance or improve the qualities of a bioplastic. The determination of the best sample is based on the solubility and biodegradability of each film. The solubility of the films is tested in distilled water only. The biodegradability of the films is tested for a week in loam soil acquired at the Gulayan ng Paaralan of Sergeant Miguel Canoy – Memorial Central School in Buru-un, Iligan City. The extraction of pectin and production of bioplastic is conducted in the laboratory of Philippine Science High School – Central Mindanao Campus located in Balo-i, Lanao del Norte for 2 months. The (50) sweet oranges are bought in the local market of Linamon, Lanao del Norte. The acids used are bought at Joelmar Marketing, Iligan City.

REVIEW OF RELATED LITERATURE

Plastics are organic materials that are made up of chemicals. The most common use of plastics is packaging. Plastic packaging is very convenient for consumers as plastics can be very durable and versatile. However, plastics can be very hazardous for the environment. They pose a great threat to humanity by contaminating the land, water, soil and overall environment (Garcia et al., 2003).

The most common and most used type of plastic is those made from the synthetic polymeric material. The most basic plastic materials used are usually obtained from natural gas, coal, and petroleum. These types of plastic can be molded into different shapes varying from its rigid or slightly elastic form. Normally, synthetic plastics almost take up 1000 years to decompose in landfills. Synthetic plastics are highly resistant to microbial degradation which causes the long time it takes to degrade (Atlas, 1993). Plastics that are not completely degraded are a problem because not only do they fill up the landfills which cause pollution, plastics also have the potential to leach their chemical toxins into water sources that result to health dangers such as neurological problems and cancers when passed onto humans. Even though plastics manufacture harmful effects on the environment, the production of plastics has increased from just 0.5 million tonnes in 1950 to 260 million tonnes in 2007 (Plastics Europe, 2008).

The society cannot just deny the usage plastics have contributed. In the world of today, it is safe to say that plastics are almost as important as technology. Thus, more researchers are studying to find an alternative in producing plastics that do not create much energy and produce such hazardous effects. Biodegradable plastics can be the substitute or alternative to synthetic plastics as they are environmentally-friendly. Biodegradable plastics are plastics produced from fossil materials or synthesized from biomass and renewable resources, otherwise known as bioplastics. Biodegradable plastics are plastics that take a shorter time to degrade because they are composed of natural materials. Biodegradable and bio-based plastics can be said to be better than synthetic plastics as they increase soil fertility, low accumulation of plastic materials in the environment and a reduction in the cost of waste management (Aiba et al., 2009). The degradation of biodegradable plastics results from the action of bacteria, fungi, and other naturally occurring micro-organisms. Thus, all biodegradable plastics can be degraded by microbes under certain conditions. Biodegradable plastics made from starch have been introduced and applied to the market now.

The most common biopolymer that makes most of the biodegradable plastics is starch. Starch makes a suitable part in the production of biodegradable plastics considering its biodegradability, renewability, abundance and low cost. The major sources of starch such as corn, cassava, and potato are all abundant in amount in nature. Polylactic acid and polyhydroxyalkanoate are the main starch-derived material that is available in the market now. Starch is a polysaccharide that can be found in plants. Polysaccharides are carbohydrate polymers which consist of thousands of monosaccharides. Starch has two types of molecules which are amylose, which is usually a mixture of 10-20%, and amylopectin, taking up about 80-90% (Ophardt, 2003).

Pectin is a natural fiber found in primary cell walls in plants. Pectin is a structural acidic heteropolysaccharide, containing two or more different monosaccharide unit, with galacturonic acid, a sugar acid derived from galactose, as its main component. Pectin is commonly used in food especially in modifying the texture of jams, jellies and in low-fat dairy products. Various sources of pectin are available but it is found that pectin extracted from citrus peels are the main source of commercial pectin (Axelos et al., 1995). Pectin is isolated based on their solubility by different methods: extraction in water or buffer solutions, solutions of chelating agents, dilute acids or dilute sodium hydroxide or sodium carbonate (Gnanasambandam & Proctor, 1999). Pectin contains a complex structure that results in a diverse molecular structure when extracting from various materials. When bound with sugar and acids, pectin is able to form a gel through designating the water-soluble pectin acid of varying methyl ester content and degree of neutralization (Girma & Worku, 2016).

METHODOLOGY

Preparation and Collection of the Orange Peels

Fifty sweet oranges (*Citrus sinensis*) were gathered and obtained from the local market in Linamon, Lanao del Norte. The said oranges were peeled off and divided into four parts. Eventually, the peels were sliced and further cut into smaller pieces using a knife. Afterward, the peels were washed to remove the glycosides, the bitter taste of the peels (Kanse et al., 2017).

Pretreatment of the Orange Peels

Following the preparation of the peels, the peels were blanched to inactivate the enzymes by mixing it with water heated constantly at 95°C for 3 minutes (Altaf, Immanuel, & Iftikhar, 2015). After that, the peels were cooled by placing it in an ice water bucket for the same duration in blanching the peels.

Subsequently, the peels were macerated by adding 1 liter of 95% ethanol to the peels, leaving it soaked for 20 minutes (Ani & Abel, 2018). Then, the peels were dried using a drying oven at 55°C for 24 hours (Tang, Wong, & Woo, 2011). After drying, the peels were powdered using a grinding machine and weighed on a top-loading balance.

Extraction of Pectin

Ten (10) grams of powdered orange peels were separately transferred into a beaker containing 250 mL of distilled water and 2.0 mL of 1.0 M hydrochloric acid (HCl) as a reagent (Alamineh, 2018). The pH of the solution was measured and adjusted to pH value of 2.0 using a digital pH meter. Thereafter, the solution was heated at 90°C for 60 minutes using the water bath method (Hamidon & Zaidel, 2017).

Afterward, the solution was filtered through a funnel using cheesecloth. The resulting filtrate was precipitated by adding an equal ratio of 95% ethanol to the solution and was left to allow the pectin to float on the surface (Tyagi, 2016). Then, the floated pectin was separated from the filtrate through decanting. To separate the gel pectin from ethanol and water, the extracted pectin was centrifuged at 5300 rpm for 15 minutes (Venkatanagaraju et al., 2019). The resulting extracted pectin was then purified by washing it with a 95% ethanol to remove the residual hydrochloric acid universal salt (Alamineh, 2018).

Subsequently, the purified pectin was poured into a separate petri dish for storage and was dried using a drying oven at 35°C overnight (Shan, 2016). The dried pectin was crushed and pounded using a mortar and pestle, and weighed using a top-loading balance.

Determining the Pectin Yield from Extraction Process

The percentage pectin yield was calculated by the ratio of the final weight of the dried pectin obtained from extraction to the initial weight of the dried orange peels taken for extraction using the formula:

$$\%\ \mathbf{Pectin\ Yield} = \frac{weight\ of\ dried\ pectin\ obtained\ (g)}{weight\ of\ dried\ peel\ taken\ for\ extraction} \times 100\%$$

Formation of the Bioplastic Films

The four samples namely, Sample A (the control group), Sample B, Sample C, and Sample D have the following concentrations of 100% corn starch, 75% pectin and 25%

corn starch, 50% pectin and 50% starch, and 100% pectin, respectively (as shown in Table 1).

Hence, Sample A (10.0 g of starch), Sample B (7.5 g of pectin and 2.5 g of corn starch), Sample C (5.0 g of pectin and with 5.0 g of corn starch), and Sample D (10.0 g of pectin), were separately transferred into a beaker mixed with 60 mL of distilled water, 5 mL of glycerin, which serves as a plasticizer, and 5 mL of vinegar (Prasteen et al., 2018). Afterward, each mixture was constantly heated and stirred using a hot plate and magnetic stirrer at 80°C and 900 rpm, respectively for at least 45 minutes until the solution starts to gelate and form a gel (Wahyuningtiyas & Suryanto, 2017). The gel-like solution was then poured into a stainless steel tray and sun-dried. When dried out completely, the films were gently scraped and peeled off from their respective trays.

Table 1. Composition of different samples by weight basis.

Components	**Sample A**	**Sample B**	**Sample C**	**Sample D**
Pectin	0 g	7.5 g	5 g	10 g
Starch	10 g	2.5 g	5 g	0 g
Glycerin	5 mL	5 mL	5 mL	5 mL
Vinegar	5 mL	5 mL	5 mL	5 mL
Distilled Water	60 mL	60 mL	60 mL	60 mL

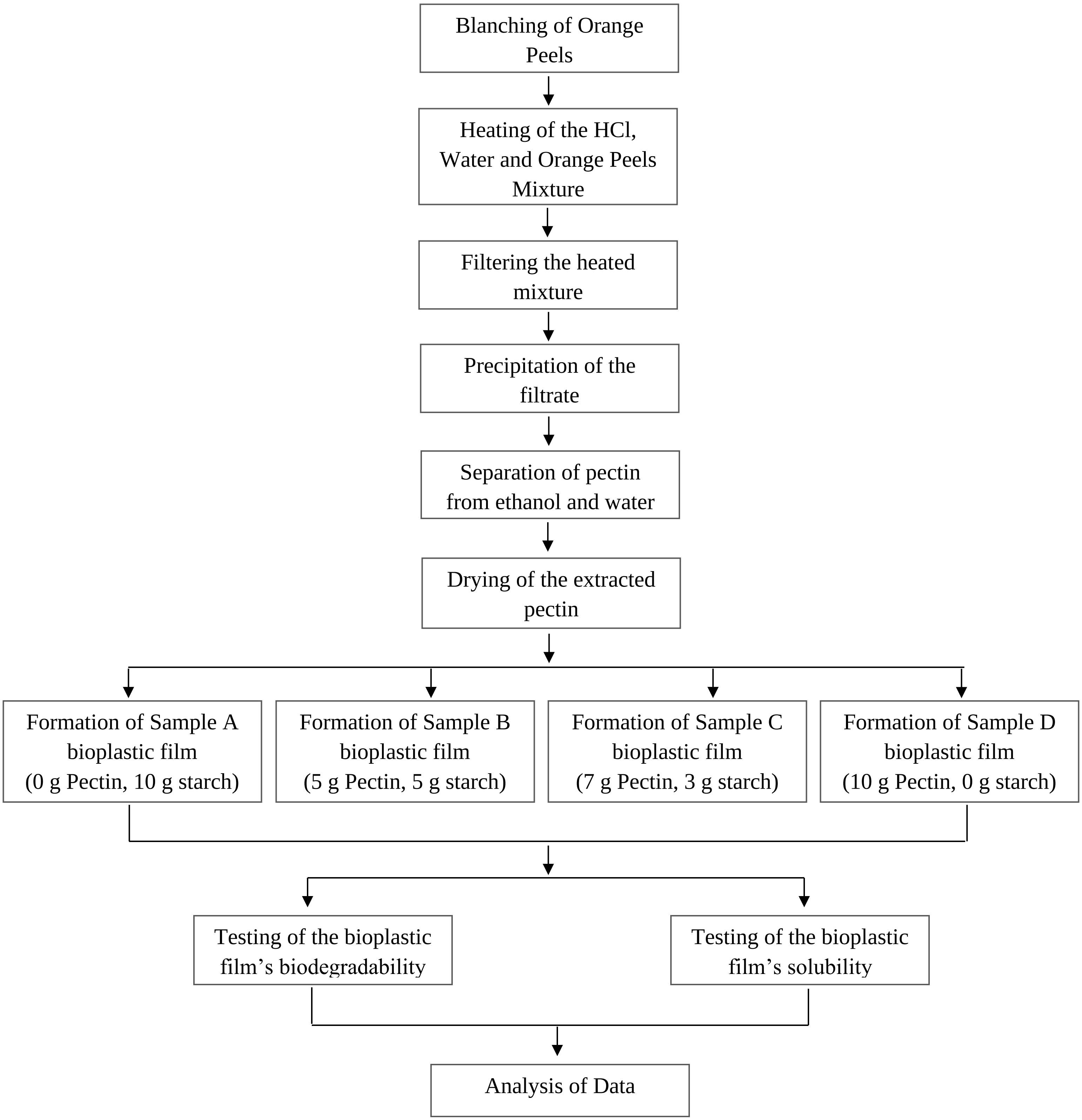


Fig 1: Flow Chart of Processes

RESULTS AND DISCUSSIONS

Pectin Yield from Extraction Process

The percentage pectin yield was calculated by the ratio of the final weight of the dried pectin obtained from extraction to the initial weight of the dried orange peels taken for extraction using the formula:

$$\% \,\mathbf{Pectin\ Yield} = \frac{weight\ of\ dried\ pectin\ obtained\ (g)}{weight\ of\ dried\ peel\ taken\ for\ extraction} \times 100\%$$

$$\mathbf{12.97}\ \% = \frac{1.297\ g}{10g} \times 100\%$$

The total pectin yield of a single sample using the hydrochloric acid extraction method is 12.97%.

Solubility Percentage of the Bioplastic Films

The solubility of the four samples of the bioplastic films were measured using the solubility test by soaking the films into the water for an hour. Table 2 shows the average solubility percentage of the four samples. As illustrated in Table 2, Sample B yielded the highest average solubility percentage with an average of 87.74% from the three trials.

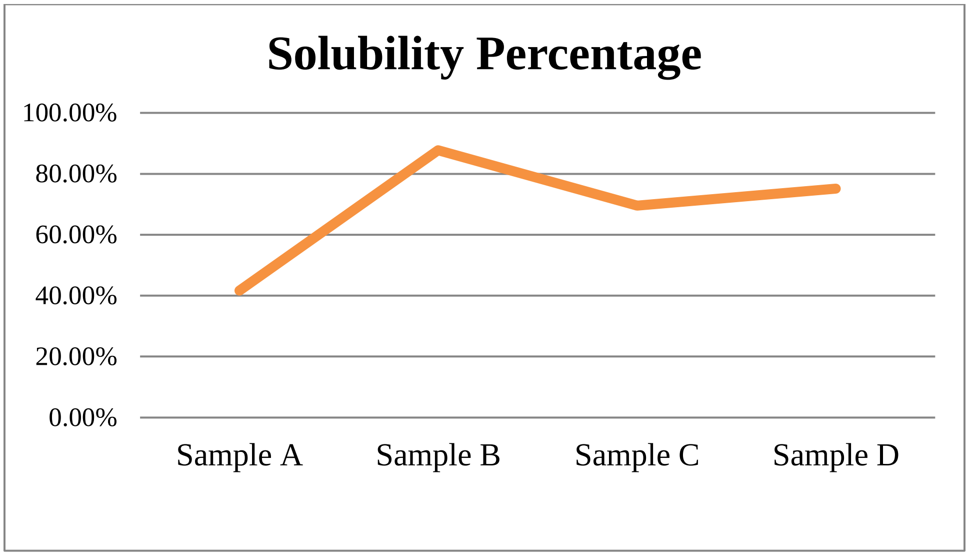
Table 2. Average solubility of the four samples

	Average Solubility Percentage
Sample A (100% Starch)	41.66666667%
Sample B (75% Starch, 25% Pectin)	87.73666667%
Sample C (50% Starch, 50% Pectin)	69.54333333%

Sample D (100% Pectin)	75.18%

Figure 2 below shows the percentage of solubility between the four samples in a line graph where the samples lies in the x-axis and the solubility of the respective samples lies in the y-axis.

Figure 2. A line graph representing the average solubility percentage of the samples



Statistical Tools for Data Analysis

Comparisons among the four samples for the solubility test will be done using one-way Analysis of Variance (ANOVA). The results and data obtained are analyzed using the single-factor of the ANOVA test at $\alpha = 0.05$ on the R software. The P-value is the calculated probability *of* obtaining an effect at least as extreme as the one in the sample data.

Table 3. Analysis of data using p-value

P-Value	Remarks
0.00177	Statistically Significant

Table 4. Comparison analysis between the samples using the p-adj

	P-adj	Remarks
Sample A-Sample D	0.0250219	Statistically Significant
Sample B-Sample D	0.0012836	Statistically Significant
Sample C-Sample D	0.0092391	Statistically Significant
Sample B-Sample D	0.1512955	Not Significant
Sample C-Sample D	0.8750204	Not Significant
Sample B-Sample C	0.3983344	Not Significant

According to Table 3, the p-value is 0.00177. Since the significance level used is 0.05, the overall result is significantly different. Thus, the null hypothesis will be rejected and a conclusion that there is a significant difference between the groups can be made. The solubility percentage of the samples is significantly different from each other. Further comparison of the samples between their p-value adjusted for multiple comparisons. In the table, the adjusted p-values showed that Sample A-Sample D, Sample B-Sample D, and Sample C-Sample D are all significantly different from each other. Thus, a conclusion can be made that all the samples are statistically significant from the control group.

Biodegradability

The interpretation of the biodegradability was done through descriptive research (Refer to Appendix for data). The pectin-based bioplastic films all degraded after a week while pieces of the starch-based films were still evident.

Discussion

The solubility and the biodegradability of the pectin-based bioplastic films suggest its effective potential as a main component in producing bioplastic films. Samples that were composed of pectin all showed greater results than the control group. Having a higher solubility percentage means that bioplastic films can be dissolved in water, which can be a great alternative in disposing of plastics. Perhaps, the reason the pectin-based bioplastics were high in solubility is because of the property of pectin of being highly water-soluble. The biodegradability of the pectin-based bioplastics also all degraded after a week which is an impressive feat as the main problem of plastics is the long time it takes to decompose. Studies have shown that the total biodegradability period of completely starch-based bioplastic takes up about three to six months. A possible reason why the films degraded so fast is again, because of pectin being highly water-soluble. Thus, the moisture content from the soil affected the biodegradability. From the two test results that were obtained, the pectin-based bioplastic illustrates comparable potency with the commercial starch-based bioplastic, proving its potential as an alternative source in creating bioplastics. However, the pectin-based bioplastics cannot be used as the convenient plastic bag as the tensile strength of the bioplastic films was not tested. Perhaps, the reason bioplastics made from pectin aren't produced because it isn't strong enough to actually carry things. Thus, the produced bioplastics films can be used as packaging instead, specifically wrapping for fruits like apples.

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

The following chapter concludes the whole study. The findings of the study are explained in the summary while the generalizations and other interferences inferred are discussed in the conclusion. Recommendations for the beneficiaries of this study end the chapter.

The scope of this chapter limits only to the use of orange peels into pectin in the production of bioplastic films. Hence, the same implications cannot be expected when treated with different conditions. Still, the conclusions presented are still relevant to further studies relating to bioplastic production from pectin.

Summary of Findings

This quantitative study was designed to determine the feasibility of the production of bioplastic films from pectin. Moreover, the researchers extracted pectin from orange peels and developed bioplastic films having varying ratios of pectin and starch. Afterward, the bioplastic films were tested of its biodegradability and solubility. The gathered data was later analyzed using one-way analysis of variance (ANOVA).

Based on the findings, extracting pectin from orange peels through acid extraction method appeared to have low pectin yield. Furthermore, different samples have different characteristics in terms of biodegradability and solubility. The data gathered manifests that the effects of different pectin amount, on the solubility and biodegradability of the films were found to be significant.

Conclusion

This study aims to determine the feasibility of producing bioplastic films from pectin. The findings show that bioplastic films created from pectin dissolve faster in water and degrade quicker in soil compared to those bioplastics made up of starch. However, pectin extraction from orange peels through acid extraction method shows impracticality considering the cost expended for it. This is also mainly because the extraction was manually processed and was done individually and not in bulk.

Since the study utilizes citrus wastes, the success of this study will not only solve the abiding problem of synthetic plastics and citrus wastes but also the competition of bioplastic production with food production. That being said, further depletion of fossil fuels will be prevented and greenhouse emission will be reduced as it is produced from abundant, renewable materials. Thus, given its competitive mechanical properties, bioplastics manufactured from pectin can be used as a sustainable packaging material for fruits and commercial goods like soap.

Recommendations

1. Other fruits like pomelo can be utilized instead of orange fruit as it is cheaper and richer in pith.
2. When the pectin floats from the mixture, let it still for 30 minutes before you start separating it. Letting the mixture sit still overnight creates more additional pectin to float.
3. The floated pectin in the mixture will be contaminated and probably lose its structure if not centrifuged for at most two days.

4. The gel pectin must be powdered for it to be able to form the bioplastic. The pectin should be powdered finely so it won't create lumps.
5. Stir the bioplastic mixture longer to achieve finer results.
6. Strain the bioplastic first before transferring to the drying tray to filter the undissolved clumps of pectin.
7. Conduct the biodegradability test for a longer time, the minimum being two weeks, and check for every two days as the pectin-based bioplastic easily degrades due to the soil's moisture, probably because pectin is highly water-soluble.
8. Measure the temperature of the surroundings as temperature could also affect the biodegradability of the plastics.
9. Test the film's tensile strength to determine its carrying capacity.

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APPENDICES

Appendix A. Raw Data Gathered

Samples	Trials	Initial Weight	Final Weight	Solubility Percentage
Sample A (100% Starch)	1	0.055g	0.025g	54.55%
	2	0.040g	0.030g	25%
	3	0.055g	0.030g	45.45%
Sample B (75% Starch, 25% Pectin)	1	0.035g	0.005g	85.71%
	2	0.050g	0.005g	90%
	3	0.004g	0.005g	87.50%
Sample C (50% Starch, 50% Pectin)	1	0.115g	0.030g	73.90%
	2	0.085g	0.035g	58.72%
	3	0.125g	0.030g	76%
Sample D (100% Pectin)	1	0.125g	0.030g	76%
	2	0.095g	0.020g	78.95%
	3	0.085g	0.025g	70.59%

Table A1. Raw Data of Solubility Test

Biodegradability Test					
Samples	Trial	Remarks			
		Day 1	Day 3	Day 5	Day 7
Sample A (100% Starch)	1	The bioplastic film is buried in a 3-cm depth of soil.	Film starts to degrade, showing noticeable change in appearance.	Slightly degraded	Not entirely degraded, there are still tiny bit of pieces of film residues left on the soil.
	2	The bioplastic film is buried in a 3-cm depth of soil.	Film starts to degrade, showing noticeable change in appearance.	Slightly degraded	Not entirely degraded, there are still tiny bit of pieces of film residues left on the soil.
	3	The bioplastic film is buried in a 3-cm depth of soil.	Film starts to degrade, showing noticeable change in appearance.	Slightly degraded	Not entirely degraded, there are still tiny bit of pieces of film residues left on the soil.
Sample B (75% Starch, 25% Pectin)	1	The bioplastic film is buried in a 3-cm depth of soil.	Film starts to degrade, showing noticeable change in appearance.	Predominantly degraded but not entirely	Completely degraded
	2	The bioplastic film is buried in a 3-cm depth of soil.	Film starts to degrade, showing noticeable change in appearance.	Predominantly degraded but not entirely	Completely degraded
	3	The bioplastic film is buried in a 3-cm depth of soil.	Film starts to degrade, showing noticeable change in appearance.	Predominantly degraded but not entirely	Completely degraded

Sample C (50% Starch, 50% Pectin)	1	The bioplastic film is buried in a 3-cm depth of soil.	Film starts to degrade, showing noticeable change in its physical appearance.	Partially degraded	Completely degraded
	2	The bioplastic film is buried in a 3-cm depth of soil.	Film starts to degrade, showing noticeable change in its physical appearance.	Partially degraded	Completely degraded
	3	The bioplastic film is buried in a 3-cm depth of soil.	Film starts to degrade, showing noticeable change in its physical appearance.	Partially degraded	Completely degraded
Sample D (100% Pectin)	1	The bioplastic film is buried in a 3-cm depth of soil.	Film starts to degrade, showing noticeable change in its physical appearance.	Almost entirely degraded	Completely degraded
	2	The bioplastic film is buried in a 3-cm depth of soil.	Film starts to degrade, showing noticeable change in its physical appearance.	Almost entirely degraded	Completely degraded
	3	The bioplastic film is buried in a 3-cm depth of soil.	Film starts to degrade, showing noticeable change in its physical appearance.	Almost entirely degraded	Completely degraded

Table A2. Observational Table for Biodegradability Test

Appendix B. Documentation

Figure B1. Slicing of orange peels

Figure B2. Blanching of orange peels

Figure B3. Soaking of orange peels

Figure B4. Drying of orange peels

Figure B5. Heating the mixture

Figure B6. Filtering the mixture

Figure B7. Precipitating the mixture

Figure B8. Separation of pectin

Figure B9. Dried and powdered pectin

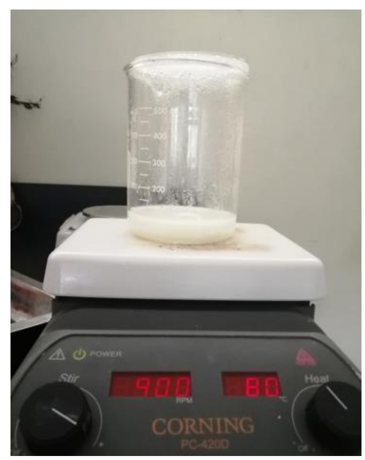

Figure B10. Formation of bioplastic

Figure B11. Sample A

Figure B12. Sample B

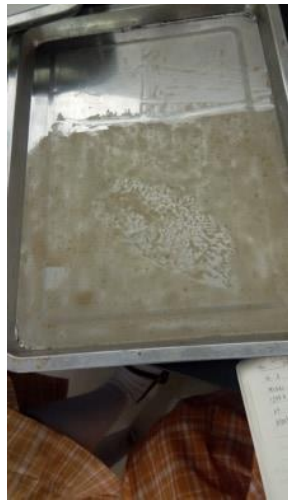

Figure B13. Sample C

Figure B14. Sample D

Figure B15. Solubility Test

Figure B16. Biodegradability Test