INSECTA Vol. 5 No. 4, 2024, pp. 201 - 211

Available online at
INSECTA
Integrative Science Education and Teaching Activity Journal
Journal homepage : https://jurnal.iainponorogo.ac.id/index.php/insecta

Article

Green Chemistry in Action: Developing and Implementing a Biodegradable Material Experiment in Senior High School Settings

Nabila Putri Sholahudin[1], Riandi[2], Eka Cahya Prima[3]*

[1,2,3]*Universitas Pendidikan Indonesia, Indonesia*

**Corresponding Address: ekacahyaprima@upi.edu*

Article Info
Article history:
Received: September 12, 2024
Accepted: October 30, 2024
Published: November 30, 2024

Keywords:
Bioplastics;
Biodegradable;
Experiment;
Green Chemistry.

ABSTRACT
Teaching senior high school students green chemistry can contribute to future scientists and professionals who are responsible for safer, less hazardous chemistry. Plastic, known for its durability, affordability, and lightweight properties, is integral to daily life across industries, including housing, healthcare, fashion, sports, and transportation. However, the plastic industry poses significant economic and environmental challenges, raising concerns about its sustainability. To address these issues, this research focuses on the transformation of orange peel waste into a fine powder to develop a biobased, biodegradable plastic. The study conducted a soil burial test over a continuous 14-day period, revealing that an increased quantity of orange peel powder positively influenced the biodegradability of the bioplastic. Enhanced biodegradation was observed with higher concentrations of orange peel. The implementation of bioplastic experiments in the classroom received positive feedback from students, as evidenced by high ratings across various statements. Overall, the findings suggest that the experiments were not only engaging but also effective in shaping students' perspectives on plastic and science.

INTRODUCTION

Plastic is widely used in everyday life, from housing to health, clothing, sport, transport, food, water, and many more because of its durability, cheapness, and lightness, making it useful in almost all industrial fields (Arjun et al., 2023; Lange, 2021; Erdal et al., 2019). However, there are some disadvantages related to economic and environmental problems caused by the plastic industry (Arjun et al., 2023). The persistent presence of plastic in the environment post-use, manifesting as soil and water waste or airborne pollutants such as CO_2 and soot during incineration, poses an unsustainable threat to the planet and its biodiversity (Lange, 2021; Park et al., 2004). Chemicals released from plastic products contribute to the buildup of harmful substances in wildlife, causing great concern for humans due to potential exposure and associated risks (Yaradoddi et al., 2021).

The environmental impact of plastic waste is increasingly worrying. Plastics in large quantities and types, especially polyolefins, polystyrene, and poly(vinyl chloride) are currently produced from fossil fuels, consumed, and thrown into the environment. Some of these materials can decompose over some time, while other debris remains nondegradable for several centuries (Yaradoddi et al., 2020; Widyastuti et al., (2021). Therefore, there is great interest in biodegradable polymers, which can be used as an alternative to traditional plastics, thereby reducing the amount of waste (Park et al., 2004). Food waste is typically considered undesirable, except when repurposed as compost. A notable trend involves the transformation of food-derived waste, such as shrimp peels, orange peels, and used ground coffee, into biodegradable plastic (Pavlovic´ et al., 2013). Additionally, Bioplastic is also derived from renewable energy resources such as corn starch, potatoes, tapioca, sugar cane bagasse, and algae (Yaradoddi et al., 2021). Indeed, food loss and waste have emerged as promising bioresources for materials in a circular bioeconomy. This paradigm shift aims to increase circularity and sustainability by offering environmentally friendly alternatives to alternatives that are problematic for the environment (Otoni et al., 2021; J & V, 2023).

In this study, the orange peel was used to produce bioplastic because orange peel is rich in starch. It is also composed of various components, including hemicelluloses, cellulose, lignin, pectin, soluble sugars, fat, ash, protein, and flavonoids. Pectin, found within the peel, serves as a crucial element contributing to the strength of bioplastics (Park et al., 2004; Mackenzie et al., (2019). The orange peel, rich in the natural substance limonene, undergoes oxidation and bonding with carbon dioxide, resulting in the production of biobased plastic. The source of this material is abundant, making it a cost-effective option for various industrial applications. Some reports indicate that materials developed using poly(limonene carbonate) (PLimC)-based plastics exhibit antimicrobial activity, effectively preventing the growth of E. coli (Yaradoddi et al., 2021). Therefore, the development of bioplastic from the waste orange peel is relevant to the present perspective. However, the development of biodegradable plastic in the education system is still rare, especially for secondary school students.

Most of the environmental pollution material covered in the curriculum consists of concrete concepts with plenty of examples observable in the surrounding environment. However, due to limited time during lessons, not all these concepts can be explored through direct observation within a single class (Rosalina & Suhardi, 2020). While environmental pollution is included in the curriculum, opportunities for students to engage in hands-on experiments to understand and address pollution issues in practical, concrete ways are still lacking. This gap suggests a need for more interactive learning experiences that allow students to investigate solutions experimentally, fostering a deeper understanding of environmental challenges and potential solutions.

Senior high school students are frequently aware of the issue of plastics accumulating in oceans and on land, but their comprehension of potential solutions is often limited to recognizing the importance of recycling (Knutson et al., 2019). Therefore, to increase demand for more environmentally friendly and sustainable chemicals, the introduction of bioplastic manufacturing must be integrated into the education system to impact attitudes and perceptions of chemistry in society positively (Cannon et al., 2023). Moreover, the concept has to emphasize the importance of recognizing environmental concerns related to materials overall, with a specific focus on polymers. This aims to involve students in making informed decisions about the materials they choose for their daily lives (Erdal et al., 2019). Through this activity, students realize that we can not only use renewable raw materials and sustainable processes to teach environmentally friendly chemistry in the laboratory but also gain benefits from waste. Orange peels are a great candidate to demonstrate waste assessment to students given that orange peels are one of the most underutilized and geographically diverse biowaste residues on the planet (Mackenzie et al., 2019; Yaradoddi et al., 2021).

Teaching senior high school students green chemistry can contribute to future scientists and professionals who are responsible for safer, less hazardous chemistry. In the laboratory setting, students commonly acquire practical skills in various areas, including solution preparation, utilization of volumetric glassware, and adhering to laboratory safety protocols. It is crucial, however, for laboratory courses to not only focus on technical skills but also to cultivate essential transferable soft skills, such as oral and written communication, teamwork, and critical thinking (Ward & Wyllie, 2019). Based on this background, the Author set out to develop a high school laboratory experiment using the combination of tapioca starch, orange peel, and palm oil. The objective of this study was to obtain the films from orange processing byproduct and tapioca starch for implementation in educational settings.

METHODS

Materials and Tools

The orange peel used in this research was from the squeeze orange (*Citrus sinensis*) in the Rutaceae family. These oranges were obtained from the waste of making squeezed oranges at a food stall in Bandung, West Java to ensure the uniform source condition. The other materials for the bioplastic experiment, palm oil and tapioca starch, were sourced from Food Ingredient Depot, located in Bandung, West Java, Indonesia. Additionally, all necessary tools and equipment for the experiment, such as beaker, analytical balance, hotplate magnetic stirrer, glass stir rod, were obtained from the laboratory of the program study.

Procedure

Experimental development began between October and December 2023 and went through several stages before reaching completion. The entire process in this research is illustrated in Figure 1.

Extraction of Orange Peel

The first step in making orange peel extract is to cut the squeezed orange peel into small pieces. These pieces are then stored in the refrigerator for approximately 8 hours. The pieces of orange peel that have been rested are transferred to the oven at a temperature of 100°C. The oven process which is carried out for 3 hours aims to dry the orange peel pieces until they reach the desired consistency. Pulverization was carried out using a chopper, which is the part of mechanical disruption method that helps in the extraction of the polymeric materials from the orange peel. The next step is to filter the results of the destruction using a 100-mesh sieve. Through this filtering process, we ensure that what is produced is fine, high-quality orange peel powder.

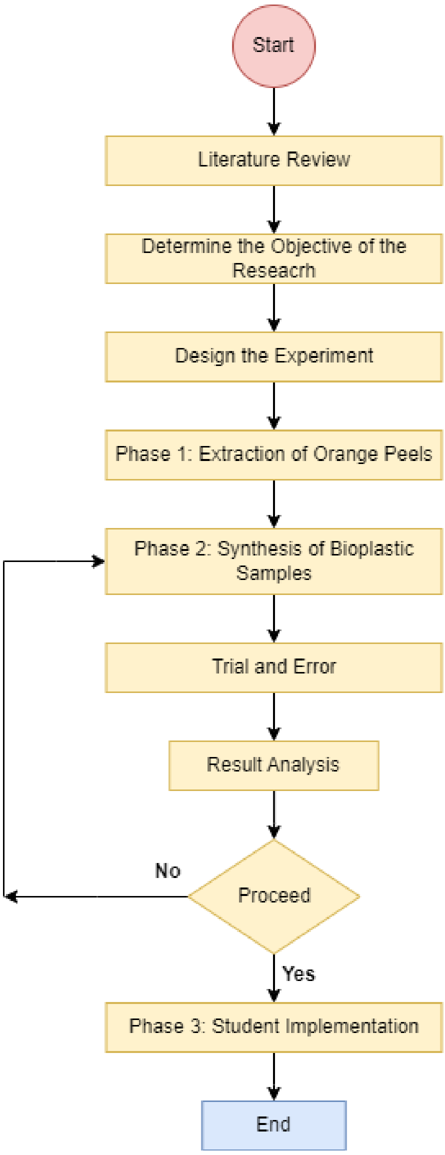

Figure1. Flowchart of the Research

Synthesis of Bioplastic Samples

The initial phase of this experiment introduces students to bioplastics by documenting their role within the context of plastic accumulation in our environment. Everyday items such as plastic bags, toilet paper, poly(ethylene terephthalate) (PET) bottles, and aluminum cans are featured, and the time these materials take to degrade in the environment, aiming to address the issue of littering (Erdal et al., 2019). Additionally, students were introduced to the principles of bioplastics, and students were also introduced to the role of bioplastics in achieving sustainability. This initial phase continued by synthesizing the bioplastic samples. The experiment was conducted by 23 science major senior high school students. The students worked in groups of 3. The synthesis of bioplastic was completed on the first day of the experiment during a 90-minute class period.

The materials used to make bioplastic films were orange peel, tapioca starch, palm oil, and distilled water. Palm oil was used as a plasticizer which makes additional starch and other ingredients plastic to produce bioplastic films. The students synthesize four different bioplastic samples based on the orange peel composition. The composition of the different ingredients is presented in Table 1. Orange peel powder was weighed and poured into each beaker according to the composition of the sample variations (sample 1=1 g; sample 2=2 g; sample 3=3 g; sample

4=4 g). 10 g of tapioca starch, 3 g of palm oil, and 100 g of distilled water were added to each beaker. The mixture in each beaker was stirred thoroughly for 10 minutes to ensure all ingredients were mixed evenly. Then the mixture was heated and stirred using a magnetic stirrer hotplate until it reached a thickened consistency. If there is no hotplate magnetic stirrer available in school laboratory, students can use Bunsen burner and stir the mixture manually using glass stir rod. After reaching this stage, the dough is flattened using a baking sheet and left to dry for 3 days at room temperature. Data analysis was performed collaboratively using the worksheet that had been provided.

Table 1. The Composition of Bioplastic Films in Each Samples

Sample	Orange Peel	Tapioca Starch	Palm Oil	Distilled Water
	Weight in gram (g)			
Sample 1 (S1)	1	10	3	100
Sample 2 (S2)	2	10	3	100
Sample 3 (S3)	3	10	3	100
Sample 4 (S4)	4	10	3	100

Degradation of Bioplastic Samples

In the second phase of this experiment, a biodegradation test was conducted. A biodegradability test was performed to determine the ability of the film to degrade naturally. The biodegradability of the samples was demonstrated through the soil burial method. The soil burial method was adapted from the earlier investigation conducted by Sambudi et al., (2022), with certain modifications. Bioplastic films (S1, S2, S3, S4) and synthetic polyethylene films (S5) as a control variable were cut into 3 cm x 4 cm in size. The films were buried in 5 cm depth. A certain amount of water is sprinkled on the soil, so that the activity of bacterial enzymes can be enriched (Veena & Rani, 2022). Additionally, in the context of soil microbial activity, maintaining an optimal moisture content is essential for facilitating the degradation or disintegration of the samples (Yaradoddi et al., 2021). A degradation sample was observed for 14 days. The biodegradation of plastic films and synthetic polyethylene films was compared. The degradation value can be calculated using equation (1).

$$\text{Biodegradation } (\%) = \frac{\text{initial mass} - \text{final mass}}{\text{initial mass}} \text{ x } 100\% \qquad (1)$$

Data Collection of Students' Response

The student questionnaire underwent adaptation and modification, drawing inspiration from the survey in the prior research conducted by Knutson et al., (2019) and Fagnani et al., (2020), with minor adjustments. The survey comprised 10 statements prompting students to assess their impression regarding the experimental design, bioplastic synthesis, and the practical use of the experiment. Responses were rated on a 1−5 Likert scale, with 5 indicating the most positive response and 1 representing the least positive response.

RESULTS AND DISCUSSION

Biodegradation

All the soil-buried bioplastic samples were taken from the soil after 14 days of burial time. The biodegradation value of each sample was compared with synthetic polyethylene. On day 14, the bioplastic degraded, and the color of the bioplastic films changed as can be seen in Figure 1. No changes were observed in the synthetic polyethylene film. The biodegradation of each sample is shown in Table 2. Table 2 shows that biodegradation values in each sample range from 78%-81%.

Table 2. Biodegradation Value of Each Sample

Sample	Initial Mass (g)	Final Mass (g)	Biodegradation Value (%)
S1	0.935	0.205	78.04
S2	0.932	0.187	79.94

Sample	Initial Mass (g)	Final Mass (g)	Biodegradation Value (%)
S3	1.081	0.216	80.02
S4	1.006	0.189	81.21
S5	0.043	0.043	0.00

Table 2 shows that sample 4 has the highest biodegradation value (81.21%). This proved that the highest composition of orange peel resulted in the highest rate of biodegradation. It is caused by the starch content in orange peel. Starch is entirely biodegradable in diverse environmental conditions. Microorganisms or enzymes can hydrolyze it into glucose, which is subsequently metabolized into carbon dioxide and water (Lu & Xiao, 2009). Indeed, the ability of a plastic to undergo biodegradation is contingent upon its hydrolysable or non-hydrolysable characteristics (Bandini et al., 2022). Research conducted by Widyastuti et al., (2021) created bioplastic using banana peel with varying tapioca flour and glycerol. They assessed its biodegradability through soil burial, observing a decrease in bioplastic mass within a week. In contrast to their findings, our bioplastic films demonstrated a prolonged resistance to biodegradation.

Classroom Implementation

This experiment took place in an academic setting, specifically in a senior high school, involving 23 science major students. The synthesis of bioplastic was carried out on the first day of the experiment within a 90-minute class period. Subsequently, the bioplastic samples were allowed to dry over three days. Collaborative data analysis was conducted using the provided worksheet.

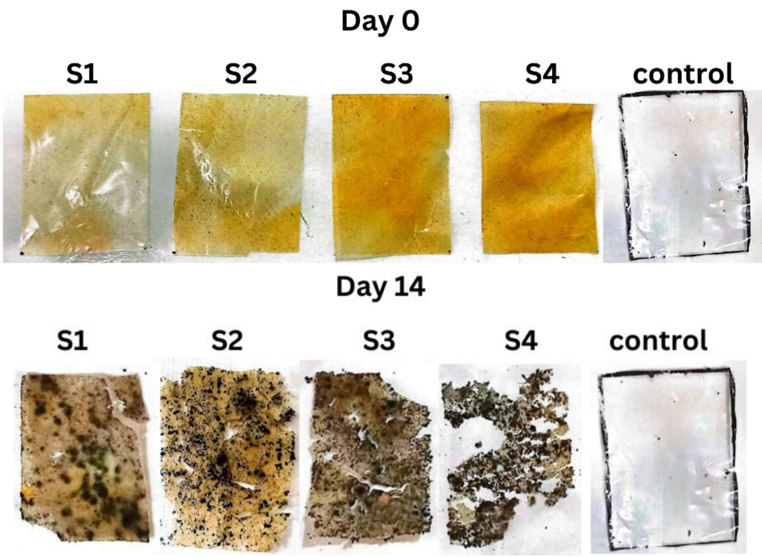

Figure 2. The Initial Bioplastic and Final Bioplastic After 14 Days of Burial Soil Method

67% of student reports agreed that sample 4 decomposed the fastest, while another 33% stated that sample 3 decomposed the fastest. This is in line with research conducted by (Yaradoddi et al., 2021) which tested bioplastics from orange peel, HCl, and glycerin. The results of his research prove that orange peel contains starch, pectin, and cellulose which are carbon sources that are highly sought after for microbial growth and reproduction. The bioplastic obtained turned out to be stiff and less flexible. Most of the students reported that the samples they made were quite fragile so they had difficulty removing them from the mold, but sample 4 has stronger characteristics than the other samples. This is because the pectin content came from the orange peel powder and its cellulosic fibers provided the necessary strength for the bioplastic sample (Yaradoddi et al., 2021). Additionally, Dibha et al., (2023) stated that orange peel powder acts as a biodegradable component which can provide higher oxygen permeability to microorganisms.

Students' Feedback

A summary of students' feedback on the implementation of bioplastic production from food waste is provided in Figure 2, Figure 3, and Figure 4. The results collectively affirm the success of each aspect of the experiment, including students' overall impression, the synthesis of bioplastic, and the practical use of the experiment. Students, in general, responded positively, with a majority expressing the significance of the experiment. They acknowledged an increase in their understanding of environmentally sustainable polymers and recognized the suitability of incorporating the topic into the school curriculum. Many students found value in synthesizing polymer samples, gaining insights into green chemistry, and observing polymer degradation. Additionally, students appreciated the experiment's societal relevance and the utilization of common household items such as starch, orange peel, and palm oil.

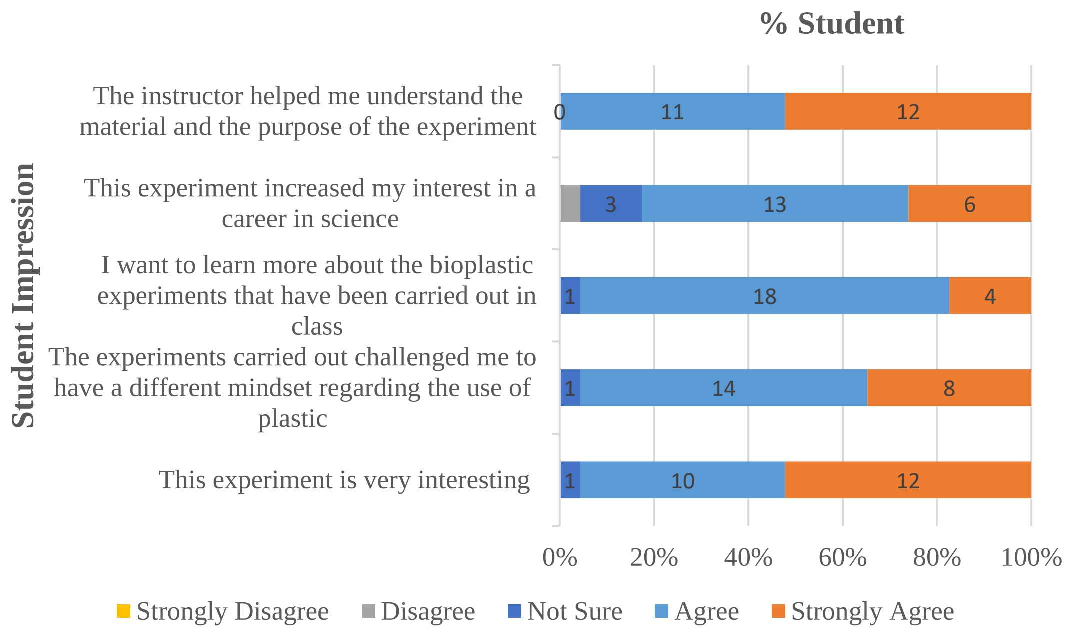

Figure 3. Student Response on Their Impression

Figure 3 shows the students' impression towards the experiment. The positive response to the experiment's interesting and its potential to influence career interests suggests that hands-on experiences like bioplastic synthesis can be engaging and impactful in science education.

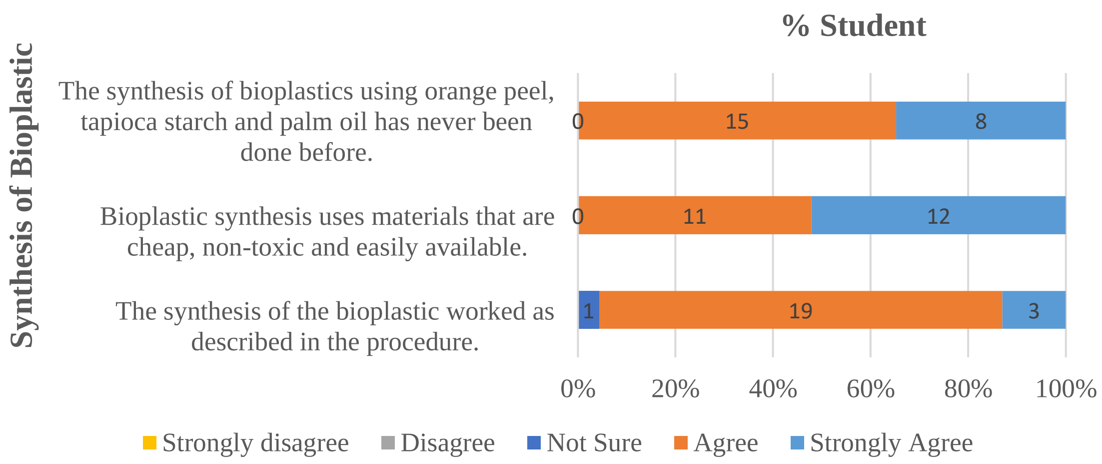

Figure 4. Student Response about the Synthesis of Bioplastic

Figure 4 shows the students' response toward the synthesis of bioplastic. The success of the synthesis process and the use of environmentally friendly materials collectively enhance the experiment's credibility. Moreover, this experiment used food waste as the raw material. Utilization of food waste as a source of raw materials of bioplastics is much sought after because it can significantly improve the sustainability of our economy (Perotto et al., 2018). Besides that, students see the topic as important and suitable for inclusion in the school curriculum. This experiment was discovered to generate enthusiasm among students, and when coupled with questionnaire results, it indicates the useful activity (Erdal et al., 2019; Fagnani et al., 2020).

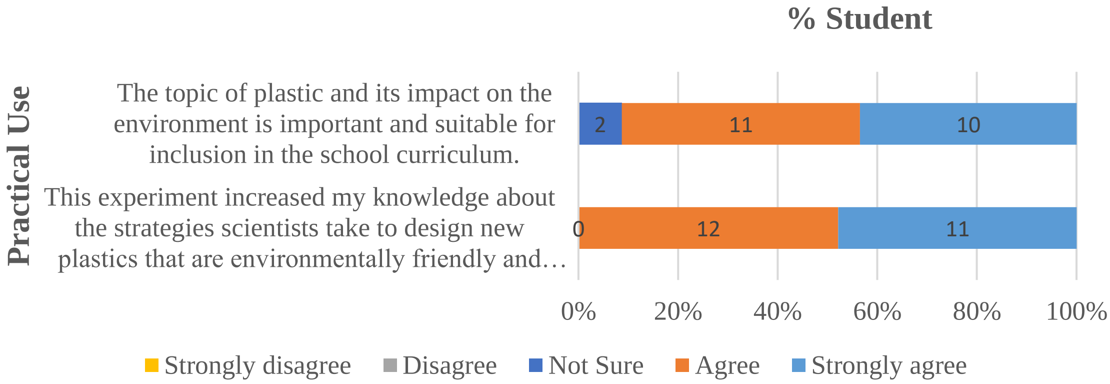

Figure 5. Students' Response to the Practical Use of Experiment

Figure 5 shows the students' responses to the experiment's practical use. The positive impact on knowledge about sustainable plastics implies that the experiment contributes to the educational goals of raising awareness about environmental issues and promoting sustainable practices. The statement supports the argument for curriculum inclusion by highlighting the educational benefits and the potential to inspire students to think critically about real-world problems, fostering a deeper understanding of science and sustainability. Nearly all students expressed that the topic of plastic and its impact on the environment is important and suitable for inclusion in the school curriculum. This consideration can be valuable for policymakers and educators aiming to enhance students' environmental awareness. The use of eco-friendly, accessible, and affordable materials, along with a variety of learning objectives—from simple observation to experimental implementation—enables instructors to tailor the experiment to fit classroom settings, allowing both students and teachers to integrate this activity into their classes.

Ward & Wyllie (2019) found that involving students in a semester-long project on chitosan-alginate bioplastics led to heightened engagement and skill development, particularly in experiment design and critical thinking. This study demonstrates the educational benefits of incorporating sustainable plastics into the curriculum, which supports this finding that experiments on sustainable plastics can effectively raise students' awareness of environmental issues. The alignment between Ward's findings and this research underscores how the experiment with bioplastics not only increases knowledge but also cultivates essential scientific skills, further advocating for these topics' inclusion in science education to promote both critical skills and environmental consciousness. This experiment also serves to develop students' inquiry skills and autonomous learning, as they are encouraged to explore how bioplastics degrade and understand their role in fostering green chemistry (Fagnani et al., 2020; Ward & Wyllie, 2019).

Similarly, Veena & Rani (2022) demonstrated that bioplastics derived from organic waste, such as banana peels, contribute positively to environmental sustainability and education. The study's focus on biodegradable materials derived from renewable sources highlights how sustainable plastics can inspire eco-friendly thinking among students. This overlap confirms that by engaging students in the creation and study of bioplastics, educators can deepen students' understanding of plastic waste issues and sustainable solutions. Yaradoddi et al. (2021)

explored the production of bioplastic film from food waste, particularly orange peels, and found that it had excellent biodegradability and strength. This research not only highlights the potential of bioplastics for green applications but also provides a practical, accessible approach to sustainable education. The alignment with this finding shows that hands-on experiments with sustainable materials can significantly improve students' grasp of science and environmental stewardship. Knutson et al. (2019) focused on synthesizing biobased polymers in high school and college labs using safe, renewable materials, and observed strong educational outcomes. Knutson’s experiment encouraged students to investigate degradation processes and analyze data through spectroscopy and colorimetry. This supports the research findings by demonstrating that sustainability-focused experiments help students connect scientific principles to real-world environmental issues, such as plastic pollution.

According to Kuncorowati et al. (2021), when students engage in practical experiments in a laboratory setting, they gain several benefits that enhance their learning experience and understanding of the material. Furthermore, the design of this experiment offers flexibility for expansion, allowing students to explore a variety of scientific concepts and experimental variables. Students could investigate the properties and effectiveness of different plant starches, such as corn, potato, or cassava, to understand how these natural sources impact the strength, flexibility, and biodegradability of the bioplastic. Additionally, they could experiment with adding other environmentally friendly additives, such as glycerol or citric acid, to modify the polymer’s properties, gaining insight into the ways additives affect polymer formation and stability. By adjusting reaction conditions, such as temperature, pH, or different degradation media (e.g., soil, water, or compost), students can also observe how these factors influence the rate and extent of bioplastic degradation. This experiment could foster critical thinking, as students compare results across varying conditions and analyze how each factor contributes to environmental sustainability. Such extensions would encourage students to approach scientific inquiries creatively and thoughtfully, promoting a deeper understanding of both chemistry and sustainability (Ward & Wyllie, 2019). Additionally, organizing hands-on activities serves to present authentic phenomena, and foster higher levels of student participation and active involvement in the teaching and learning process (Purnama et al., 2023).

CONCLUSION

In this research, orange peel waste was processed into a fine powder to create a biobased, biodegradable plastic. The soil burial test conducted over a continuous 14-day period led to the conclusion that the enhanced quantity of orange peel powder positively influenced the biodegradability of the bioplastic. The study observed improved biodegradation as the concentration of orange peel increased. The classroom implementation and the data collection from the students generally had positive impressions of the bioplastic experiments, with high average ratings across most statements. Overall, the feedback suggests that the experiments were engaging, educational, and effective in influencing students' perspectives on plastic and science. In future research, students could investigate the properties and effectiveness of different plant starches, such as corn, potato, or cassava, to understand how these natural sources impact the strength, flexibility, and biodegradability of the bioplastic.

REFERENCES

Arjun, J., Manju, R., Rajeswaran, S. R., & Chandhru, M. (2023). Banana peel starch to biodegradable alternative products for commercial plastics. *GSC Biological and Pharmaceutical Sciences*, *22*(2), 234–244. https://doi.org/https://doi.org/10.30574/gscbps.2023.22.2.0066

Bandini, F., Taskin, E., Bellotti, G., Vaccari, F., Misci, C., Guerrieri, M. C., Cocconcelli, P. S., & Puglisi, E. (2022). The treatment of the organic fraction of municipal solid waste (OFMSW) as a possible source of micro - and nano - plastics and bioplastics in agroecosystems : a review. *Chemical and Biological Technologies in Agriculture*, *9*(4), 1–17. https://doi.org/10.1186/s40538-021-00269-w

Cannon, A. S., Anderson, K. R., Enright, M. C., Kleinsasser, D. G., Klotz, A. R., Neil, N. J. O., & Tucker, L. J. (2023). Green Chemistry Teacher Professional Development in New York State High Schools: A Model for Advancing Green Chemistry. *Journal of Chemical Education*, *100*(6), 2224–2232. https://doi.org/10.1021/acs.jchemed.2c01173

Dibha, A. F., Masruri, M., & Srihardyastutie, A. (2023). Degradable Bioplastic Developed from Pine-Wood Nanocellulose as a Filler Combined with Orange Peel Extract. *Indonesian Journal of Chemistry*, *23*(1), 127–139. https://doi.org/10.22146/ijc.75520

Erdal, N. B., Hakkarainen, M., & Blomqvist, A. G. (2019). Polymers, Giant Molecules with Properties: An Entertaining Activity Introducing Polymers to Young Students. *Journal of Chemical Education*, A-E. https://doi.org/10.1021/acs.jchemed.8b00918

Fagnani, D. E., Hall, A. O., Zurcher, D. M., Sekoni, K. N., Barbu, B. N., & Mcneil, A. J. (2020). Short Course on Sustainable Polymers for High School Students. *Journal of Chemical Education*, A-I. https://doi.org/I https://dx.doi.org/10.1021/acs.jchemed.0c00507

J, R. B., & V, G. S. (2023). Review on food waste valorisation for bioplastic production towards a circular economy : sustainable approaches and biodegradability. *Sustainable Energy & Fuels*, *7*, 3165–3184. https://doi.org/10.1039/d3se00500c

Knutson, C. M., Hilker, A. P., Tolstyka, Z. P., Anderson, C. B., Wilbon, P. A., Mathers, R. T., Wentzel, M. T., Perkins, A. L., & Wissinger, J. E. (2019). Dyeing to Degrade: A Bioplastics Experiment for College and High School Classrooms. *Journal of Chemical Education*, *96*(11), 2565–2573. https://doi.org/10.1021/acs.jchemed.9b00461

Kuncorowati, W., Habibi, M. W., Mosrifa, C. T., & Ilafi, M. M. (2021). The Efectiveness of Utilization of the Science Laboratory in Integrated Science Learning at MTs Unggulan Al Qodiri 1 Jember. *Integrative Science Education and Teaching Activity Journal*, *2*(2), 165–174. https://doi.org/https://doi.org/10.21154/insecta.v2i2.3287

Lange, J. (2021). Managing Plastic Waste - Sorting, Recycling, Disposal, and Product Redesign. *ACS Sustainable Chemistry & Engineering*, *9*, 15722−15738. https://doi.org/10.1021/acssuschemeng.1c05013

Lu, D., & Xiao, C. (2009). Starch-based completely biodegradable polymer materials. *EXPRESS Polymer Letter*, *3*(6), 366–375. https://doi.org/10.3144/expresspolymlett.2009.46

Mackenzie, L. S., Tyrrell, H., Thomas, R., Matharu, A. S., Clark, J. H., & Hurst, G. A. (2019). Valorization of Waste Orange Peel to Produce Shear-Thinning Gels. *Journal of Chemical Education*, *96*(12), 3025–3029. https://doi.org/10.1021/acs.jchemed.8b01009

Otoni, C. G., Azeredo, H. M. C., Mattos, B. D., Beaumont, M., Correa, D. S., & Rojas, O. J. (2021). The Food–Materials Nexus: Next Generation Bioplastics and Advanced Materials from Agri-Food Residues. *Advance Material*, *33*. https://doi.org/https://doi.org/10.1002/adma.202102520

Park, H., Misra, M., Drzal, L. T., & Mohanty, A. K. (2004). " Green " Nanocomposites from Cellulose Acetate Bioplastic and Clay : Effect of Eco-Friendly Triethyl Citrate Plasticizer. *Biomacromolecules*, *5*(6), 2281–2288. https://doi.org/https://doi.org/10.1021/bm049690f

Pavlovic´, M. D., Buntic´, A. V., Šiler-Marinkovic´, S. S., & -Brankovic, S. I. D. (2013). Ethanol influenced fast microwave-assisted extraction for natural antioxidants obtaining from spent filter coffee. *Separation and Purification Technology, 118*, 503–510. https://doi.org/http://dx.doi.org/10.1016/j.seppur.2013.07.035

Perotto, G., Ceseracciu, L., Simonutti, R., Paul, U. C., Puyol, S. G.-, Tran, T.-N., Bayer, I. S., & Athanassiou, A. (2018). Green Chemistry. *The Royal Society of Chemistry*. https://doi.org/10.1039/C7GC03368K

Purnama, A. N. H., Winarno, N., Prima, E. C., & Ahmad, N. J. (2023). Fostering Students' Concept Mastery through STEM-Engineering Design Process in Thermal Energy and Heat Transfer Topic. *Integrative Science Education and Teaching Activity Journal*, *4*(2), 209–230. https://doi.org/https://doi.org/10.21154/insecta.v4i2.7240

Rosalina, S. S., & Suhardi, A. (2020). Need Analysis of Interactive Multimedia Development with Contextual Approach on Pollution Material. *Integrative Science Education and Teaching Activity Journal*, *1*(1), 93–108. https://doi.org/https://doi.org/10.21154/insecta.v1i1.2107

Sambudi, N. S., Lin, W. Y., Haru, N. Y., & Mutiari, D. (2022). Modification of Poly(lactic acid) with Orange Peel Powder as Biodegradable Composite. *Polymers*, *14*(4126), 1–12. https://doi.org/https://doi.org/10.3390/polym14194126

Veena, S., & Rani, M. E. (2022). Bioplastics from banana peels and biodegradation by micro organisms. *International Journal of Creative Research Thought (IJCRT)*, *10*(8), 217–224.

Ward, A. M., & Wyllie, G. R. A. (2019). Bioplastics in the General Chemistry Laboratory: Building a Semester-Long Research Experience. *Journal of Chemical Education*, *96*(4), 668–676. https://doi.org/10.1021/acs.jchemed.8b00666

Widyastuti, S., Ratnawati, R., & Priyono, N. S. (2021). Production of bioplastics from organic waste with tapioca flour and glycerol. *Journal of Natural Resources and Environmental Management*, *11*(4), 677–684. https://doi.org/http://dx.doi.org/10.29244/jpsl.11.4.677-684

Yaradoddi, J. S., Banapurmath, N. R., & Ganachari, S. V. (2020). Biodegradable carboxymethyl cellulose based material for sustainable packaging application. *Sientific Reports*, *10*, 1–13. https://doi.org/https://doi.org/10.1038/s41598-020-78912-z

Yaradoddi, J. S., Banapurmath, N. R., Ganachari, S. V, Soudagar, M. E. M., Sajjan, A. M., Kamat, S., Mujtaba, M. A., Shettar, A. S., Anqi, A. E., Safaei, M. R., Elfasakhany, A., Siddiqui, I. H., & Ali, M. A. (2021). Bio-based Material from Fruit Waste of Orange Peel for Industrial Applications Bio-based material from fruit waste of orange peel for industrial applications. *Journal of Materials Research and Technology*, *September*. https://doi.org/10.1016/j.jmrt.2021.09.016