# Teacher Guide – part 1

## Synthesis of Bioplastic from Banana Peel

This teaching unit is designed as guided inquiry-based learning. In the preliminary activity, the students explore a bioplastic synthesis from banana peel through an experiment and by using the textbook and other available sources. Afterwards, they inquire a pre-determined research question.

Students’ age
The experiment is suitable for students in the 9th grade (14–15 years old).

### Time required

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| --- | --- |
| Inquiry Phase | Time |
| Preliminary Activity | 40 minutes |
| Generating Researchable Questions  | 0 minutes |
| Planning | 15 minutes |
| Carrying Out the Plan | 90 minutes |
| Organizing the Data | 10 minutes |
| Communicating the Results | 15 minutes |
| Conclusion | 10 minutes |

### Curricular relevance

According to the Slovenian Chemistry Curriculum for Primary School (Chemistry Curriculum for Primary School, 2011).

* Students define polysaccharides as natural polymers.
* Students understand the importance and impact of organic oxygen compounds on everyday life and the environment.
* Students are encouraged to develop experimental-research skills.
* Students understand the interdependence of the structure, properties, and uses of chemical compounds.
* Students develop a responsible attitude towards use of chemical compounds and responsibility for health and the environment (chemical safety).
* Students are encouraged to observe systematically and use observations as a source of data.

### Introduction

Plastic materials (plastics) contain artificial polymers as their main component, which are characterised by high molecular weights. Due to the ease of processing and the numerous possibilities for manufacturing low-cost products that increase the standard of living, quality and comfort of life, polymeric materials have successfully penetrated the world markets. Depending on their origin, polymers can be divided into natural (e.g., proteins, polysaccharides, and DNA molecules) and artificial or synthetic.

Petrochemistry is a field of chemistry that includes technical processes and chemical syntheses for the industrial extraction of products from oil and natural gas. Currently, almost all polymeric materials are produced by the petrochemical industry i.e., they are produced from fossil (non-renewable) sources. Due to the mass consumption of disposable plastic products intended for very short-term use (e.g., plastic pots, plastic bags), the amount of plastic waste is increasing.

Some see bioplastics as an alternative option. The current definition refers to bioplastics as biodegradable plastics and/or plastics made from renewable raw materials. According to this definition, bioplastics also include plastics that are not biodegradable but are made from a renewable resource (e.g., polyethylene from sugar cane).

Depending on the raw material, bioplastics are divided into:

1. bioplastics from renewable resources
2. bioplastics from fossil resources
3. bioplastics from a mixture of renewable and fossil resources

Polymers based on renewable resources can be divided into three categories:

1. polymers extracted/removed directly from biomass: polysaccharides, e.g., starch and cellulose; proteins, e.g., casein and gluten
2. polymers produced by classical chemical syntheses using monomers from renewable raw materials (e.g., polyethylene)
3. polymers obtained with the help of microorganisms or genetically modified bacteria

Due to its wide availability, low cost, renewability and biodegradability, starch is often used to produce bioplastics. Many previous studies have been conducted using starch as a natural biopolymer. Starch consists of a long chain of two glucose units linked together, namely branched polymerised amylopectin and amylose, which give it a granular structure. Starch can behave like a thermoplastic in the presence of plasticisers and with the application of heat and mechanical treatment.

If not disposed of properly the amount of food waste from various sources can be a burden on the environment. Therefore, implementing a biorefinery platform for food waste is an ideal option (e.g., producing value-added products while reducing the amount of waste). It is expected that the implementation of such a process will reduce the production costs of biodegradable plastics (e.g., compared to traditional production routes using overpriced pure substrates (e.g., glucose)).

One of the most common starchy wastes is banana peels. In some parts of the world, the disposal of tonnes of banana peel is a problem, especially in industries that produce banana products such as banana cakes, banana crisps, banana fritters, and more. These industries use the banana flesh as raw material and dispose of the peels at the end of the process.

Banana peels contain a high percentage (about 18.5 %) of starch. As the banana peels ripen, the glucose content increases. Therefore, banana peels that are not too ripe can be proposed as a suitable resource to produce bioplastics.

Although food waste is a good feedstock to produce bioplastics, it needs to be pre-treated to improve or change the physical, chemical, and biological properties. Successful conversion processes refer to the partial or complete release of monomers from the food waste (e.g., lignocellulosic components) with increasing accessibility of proteins, lipids, and polysaccharides (e.g., starch and cellulose) for subsequent enzymatic hydrolysis and fermentation. In addition, multiple methods can be integrated into a single treatment system for better performance.

### Risk Assessment

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| **List significant hazards** | **Describe what could happen** | **Precautionary measures** | **Measures to be taken if something goes wrong** |
| 0.2 M sodium metabisulfite | GHS pictogram for health hazard.GHS pictogram for corrosive substances.**H302** Harmful if swallowed.**H313** May be harmful to skin.**H319** Causes serious eye irritation. | **P281** Wear protective equipment for hands, eyes, face, and respiratory tract.**P305 + P351 + P338** IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. | QR code to safety data sheet for sodium metabisulfite. |
| 0.2 M hydrochloric acid | Slika, ki vsebuje besede znak, ospredje, promet, ustavi  Opis je samodejno ustvarjen**H290** May be corrosive to metals. | **P234** Keep only in original packaging.**P390** Absorb spillage to prevent material damage. | QR code to safety data sheet for hydrochloric acid. |
| 0.2 M sodium hydroxide | Slika, ki vsebuje besede znak, ospredje, promet, ustavi  Opis je samodejno ustvarjen**H290** May be corrosive to metals.**H315** Causes skin irritation.**H319** Causes serious eye irritation | **P234** Keep only in original packaging.**P264** Wash skin thoroughly after handling.**P280** Wear protective gloves/ eye protection/ face protection.**P302 + P352** IF ON SKIN: Wash with plenty of water.**P305 + P351 + P338** IF IN EYES: Rinse cautiously with water for several minutes.Remove contact lenses, if present and easy to do. Continue rinsing.**P332 + P313** If skin irritation occurs: Get medical advice/ attention. | QR code to safety data sheet for sodium hydroxide. |

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| **Disposal and any other comments** | Reaction products should be disposed in accordance with instructions written in SDS and local/regional/national/international regulations.Students should wear personal protective equipment (gloves, goggles, and lab coat). |
| **In case of emergency** | In case of emergency call 112 or personal doctor. |

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| **Date of assessment** | 13-2-2023 | **Written by** | CheSSE | **Class / lesson** | EXAMPLE |

## Preliminary Activity

This inquiry begins with an activity to reinforce knowledge about bioplastic synthesis from banana peels.

#### Example answers to the questions (where relevant)

1. What is bioplastic? *Answers will vary. Bioplastic is defined as biodegradable plastic and/or plastic from renewable sources. According to this definition, bioplastic also include plastic that is not biodegradable, but are made from a renewable resource (e.g., polyethylene from sugar cane). Depending on the source, bioplastics are divided into (1) bioplastics from renewable sources, (2) bioplastics from fossil sources and (3) bioplastics from a mixture of renewable and fossil resources.*
2. List other plant sources that could be used in synthesis of bioplastic. *Answers will vary. Sugar cane, corn, potato peels, etc.*
3. What is the role of glycerol in the synthesis of bioplastic? *Glycerol is added as a plasticizer or dispersant, additive that increase the plasticity or fluidity of a material.*
4. List at least three factors that could possibly affect the properties (e.g., biodegradation, strength, elasticity) of synthesized bioplastic. *Answers will vary. Some factors affecting the properties of synthesized bioplastic are the ripeness of banana peels, method of pre-treatment of food waste (banana peels), the amount and type of plasticizer etc.*

## Generating Researchable Questions

**Note**: Researchable questions are assigned by the instructor in the Guided Inquiry-Based Learning. Some possible researchable questions for this experiment are listed below:

**1RQ:** How does the volume of added glycerol in the synthesis of a bioplastic from banana peels affect its properties, e.g., elasticity? (sample results provided - note: student results will vary depending on experimental design)

**2RQ:** How does the degree of ripeness of banana peels affect the efficiency of the synthesis of bioplastic from banana peels? (no sample results provided)

**3RQ:** How does the biodegradability of bioplastic from banana peels and artificial plastic (e.g., PET) differ? (no sample results provided)

There are many more possible researchable questions. Students should choose a researchable question that addresses the learning outcomes of your specific standards. Be sure to emphasize experimental control and variables. Instructors using the Guided Inquiry approach select the researchable questions to be investigated by students. Assigning multiple researchable questions is desirable as it enhances student interaction and learning during the different phases.

### Planning (example)

During this phase, students should formulate a hypothesis, plan the experimental procedure, and write a method they will use to collect data. Circulate among the student groups asking questions and making helpful suggestions.

#### Formulating a hypothesis

The volume of added glycerol in the synthesis of a bioplastic from banana peels affect its properties, e.g., elasticity.

#### Postulate the controlled, independent, and dependent variables

**Controlled variables**: preparation of banana peels, the concentration and volume of hydrochloric acid and sodium hydroxide solutions, drying time, and temperature

**Independent variable**: the volume of glycerol (0, 1 and 2 mL)

**Dependent variable**: the elasticity of bioplastic film

#### Planning of the experimental procedure

**Preparation of banana peels**

1. Cut the banana peels into small pieces and place them in 0.2 M solution of sodium metabisulphite for 45 minutes. This will increase the biodegradation period of plastic, as sodium metabisulphite is an antioxidant and preservative.
2. Transfer the ​​banana peels into boiling distilled water, and boil for about 30 minutes.
3. Drain the water and place the banana peels on filter paper and allow to air-dry for about 30 minutes.
4. Puree the dried peels into a smooth paste using a hand blender.

**Preparation of bioplastics from banana peels (with different amount of added glycerol)**

1. Weigh 25 g of banana paste into a beaker.
2. Add 3 mL of 0.5 M hydrochloric acid and 2 mL of glycerol to the beaker and stir.
3. Add 3 mL of 0.5 M sodium hydroxide and stir.
4. Spread a thin layer of the mixture onto petri dish and allow it to air-dry at room temperature for at least 24 hours.
5. When the mixture is dry, remove it from the petri dish.
6. Repeat the procedure to prepare bioplastic film with 0 mL and 1 mL of added glycerol.

**Testing the elasticity of bioplastic film with different volume of added glycerol**

1. Cut the 2 cm x 2 cm samples of bioplastic films (with added 0, 1 and 2 mL of glycerol).
2. Fold the bioplastic films in half and place the 50 g measuring weight on it for 10 seconds.
3. Observe and record any changes of deformation of the bioplastic film samples.
4. Planning of collecting the data
5. We will test the elasticity of a bioplastic films with different volume of added glycerol and record the observations and conclusions in table 1 (see below).

Planning of collecting the data

We will test the elasticity of a bioplastic films with different volume of added glycerol and record the observations and conclusions in the table.

### Carrying out the Plan (example)

During this phase, students use their plan to carry out the experiment and collect data. Circulate among the student groups asking questions and making helpful suggestions.

### Life Cycle Analysis (sample results)

Use a life cycle analysis (LCA) – an evaluation of the environmental impact of a product over its entire lifecycle to assess the overall sustainability of a product to determine which plastic – bioplastic from renewable resource (e.g., banana peels) or plastic from fossil resources (e.g., PEF) is more favourable from a sustainable point of view.

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| --- | --- | --- |
|  | **Bioplastics from renewable resources (e.g., waste banana peels)** | **Plastics from fossil resources (e.g., PET)** |
| **MATERIALS** What was used to make the product? (e.g., plastics, metals)  |   |   |
| **PRODUCTION** How and where was it produced? (e.g., in your country or overseas)  |   |   |
| **DISTRIBUTION** How was it transported at each stage of the lifecycle? (e.g., ship, lorry, train)  |   |   |
| **USE** What impact do the products have during the use stage? (e.g., environmental impact, efficiency)  |   |   |
| **DISPOSAL** How can it be disposed of? (e.g., recycled, landfill)  |   |   |
| **OTHER NOTES/** **REMARKS**  |   |   |

You might also be interested in examining the greenness of the production of bioplastic from banana peels. For instructions see Student Worksheet – Part 2.

### Results and Discussion (example)

Students organize, interpret, and communicate their experimental results using tables, graphs and/or charts. Students should take into consideration also life cycle analysis. If they evaluated experimental work with green chemistry metrics (see Student Worksheet – Part 2), they should discuss the findings and their implications. Interaction among student groups is important as well as collection of information that will be utilized during the Conclusion phase.

Table 1: Results of elasticity of bioplastic film with different amount of added glycerol.

| **Bioplastic** | **Observations** |
| --- | --- |
| Bioplastic from banana peels with 0 mL of added glycerol  | Under pressure the film breaks. |
| Bioplastic from banana peels with 1 mL of added glycerol | The film returns to its original shape; however, a fold is visible. |
| Bioplastic from banana peels with 2 mL of added glycerol | The film returns to its original shape; however, a fold is visible. |

The data in table 1 show that the volume of added glycerol in the synthesis of bioplastic from banana peels affect its elasticity, deformation under pressure. Based on the life cycle analysis it can be concluded that the bioplastic from renewable resources (e.g., banana peels) is more favourable from a sustainable point of view than the plastic from fossil resources (e.g., PET). The evaluation of the experimental work – synthesis of bioplastic from banana peels using green chemistry metrics – shows that the experiment could be optimised, especially regarding principles 1, 5, 10 and 12. In the future, sodium bicarbonate could be used as a preservative for the plastic instead of sodium metabisulphite, although it requires higher temperatures (350˚C) to be efficient.

### Conclusion (example)

In this phase the students summarize and evaluate the results presented in the Results and Discussion phase.

### Discussion phase

Waste banana peels can serve as an organic material that is abundantly available, inexpensive, and environmentally friendly. Producing bioplastic from banana peels instead of petroleum-based plastics can be an effective solution leading to a reduction in the use of non-renewable raw materials. In the synthesis of a bioplastic from banana peels, glycerol is used as a plasticizer, an additive as it improves the plasticity, elasticity of a material.

# Teacher Guide – part 2

## Evaluation of experimental work with green chemistry metrics (sample results)

Evaluate the experiment *Synthesis of bioplastic from banana peel* using green chemistry metrics. In this activity you will

* determine the hazards of the substances used in the experiment, thereby you will learn how to obtain and use safety data sheets and develop a practical understanding of hazard (H) and precautionary (P) statements
* determine the value of perceived greenness of the experiment, thereby you will be introduced to the 12 principles of green chemistry
* construct the green star of the experiment, thereby you will present the data obtained using graphical means to get a better overview of greenness of the experiment.

Follow the instructions below and use Appendix 2, 3, and 4 to help with the activity.

### 1. Determine the hazards of the substances used in experimental work

* In table 1, insert the names of the chemical compounds included in the experiment in the first column.
* For each chemical used, consult the safety data sheets you can obtain via the QR code in the risk assessment and write the hazard codes of each chemical in the second column.
* Use appendix 2 to obtain scores\* (1–3) attributed to health, environment, and physical hazards. Insert the obtained scores in the appropriate column. If no hazard code is assigned for a chemical, assign a score of 1.

Table 1: Hazards of the substances used in experimental work, according to the protocol described in the preliminary activity.

|  | Hazard code | Scores (S) attributed to hazards\* |
| --- | --- | --- |
| Health | Environment | Physical |
| banana peels | Not classified as hazardous | 1 | 1 | 1 |
| sodium metabisulfite(CAS 7681-57-4) | H302, H313, H319 | 2 | 1 | 1 |
| 0.2 M hydrochloric acid | Not classified as hazardous | 1 | 1 | 1 |
| 0.2 M sodium hydroxide | H290, H315, H319 | 2 | 1 | 2 |
| glycerol(CAS 56-81-5) | Not classified as hazardous | 1 | 1 | 1 |
| water | Not classified as hazardous | 1 | 1 | 1 |
| bioplastic |  | 1 | 1 | 1 |

\* Scores (S) attributed to hazards on a scale from 1 (low hazard) to 3 (high hazard)

### 2. Determine the value of perceived greenness

* To fill table 2, see the Green Chemistry Principles and Criteria for assessment of the value of perceived greenness (appendix 2).
* Decide the number of principles (e.g., 6 or 10 principles) that provides the most meaningful evaluation of perceived greenness of the experiment.
* The value (V) of perceived greenness can be derived from appendix 2. V ranges from 1 (minimum) to 3 (maximum). Write NA when non applicable.

Table 2: Green chemistry principles and the value of perceived greenness to build the green star of the experimental work, according to the protocol described in the preliminary activity.

|  |  |  |
| --- | --- | --- |
| Green Chemistry Principle | Value of perceived greenness (V) | Explanation (optional) |
| P1 – prevention | 2 | sodium metabisulfite solution, sodium hydroxide solution |
| P2 – atom economy\* |  |  |
| P3 – less hazardous chemical synthesis\* |  |  |
| P4 – designing safer chemicals\*\* |  |  |
| P5 – safer solvents and auxiliary substances | 2 | sodium metabisulfite solution, sodium hydroxide solution |
| P6 – increase energy efficiency | 2 | room pressure and temperature between 0 and 100 ºC when heating is needed |
| P7 – use renewable feedstocks | 2 | banana peels |
| P8 – reduce derivatives\* |  |  |
| P9 – catalysts\* |  |  |
| P10 – design for degradation | 2 | sodium metabisulfite solution |
| P11 – real-time analysis for pollution prevention\*\* |  |  |
| P12 – safer chemistry for accident prevention | 2 | sodium metabisulfite solution, sodium hydroxide solution |

\* Applicable when using 10 or 12 Principles. \*\* Applicable only when using all 12 Principles

### 3. Construction of the green star

The green star presents the results of the greenness assessment of the experimental protocol.



Figure 2: Greenness assessment of the experimental work

### 4. Consider further possibilities to optimize the experimental protocol

### References

MIZS (Ministry of Education, Science and Sport of the Republic of Slovenia). (2011). Program osnovna šola. Kemija. Učni načrt. <https://www.gov.si/assets/ministrstva/MIZS/Dokumenti/Osnovna-sola/Ucni-nacrti/obvezni/UN_kemija.pdf>

Ribeiro, M. G. T., Costa, D. A., & Machado, A. A. (2010). “Green Star”: a holistic Green Chemistry metric for evaluation of teaching laboratory experiments. *Green Chemistry Letters and Reviews, 3*(2), 149-159. <https://doi.org/10.1080/17518251003623376>

Ribeiro, M. G. T., & Machado, A. A. (2014). Green star construction. <http://educa.fc.up.pt/documentosQV/EV/Construction%20of%20Green%20Star_6_points_GSAI.xlsx>