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BIOPLASTIC FROM JACKFRUIT SEED STARCH AND IT IS POTENCY FOR EDUCATION FOR SUSTAINABLE DEVELOPMENT (ESD) IN CHEMISTRY LEARNING

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Abstract: Plastic waste is a severe environmental problem. One solution is with bioplastic from jackfruit seed starch (JS). However, this bioplastic has weaknesses, such as not being heat resistant and having low mechanical properties, so adding chitosan (CH) and glycerol is necessary to strengthen it. This study aims to determine the optimum conditions for making bioplastics from jackfruit seed starch (JS) with the addition of chitosan (CH) and its potential in ESD-oriented chemistry learning. The methods used were laboratory experiments to determine the optimum conditions for making bioplastics, and an open-ended questionnaire to determine the potential of bioplastics as an ESD-oriented chemistry learning topic. The results of this study obtained tensile strength A1 (0.904 MPa), A2 (0.669 MPa), A3 (0.541 MPa), A4 (0.618 MPa), A5 (1.357 MPa), and A6 (6.140 MPa). The elongation test resulted in A1 (15.8%), A2 (16.5%), A3 (23.7%), A4 (35.7%), A5 (58.1%), and A6 (40.1%). The addition of chitosan increases the tensile strength and elongation values of bioplastics. The A3 and A4 bioplastics biodegradation tests were optimally decomposed within 5 days with a mass loss of 94%. Questionnaire results from 40 students showed that the topic of bioplastics has the potential to be integrated with project-based ESD lectures. Thus, bioplastic making can be used as one of the chemistry learning topics in project-based ESD lectures.

Keywords: Bioplastics, Jackfruit seeds, ESD, Chemistry learning

Abstrak: Sampah plastik menjadi masalah lingkungan yang serius. Salah satu solusinya dengan bioplastik dari pati biji nangka (JS). Namun, bioplastik ini mempunyai kelemahan seperti tidak tahan panas dan sifat mekanik yang rendah, sehingga perlu ditambahkan kitosan (CH) dan gliserol untuk memperkuatnya. Penelitian ini bertujuan untuk mengetahui kondisi optimum pembuatan bioplastik dari pati biji nangka (JS) dengan penambahan kitosan (CH) dan potensinya dalam pembelajaran kimia. Metode yang digunakan adalah eksperimen laboratorium untuk menentukan kondisi optimum pembuatan bioplastik dan kuesioner untuk mengetahui potensi bioplastik sebagai topik pembelajaran kimia berorientasi ESD. Hasil dari penelitian ini diperoleh kekuatan tarik A1 (0,904 MPa),A2 (0,669 MPa), A3 (0,541 MPa), A4 (0,618 MPa), A5 (1,357 MPa), dan A6 (6,140 MPa). Uji elongasi menghasilkan A1 (15,8%), A2 (16,5%), A3 (23,7%), A4 (35,7%), A5 (58,1%), dan A6 (40,1 %). Penambahan kitosan meningkatkan kekuatan tarik dan nilai elongasi bioplastik.Uji biodegradasi bioplastik A3 dan A4 terurai secara optimal dalam waktu 5 hari dengan kehilangan massa 94%. Hasil kuesioner dari 40 mahasiswa menujukkan bahwa topik bioplastik berpotensi untuk diintegrasikan dalam perkuliahan bermuatan ESD berbasis proyek. Dengan demikian, pembuatan bioplastik dapat digunakan sebagai salah satu topik pembelajaran kimia dalam perkuliahan ESD berbasis proyek.

Kata kunci: Bioplastik, Biji nangka, ESD, Pembelajaran kimia

INTRODUCTION

An environmental issue that still needs to be comprehensively resolved is plastic waste (Sikorska *et al.*, 2021; Vikhareva *et al.*, 2021). Plastics from petroleum-derived raw materials can pollute soil, water and air and take hundreds of years to decompose (Hasan *et al.,* 2020; Nguyen *et al.*, 2022; Pilapitiya & Ratnayake, 2024). The negative impact of plastic is not only on the environment but also on human health and results in unsustainability (Nguyen *et al.*, 2022). In Indonesia, plastic waste reaches 11 million tons annually, of which 18.5% is plastic waste (KLHK, 2020).

One of the innovative solutions to reduce plastic waste is bioplastics; this is in line with the research of Lothfy *et al.* (2018) and Nguyen *et al.* (2022), where bioplastics are environmentally friendly plastics that also have the potential to replace conventional plastics. Bioplastics are plastics made from bio-based materials that are biodegradable or have both properties (Gill, 2014). Bioplastics are made from renewable sources or organic compounds in plant parts such as cellulose, protein, and starch (Suderman et al., 2018; Hasan *et al.*, 2019). One of the raw materials used to make bioplastics is starch. Starch is the leading choice because it has many advantages: cheap, abundant, and easily obtained from various carbohydrate sources such as corn, rice, sago, and tubers (Marichelvam *et al.,* 2019; Hasan *et al.,* 2020).

Research by Lothfy *et al.* (2018) showed that jackfruit seeds are a potential starch source for making bioplastics. Jackfruit produced commercially in the agricultural industry produces about 8-15% of waste. Using jackfruit seed starch for bioplastics can help reduce jackfruit waste while overcoming the problem of plastic waste. However, jackfruit seed starch bioplastics still have weaknesses, such as not being heat-resistant, having low mechanical properties, and not being resistant to microorganisms and water (Rosally *et al.,* 2020). To overcome this, chitosan and glycerol are added to manufacture bioplastics.

Chitosan, which serves to increase the strength of bioplastics and provide antimicrobial properties, is generally obtained from crab shell waste (Wahab *et al.*, 2023), shrimp shells (Matouri *et al.,* 2024), and brown clam shells (Varma and Vasudevan, 2020). Glycerol, which can be obtained through hydrolysis of fatty acids or vegetable oils (Andaka, 2012), plays a role in increasing the elasticity of bioplastics and acts as a plasticizer (Lubis *et al.*, 2018; Maulida *et al.*, 2018). Using environmentally friendly materials such as jackfruit seeds, chitosan, and glycerol to make bioplastics is a natural step in preserving the environment. This is one of the applications of the three pillars, namely social, economic, and environmental, in ESD.

ESD is a learning approach based on sustainability principles that aim to equip the younger generation with knowledge, skills, and attitudes to protect the environment (Pratiwi *et al.,* 2023). ESD can be integrated into chemistry learning by involving the context of bioplastics and incorporating innovative pedagogy (De Waard, Prins and Van Joolingen, 2020). This is in line with the research of Burmeister and Eilks (2012), which shows that bioplastics are a suitable topic for ESD in chemistry learning. The importance of including bioplastics in ESD-laden chemistry learning needs to be explored further. A preliminary study can determine students' understanding and readiness to learn about bioplastics and identify its potential.

From this background, manufacturing bioplastics from jackfruit seed waste to be used in the context of ESD requires an optimization process to direct project-based learning in specific lectures that equip prospective chemistry teacher students. Related to this, this research needs to be carried out to determine the optimum conditions for making bioplastics and its potential to teach chemistry with ESD content.

METHOD

This research adopted a laboratory experiment method with qualitative data analysis from open-ended questionnaires. The focus of this research is to integrate ESD in chemistry learning through the topic of JS-CH bioplastic as an environmentally friendly plastic. A total of 40 chemistry education students at one of the universities in Bandung City became participants in this study. Data obtained from experiments and questionnaires were analyzed to reveal students' perceptions of chemistry learning that has been implemented, as well as the potential of JS-CH bioplastic as a relevant learning medium. The results of the study are expected to contribute to the development of a sustainability-oriented chemistry learning curriculum, especially in the context of chemistry teacher education to find out students' expectations of the chemistry learning they have taken.

Tools and Materials

The tools used in the production of bioplastics include a mixer, a filter cloth, a basin, a 100 mesh sieve, a mortar and pestle, an analytical balance, a beaker, a spatula, a magnetic stirrer, a thermometer, a hot plate, a stirring rod, a stand and clamp, and an oven. Jackfruit seeds obtained from traditional markets are the primary raw material used in the production of bioplastics. Other materials used are chitosan, glycerin, and 1% acetic acid. Chitosan and glycerin are added to strengthen the properties of bioplastics, while acetic acid is used to dissolve chitosan.

Preparation of Jackfruit Seed Starch

Extracting starch from jackfruit seeds begins with sorting and peeling the outer skin and the rind. Peeled jackfruit seeds are washed and sliced thinly. The sliced jackfruit seeds are mixed with water with a ratio of jackfruit seeds: water = ¼ (w/v) or 250 grams in 1 liter of water, then mashed.

The resulting jackfruit seed pulp was filtered, and the filtrate was sedimented for 24 hours. The starch precipitate was separated from the solution using a filter cloth. The starch precipitate obtained was then baked at 100˚C for 30 minutes. After drying, the starch was crushed with a mortar until smooth and sieved using a 100-mesh sieve. This extraction process produces jackfruit seed starch that is ready to make bioplastics.

Preparation of bioplastics

The manufacture of bioplastics from jackfruit seed starch using the method by Susilowati et al. (2021) begins with dissolving chitosan in 1% acetic acid. Furthermore, jackfruit seed starch was mixed with distilled water and stirred at 80-85˚C for 50 minutes. After that, the temperature was lowered to 50˚C and glycerol was added as a plasticizer, as much as 1 ml and stirred for 15 minutes.

Table 1. Experimental Design

Starch/Chitosan	Volume of Starch (ml)	Volume of Chitosan (ml)	Volume of Glycerol (ml)
10:0	50	0	1
9:1	45	5	1
8:2	40	10	1
7:3	35	15	1
6:4	30	20	1
5:5	25	25	1

The chitosan solution was then put into a beaker and stirred again for 10 minutes. After mixing the ingredients, the bioplastic solution was poured into a mould and dried in an oven at 60˚C. The bioplastics formed were then tested for mechanical properties using a Universal Testing Machine and biodegradation tests. The manufacture of bioplastics in this study varied between 2% jackfruit seed starch and 1% chitosan. The experimental design is presented in Table 1.

Characterization of Bioplastics

Tensile Strength Test

The tensile strength test was carried out by cutting bioplastics in a particular shape (dumbbell) with a length of 10.5 cm and a width of 2.5 cm. The sample is clamped on the tensile strength tester with a maximum load of 5kgf at 200 mm/minute. Furthermore, the tool is run according to predetermined conditions until the sample is cut, and the above procedure is repeated for each sample for 2 (two) tensile tests.

Elongation Test

Elongation testing of bioplastics is the same as the tensile strength test. Elongation is obtained by dividing the breaking strain by the initial length expressed as a percentage.

Biodegradation Test

The biodegradation test of bioplastics was measured in several ways, namely: (1) bioplastics planted in soil, (2) bioplastics planted using a mixture of soil and compost, and (3) bioplastics tested using microorganisms. In this study, the bioplastic biodegradation test was carried out by planting it in soil with compost (Arooj *et al.,* 2024). The compost used is from Cihideung Farmer's Root Media. Each bioplastic sample measures 3 × 2 cm. The samples were inserted into the soil 10 cm deep. At the beginning of the experiment, the soil was irrigated to half of its water storage capacity, and then the evaporated water was reduced by regular irrigation. The samples were monitored daily, and the mass loss was calculated by cleaning the adhering soil particles with a brush, drying them overnight, and weighing them as (Wt). The mass loss (%) of each sample was calculated using the following equation:

$$Mass\ loss\ (\%) = \frac{Wo - Wt}{Wo}\ x\ 100$$

Where Wo is the initial mass of the dry film, and Wt is the final dry mass after being incorporated into the soil for different time intervals.

RESULTS AND DISCUSSION

Starch from Jackfruit Seeds

This study uses starch extracted from jackfruit seeds to manufacture bioplastics. The jackfruit seeds used came from jackfruit traders in Bandung City.

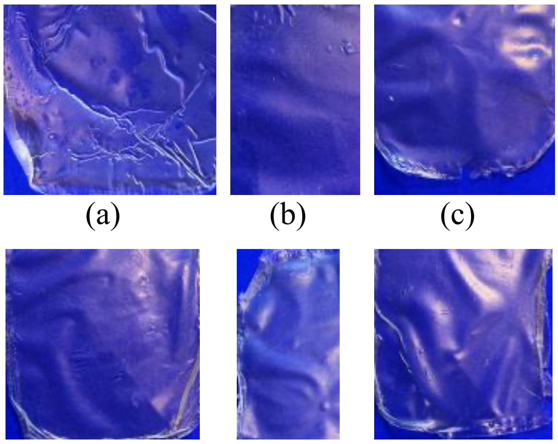
(a) (b)

Figure 1. (a) Jackfruit Seed (b) Jackfruit Seed Starch

The yield of starch obtained from the extraction of jackfruit seed starch is 20.27%. From 50 grams of jackfruit seeds, 10.1867 grams of dry starch is obtained, and then the starch that has been obtained is analyzed. The starch produced is a white powder measuring ±100 mesh. The jackfruit seeds obtained are shown in Figure 1 (a), and the extraction results in the form of starch are shown in Figure 1 (b).

Bioplastics

Bioplastics produced from this study are the result of variations of 2% starch and 1% chitosan with a volume ratio of A1 (10:0), A2 (9:1), A3 (8:2), A4 (7:3), A5 (6:4), and A6 (5:5) which have a thickness of 0.0915 mm - 0.2530 mm shown in Table 2. Based on visual observations, the bioplastics produced are transparent, and there is no difference in color with increasing percentages of starch and chitosan. The bioplastics obtained are depicted in Figure 2.



(a) (b) (c)

(d) (e) (f)

Figure 2. The results of transparent bioplastics from JS-CH ratio (a) 10:0, (b) 9:1, (c) 8:2, (d) 7:3, (e) 6:4, (f) 5:5

Table 2. The result of Thickness Bioplastic of JS-CH

Comparison	Thickness (mm)
10:0	0.2530
9:1	0.2365
8:2	0.1965
7:3	0.1940
6:4	0.1905
5:5	0.0915

Characterization of Bioplastics

Tensile Strength Test

The tensile strength test in this study was carried out to determine the maximum load bioplastics can withstand. Tensile strength is the maximum force exerted constantly until the bioplastic is cut off. Figure 3 presents the tensile test results of bioplastics from jackfruit seed starch and chitosan.

The mechanical properties of bioplastics are strongly influenced by the composition of the components, including starch, chitosan, and glycerol, which are plasticizers (Mutmainna *et al.*, 2024). Figure 3 shows that adding chitosan to bioplastics improves its mechanical properties. This finding resulted in the tensile strength of bioplastics in A1 (0.904 MPa), A2 (0.669 MPa), A3 (0.541 MPa), A4 (0.618 MPa), A5 (1.357 MPa), and A6 (6.140 MPa). This supports the potential of jackfruit seed starch-based bioplastics as an alternative to conventional plastics.

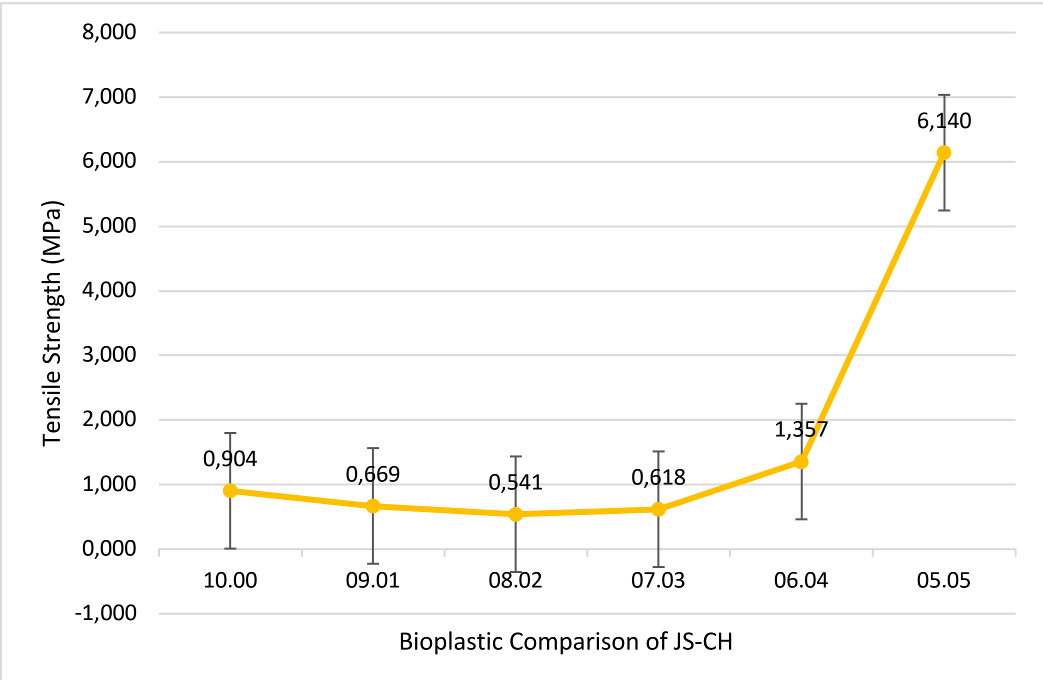


Figure 3. The Graph of Tensile Strength Test Results of Bioplastic JS-CH

This study's results align with (Akter *et al.*, 2014), who explained that the higher the chitosan content in a polymer mixture, the greater the tensile strength value of bioplastics. This increase can be attributed to more hydrogen bonds between NH_3^+ from chitosan and OH^- from starch. The amino group (NH_2) of chitosan is protonated to NH_3^+ in an acetic acid solution. At the same time, the regularly arranged crystals in the molecular structure of starch are disrupted during the gelatinisation process, which results in OH^- groups being exposed to form hydrogen bonds with NH_3^+ of chitosan. Therefore, the chemical bonds of bioplastics are stronger and more difficult to break (Merino & Alvarez, 2020; Tan *et al.*, 2022). The high flexibility of bioplastics is influenced by the interaction of amylose molecules from starch and chitosan because the interaction of amylose and chitosan molecules is more accessible than that of amylopectin (Hasan *et al.,* 2020).

Elongation Test

Elongation break is the percentage of length increase achieved by a material, in this case bioplastics, before breaking. The effect of the elongation break ratio of jackfruit seed starch and chitosan bioplastics is shown in Figure 4, which ranges from 15% to 58%. The breaking elongation of bioplastics produced by A1 (15.89%), A2 (16.59%), A3 (23.77%), A4 (35.75%), A5 (58.1%), and A6 (40.11%).

The increase in chitosan volume addition causes the elongation value to increase until it reaches the optimum value. The elongation value of A5 was 58.1%, after which the elongation value decreased to A6 by 40.1%. The decrease in elongation value is due to the volume of chitosan, which acts as a reinforcement in bioplastics, causing its elasticity to decrease. This is because the chitosan structure contains more hydrogen bonds, making bioplastics stronger (Syaubari *et al.*, 2022).

The elongation value impacts the quality of bioplastics; the more significant the elongation value indicates that bioplastics have superior mechanical quality (Rahmatullah *et al.*, 2023). The results of this study are in line with the research (Susilowati *et al.,* 2021) that starch-swung-chitosan bioplastics have an elongation value in the range of 13.33%-51.55%, whereas with the addition of sewage starch, the elongation value decreases the more rigid it is.

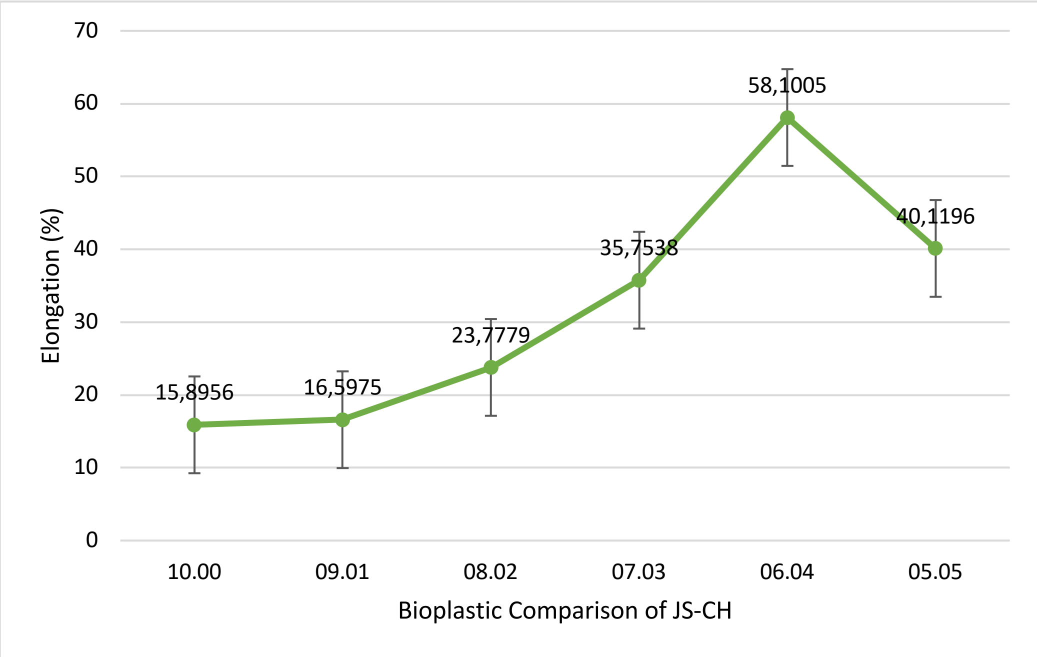


Figure 4. The Graph of Elongation Test Results of JS-CH Bioplastic

Biodegradation Test

Biodegradation testing is carried out to determine the time required for bioplastics to decompose in the environment. The composting method is one method that can be used to test biodegradation. This method involves various environmental factors such as temperature, moisture content, sample size, plasticizer (glycerol), and type of compost (Ali *et al.,* 2023). Research by Zoungranan *et al.* (2020) showed low initial biodegradation rates of bioplastics (around 10%) to more significant biodegradation rates (over 90%).

The results of the biodegradation test are shown in Table 3, which shows the variation of decomposition time between samples. A5 and A6 bioplastics decomposed the fastest in 3 days. The speed of degradation is influenced by several factors, one of which is the addition of chitosan to the sample. Chitosan is a natural biopolymer compound known to have antibacterial properties and improve the biodegradation properties of bioplastics. This is in line with (Syaubari *et al.*, 2022), who showed that bioplastics from watermelon rind with adding chitosan and glycerol degraded for 5-10 days.

Table 3. Picture of Visual Biodegradable Bioplastic Decomposition

Sam-ple	Day					
	0	1	3	5	7	9	11
K							
A1							-
A2					Decomposed	-	-
A3					-	-	-
A4					-	-	-
A5				Decomposed	-	-	-
A6				Decomposed	-	-	-

Description for sample:
K: Conventional plastic, A1: starch 2% 50 ml + glycerol 1 ml, A2: starch 2% 45 ml + glycerol 1 ml + chitosan 5 ml, A3: starch 2% 40 ml + glycerol 1 ml + chitosan 10 ml, A4: starch 2% 35 ml + glycerol 1 ml + chitosan 15 ml, A5: starch 2% 30 ml + glycerol 1 ml + chitosan 20 ml, A6: starch 2% 25 ml + glycerol 1 ml + chitosan 25 ml

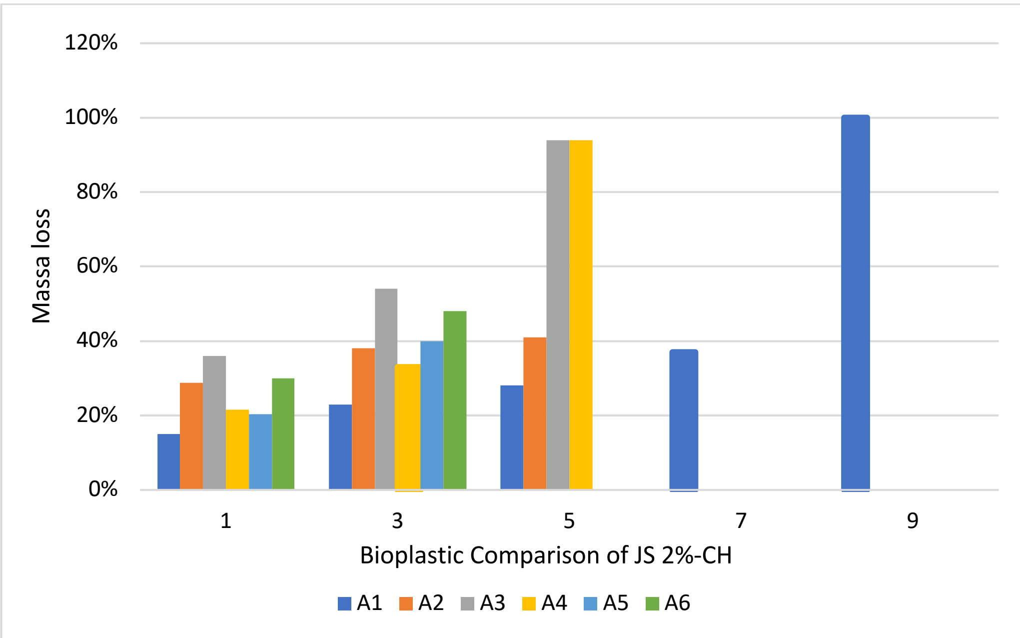


Figure 5. Calculation Result of Mass Loss from Biodegradation Assay of Bioplastic JS-CH

The biodegradation of bioplastics can also be measured through mass loss (%), shown in Figure 5. The results of this study show that A3 and A4 bioplastics have a mass loss, reaching 94%. Compared to other bioplastics, they degraded only 4%-77%. This biodegradation process is driven by microorganisms that secrete catalytic agents such as hydrolase enzymes. These enzymes play an essential role in breaking down hydrolytic bonds in bioplastics, resulting in new biomass, metabolites, and gas release (Liao & Chen, 2021).

Bioplastics as Eco-Plastic in Learning Contained Education for Sustainable Development (ESD)

Based on the data from the questionnaire results shown in Figure 6, it is known that 50% of students stated that the context of bioplastics as an environmentally friendly plastic has not been presented in chemistry courses in the chemistry education study program. Bioplastics as a substitute for conventional plastics and environmentally friendly products contribute significantly to various aspects of the SDGs, especially in achieving a more sustainable environment.

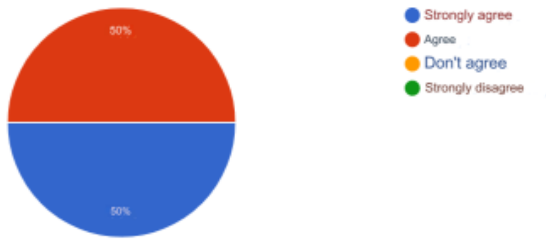


Figure 6. Percentage of bioplastic context taught in lecture

Table 4. Themes and sub-themes

Theme	Sub-themes
Aspects of the SDGs	Understanding of ESD principles Application of ESD principles
Context of bioplastic	Understanding the context of bioplastic Selection of bioplastic raw materials Making bioplastics Application of bioplastics as a solution to environmental problems
Improving 21st-century skills	Critical thinking skills Collaboration opportunities Presentation and communication skills

Integrating the context of bioplastics in learning is essential given their contribution to promoting sustainability in the economic, social, and environmental fields. Starch-based bioplastics have been identified as a potential solution to a variety of challenges, including the use of sustainable raw materials, packaging that supports a circular economy, and economies of scale (Parveen, Swami and Raja, 2024). This fact encourages researchers to explore the potential and need for the integration of bioplastics as environmentally friendly plastics in ESD-enhanced learning. A course with ESD content in the context of bioplastics is expected to meet student expectations, which are presented in a summary table of theme groups in the Table 4.

Theme 1: Aspects of the SDGs

The students expressed their hope that SDGs-oriented learning with the topic of bioplastics can provide a deep understanding of the concepts and aspects of sustainability. In addition to theoretical understanding, they also expect the application of sustainable principles. This application can be in the form of raising awareness about alternatives to conventional plastics to reduce the negative impact of plastic waste on health and the environment. Indirectly, students will be trained to care more about the environment. Students can utilize biological natural resources as the main material for making bioplastics, which can increase their sensitivity to the potential of natural resources around them.

Theme 2: Bioplastic Context

In the first sub-theme, understanding the context of bioplastics, students are expected to gain an in-depth understanding of starch-based bioplastics as environmentally friendly plastics. This understanding includes the definition of bioplastics, the types of basic materials used in making bioplastics, and their advantages and disadvantages. In addition, students will also learn the application of bioplastics, especially as packaging materials. In addition, understanding the steps of making bioplastics, including mechanical properties and biodegradation properties in the environment, is also an important focus. With this comprehensive understanding, students are expected to be able to explain the potential of bioplastics as an environmentally friendly plastic solution.

In the second sub-theme, the selection of basic materials for making bioplastics, students are expected to determine the basic materials based on the potential of natural resources available around them. The selection of this base material is an important basis for developing environmentally friendly and sustainable bioplastics. In addition, the determination of sustainable manufacturing procedures must also be studied so that the bioplastic products produced do not cause negative impacts, both in terms of health, environment and economy. Thus, students can produce bioplastics that are not only effective and innovative but also support environmental conservation efforts and community welfare.

In the third sub-theme, namely bioplastic manufacturing, students are expected to conduct direct experiments after determining the materials and procedures for making bioplastics. In this process, bioplastics are made by paying attention to the selection of materials and procedures that are environmentally friendly and minimize negative impacts on health. Through this experiment, students will gain practical experience in producing sustainable bioplastics, deepen their understanding of environmentally friendly technology, and foster awareness of the importance of innovation in the responsible management of natural resources.

In the fourth sub-theme, the application of bioplastics as environmentally friendly plastics involves biodegradation tests in soil. This test aims to introduce the context of bioplastics to the community. Students are expected not only to be able to make bioplastics but also to introduce the potential of bioplastics as environmentally friendly plastics widely. This provides an opportunity for students to contribute directly to society so that projects carried out in the laboratory can have a real impact on reducing food waste and the use of hazardous chemicals in the environment. The introduction of this bioplastic context is an important step in supporting efforts to reduce plastic waste while promoting innovations that support environmental sustainability.

Theme 3: Improving 21st-Century Skills

In the critical thinking skills sub-theme, students are expected to develop their critical thinking skills regarding Education for Sustainable Development (ESD) content in the context of bioplastics as environmentally friendly plastics, as well as innovation skills related to the development of environmentally friendly materials. In the collaboration opportunity's sub-theme, students are allowed to work in teams to improve collaboration skills between students in achieving sustainable project goals. In the presentation and communication skill's sub-theme, students want to improve their presentation and communication skills, so that they can present the projects they have worked on well.

Based on the analysis of starch content in bioplastics from various reading sources and bioplastics in ESD-enhanced learning through the answers to the open questionnaire, it was found that the context of bioplastics has a very broad and comprehensive scope of study to be included in ESD-enhanced chemistry learning. In addition, this context is explicitly related to various aspects of the Sustainable Development Goals (SDGs) in the economic, social and environmental fields. Utilizing starch from jackfruit seeds typical of the tropics can solve the problem of organic waste pollution and increase the use value of these wastes. Starch-based bioplastics have the advantage of strong mechanical properties. The application of each sub-topic in chemistry learning requires a deep understanding of chemical concepts so that students are expected to be able to learn independently. Therefore, this topic has great potential to be included in the context of chemistry learning with ESD content.

Supported by the results of the open questionnaire, it is known that 50% of students stated that this topic has never been included in ESD-laden chemistry learning, and they have high expectations for this topic to be taught in chemistry learning with ESD content and the resulting learning outcomes. The potential of bioplastic topics in sustainable development learning is significant and supports sustainability through the application of circular bioeconomy in the packaging industry and various other applications. Thus, incorporating the topic of bioplastics into sustainable development learning can help students understand the importance of green innovation in the packaging industry and the role of bioplastic materials in achieving sustainable development goals (Parveen, Swami and Raja, 2024)

CONCLUSION

Based on the experimental results, it can be concluded that jackfruit seed starch was successfully extracted with a yield of 20.27% and showed significant potential as a bioplastic raw material. JS-CH bioplastic A6 showed an optimum tensile strength of 6.140 MPa and the maximum elongation value at the A5 ratio was 58%, while the addition of chitosan improved both properties significantly. Biodegradation tests showed that A3 and A4 bioplastics had a mass loss of 94% within 3 days, indicating that these bioplastics have good biodegradability. These findings indicate that jackfruit seed starch-based bioplastics not only have technical potential in terms of strength and degradation but are also relevant for use in an educational context. The results of the questionnaire showed that the topic of bioplastics has the potential to be integrated with ESD and project-based learning approaches, highlighting the importance of developing this content in the chemistry education curriculum.

The impact of this education research is the potential integration of bioplastics from jackfruit seed starch in project-based chemistry and ESD learning, which can enrich the learning experience and increase students' awareness of sustainability and innovation of environmentally friendly materials. The practical implications include the development of more relevant and applicable teaching materials for prospective chemistry teachers. However, this study has limitations, including a limited sample size and no long-term evaluation of the application of this topic in the curriculum. Further research is needed to explore the broad practical application and identify additional factors that may influence the effectiveness of bioplastic integration in chemistry learning.

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