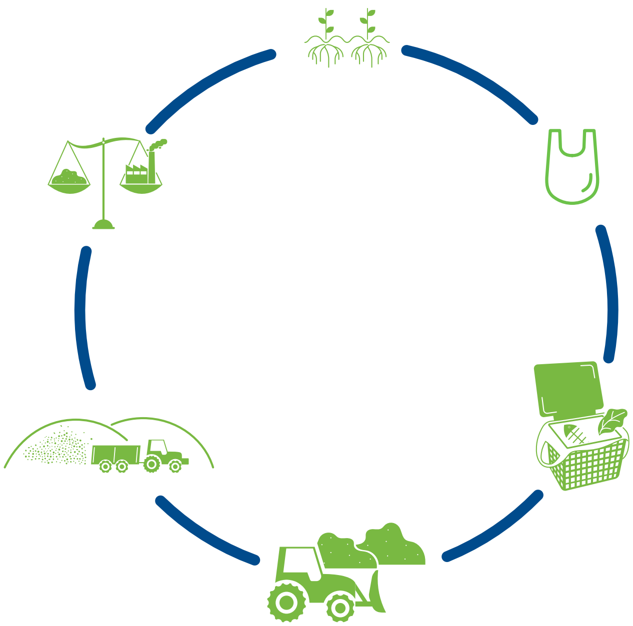
Starch-based bioplastic

From starch the revolution that will save the Earth



Abstract

Conventional plastics are environmentally harmful, derived from oil, and resistant to natural decomposition. However, in the 1990s, a team of Italian scientists, led by Catia Bastioli, pioneered a breakthrough. They developed biodegradable plastics, offering an escape from this unsustainable cycle. Bioplastics can be processed just like regular plastics, but when thrown onto a regular compost heap, they fall apart in weeks - not in the hundreds of years it takes traditional plastics to decompose. Crafted from crops, bioplastics reduce greenhouse gas emissions and the consumption of non-renewable resources. Catia Bastioli's innovative bioplastic, exemplifies this revolution. It serves as the foundation for eco-friendly solutions across various everyday items: from carrier bags and organic waste receptacles to packaging for fresh produce, paper, cups, napkins, plates, and utensils, including those used for ice cream. Bioplastic fosters a symbiotic relationship with nature, being completely biodegradable and compostable. Bioplastic is proof that through research in creating renewable materials, biodegradable and compostable products can be obtained with respect for the environment!

KEY TERMS

Biodegradability: the ability of the substances and organic materials to be degraded into simpler substances through the enzymatic activity of microorganisms.

Compostability: the ability of an organic material to transform into compost through the composting process.

Starch: a complex carbohydrate found in plants, composed of glucose molecules linked together in long chains. It serves as a primary energy storage molecule in plants and is hydrolyzed into glucose for energy production.

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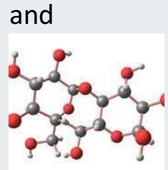
Introduction

Traditional petroleum-based plastics are not biodegradable. If burned they release toxic substances, such as polycyclic aromatic hydrocarbons and dioxins; furthermore, being non-polar, they can be deposited in adipose tissue. For this reason, the synthesis of biological plastics has been developed, i.e. biopolymers obtained from vegetables (from corn, potato or wheat starch and from agricultural waste). Precisely because they are of biological origin, bioplastics are compostable, that is, they can be placed in organic waste containers to be sent for treatment which transforms them into compost, used as fertilizer. According to EU legislation, for a material to be defined as compostable, it must be 90% biodegradable within 6 months and must not release heavy metals. To better understand the circularity of the process we can say that plants, thanks to chlorophyll photosynthesis, produce glucose which will be transformed into starch enzymatically. Therefore, starch is a fundamental energy source for plant cells and is also a food source for humans (digestion with the enzyme amylase). Chemically, starch molecules comprise two main components: amylose and amylopectin. Amylose consists of linear chains of glucose units linked by α-1,4-glycosidic bonds, while amylopectin features branched chains with occasional α-1,6-glycosidic bonds, facilitating its greater solubility and enzymatic degradation compared to amylose.



Starch serves as a crucial source of energy for both plants and animals, being hydrolyzed by enzymes such as amylase into simpler sugars like glucose, which can then be metabolized to provide energy for cellular processes. In addition to its role as an energy reserve, starch also functions as a structural component in certain plant tissues, contributing to their rigidity and texture.

Methods

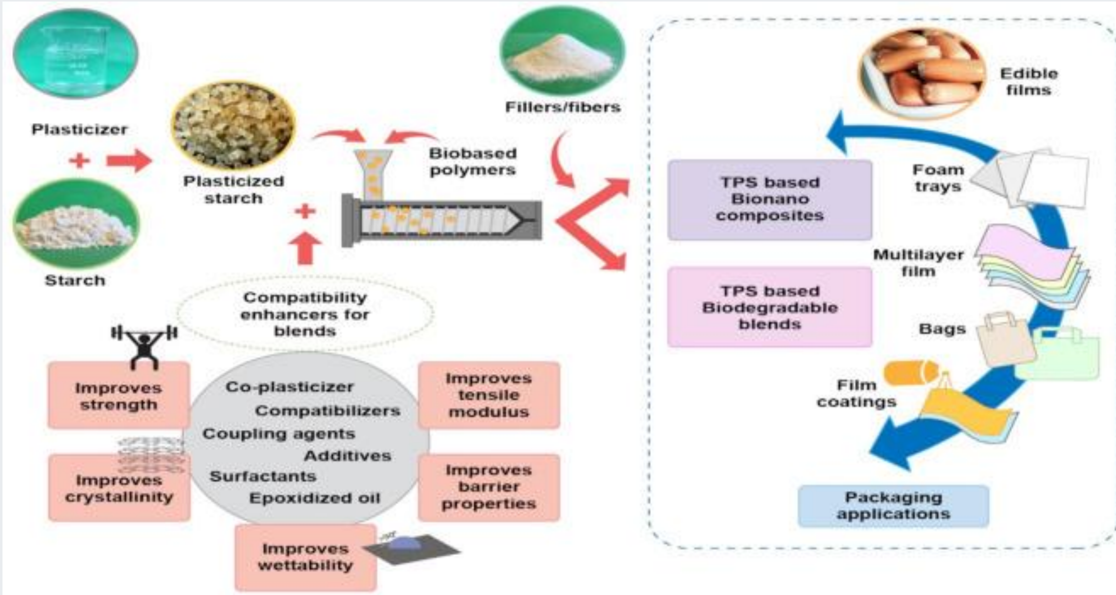
Bioplastics can be obtained from starch through a process called **plasticization**. In this process, starch is first extracted from plant sources such as corn, potatoes, or cassava. The starch is then mixed with plasticizers, which are substances that help make the starch more flexible and moldable.

Once the starch has been plasticized, it can be processed using techniques such as **extrusion or injection molding** to form various shapes and products, similar to traditional plastic manufacturing processes. These bio-plastic products can range from packaging materials to utensils and disposable tableware.

One common method of obtaining bioplastics from starch involves blending the starch with other biodegradable polymers such as polylactic acid (PLA) to improve its mechanical properties and performance. This blend can then be processed into bio-plastic products with enhanced durability and functionality while retaining the biodegradability and eco-friendly nature of starch-based materials.

Women in STEM - Facts about the author.

Catia Bastioli - Chemist, scientist and entrepreneur, CEO of the Novamont Group, an Italian industrial and innovation company, world leader in the development of bioplastics and biochemicals from renewable sources according to a circular bioeconomy model. She has been and is a member of important working groups of the European Commission on climate change, environment and bioeconomy, such as the Bioeconomy Panel, the High-Level Panel on Decarbonization Pathways Initiative and, currently, the Mission Board on Soil Health and Food. She is also President of National Green Chemistry Technological Cluster SPRING (since 2014). She is the inventor of numerous patent families in the sector of biopolymers and renewable raw material transformation processes and was awarded "European Inventor of the Year 2007" by the European Patent Office and the European Commission for her inventions relating to starch-based bioplastics between 1991 and 2001.



The plasticization process

The plasticization process of starch involves transforming starch from its native granular form into a flexible and moldable material suitable for use in bioplastic production. This process typically follows these steps:

1. **Starch Extraction**: Starch is initially extracted from plant sources such as corn, potatoes, or cassava. This extraction involves grinding or milling the raw material to release the starch granules, followed by a separation process to isolate the starch from other components of the plant.
2. **Gelatinization**: The extracted starch is then subjected to gelatinization, a process in which starch granules are heated in the presence of water. During gelatinization, the starch granules absorb water and swell, causing them to lose their crystalline structure and become amorphous. This increases the viscosity of the starch-water mixture, forming a thick gel-like substance.
3. **Plasticizer Addition**: Plasticizers, which are typically small molecules such as glycerol or sorbitol, are added to the gelatinized starch to enhance its flexibility and processability. These plasticizers act as lubricants, reducing the intermolecular forces between starch molecules and allowing them to slide past each other more easily.
4. **Mixing and Homogenization**: The plasticizer-starch mixture is then thoroughly mixed and homogenized to ensure uniform distribution of the plasticizer within the starch matrix. This step is crucial for achieving consistent mechanical properties and performance in the final bioplastic product.
5. **Processing**: The plasticized starch can now be processed using various techniques such as extrusion, injection molding, or compression molding. During processing, the plasticized starch is heated and shaped into the desired form, such as films, sheets, or molded products.
6. **Cooling and Solidification**: Once shaped, the bioplastic undergoes cooling and solidification to set its structure and lock in its shape. This may involve cooling the material gradually to room temperature or employing rapid cooling methods, depending on the specific processing conditions and requirements.

Conclusions

Biodegradable bioplastics derived from starch offer a sustainable alternative to conventional plastics, addressing environmental concerns associated with plastic waste. These innovative materials are produced through the transformation of starch, a readily available carbohydrate found in plants such as corn, potatoes, and cassava.

Starch-based bioplastics are manufactured by extracting starch from plant sources and then processing it into a polymer matrix. This matrix can be further modified and enhanced with additives to improve its mechanical properties, such as strength, flexibility, and thermal stability. Biodegradable additives may also be incorporated to facilitate the breakdown of the material once it is discarded.

One of the key advantages of starch-based bioplastics is their ability to decompose naturally through microbial activity in soil, compost, or aquatic environments. Unlike traditional plastics, which can persist in the environment for hundreds of years, biodegradable bioplastics break down into harmless substances, reducing the burden of plastic pollution.

Moreover, the production of starch-based bioplastics typically requires less energy and generates fewer greenhouse gas emissions compared to petroleum-based plastics, contributing to lower carbon footprints and mitigating climate change.

In conclusion, biodegradable bioplastics obtained from starch represent a promising avenue for reducing plastic pollution and advancing towards a more sustainable future. By harnessing the renewable resources of plants and embracing eco-friendly manufacturing processes, these materials embody the principles of environmental stewardship and responsible innovation.

Resources :

- https://www.youtube.com/watch?v=H-RtDs2AZEQ
- https://www.youtube.com/watch?v=lIH_rOwRzd8
- https://www.novamont.com/mater-bi
- https://materbi.com/
- Aarsha Surendren, Amar K. Mohanty, Qiang Liu, Manjusri Misra, *A review of biodegradable thermoplastic starches, their blends and composites: recent developments and opportunities for single-use plastic packaging alternatives*, Green Chemistry **24** (22), 8606-8636, 2022. ISSN 1463-9262, https://doi.org/10.1039/d2gc02169b
- Catia Bastioli, Paolo Magistrali, Sebastià Gestí Garcia, *Starch-based technology*, Chapter 8, Handbook of Biodegradable Polymers, 2020, DOI: 10.1515/9781501511967-008

Reflection Questions (in bold the answer for each question)

1. What is the primary benefit of bioplastics over conventional plastics?

a. Cheaper production costs
b. **Faster decomposition rate**
c. Better durability
d. Higher strength

2.From which materials are bioplastics typically derived?

a. Petroleum
b. Metals
c. **Crops like corn and potatoes**
d. Synthetic chemicals

3. What process transforms starch into a flexible material for bioplastics?

a. Polymerization
b. Vulcanization
c. **Plasticization**
d. Hydrolysis

4.What is the role of plasticizers in the production of bioplastics?

a. To increase rigidity
b. **To make the starch more flexible and moldable**
c. To enhance color
d. To increase biodegradability

5.Which of the following is a key component of starch that makes it useful for bioplastics?

a. Cellulose
b. **Amylose**
c. Lignin
d. Hemicellulose

Lesson Plan Title: Understanding Starch-Based Bioplastics

Objective:
Students will understand the environmental impact of conventional plastics and the benefits of using bioplastics.
Students will learn the process of making starch-based bioplastics from corn and their applications.

Materials:
Copies of the article "*From Starch, the Revolution that will Save the Earth*"
Samples of traditional plastics and starch-based bioplastics
Video: "*How Biodegradable Plastics are Made*"

Laboratory equipment for the bioplastic experiment:
Corn starch
Glycerol
Distilled water
Hot plate
Mixing tools
Molds
Measuring cups
Hydrochloric acid
Sodium hydroxide
Litmus paper

Introduction (15 minutes):
Hook:
Show a short video or slideshow of plastic pollution around the world.
Discussion:
Ask students what they know about plastic pollution and its impact on the environment.
Presentation:
Introduce the concept of bioplastics and their importance, referring to the article.
Activity:
Making Bioplastic from Starch (50 minutes):
Reading Session (10 minutes):
Group Activity:
Have students read the article "From Starch, the Revolution that will Save the Earth" in small groups.
Each group discusses the key points of the article and prepares a short summary.

Experiment (50 minutes):
Materials Needed:

25 mL of distilled water
2.5 g of corn starch
2.5 g of glycerol
3 mL of 0.1 M HCl

3 mL of 0.1 M NaOH
Food colouring
Litmus paper
Beaker
Hot plate
Mixing tools
Molds for shaping the bioplastic

Procedure:
Preparing the Bioplastic Mixture.
Place in a beaker with capacity: 100 mL
2.5 g of corn starch;
2.5 g of glycerine;
25 mL of water;
Mix with a glass rod until a homogeneous opaque milky mixture is obtained.
Then add 3 ml of 0.1 M HCl hydrochloric acid and heat the mixture on the heating plate for a few minutes, stirring continuously.
During heating the mixture becomes more compact and transparent, it forms like a gel that has to cool for a few minutes and then, add 3 mL of sodium hydroxide solution NaOH 0.1 M.
Check the neutralization reaction of the mixture (pH=7) by using a piece of litmus paper.
At this point put the food coloring and mix it carefully to even out the color.
Shaping the Bioplastic:
The final mixture will be poured into a suitable container, for example a Petri dish and will be left out to dry at room temperature for a few days or pour the thickened mixture into the desired shape using molds and allow it to cool and solidify completely.

Observation:
Compare the properties of the homemade bioplastic with conventional plastic samples.
The same methodology is used for the preparation of the bioplastic WITHOUT glycerol and is good to make a comparison between the properties of the film obtained "with" and "without" glycerol.
Obviously it is relevant to make the comparison in order to show the plasticizing function of the reagent; the glycerol.
Once dried, bioplastic films can be gently removed from the container used:
The material obtained using glycerol as a reagent is elastic and deformable, that is our bioplastic, while in the second case the material is rigid and fragile, crumbles and if subjected to further deformation, it breaks.

Discussion (15 minutes):
Group Presentations:
Each group presents their summary of the article and their observations from the experiment.
Address any questions students have about the process and the benefits of bioplastics.