Production and development of compostable PHBV-based films for sustainable food packaging

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Production and development of compostable PHBV-based films for sustainable food packaging

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BIOPHA-COMFPACK

University of Zagreb
Faculty of Chemical
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PTF

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ROTOPLAST

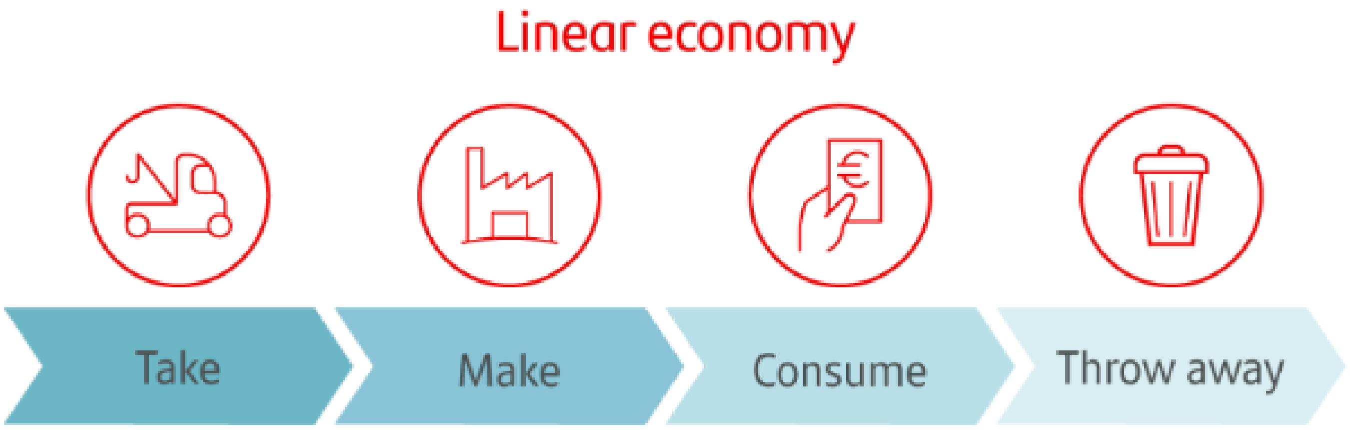
Financira
Europska unija
NextGenerationEU

This research was carried out within the framework of the project "*Production and development of compostable packaging from waste biomass for packaging industrially processed food products*" (NPOO.C3.2.R3-Il.04.0059), funded under the National Recovery and Resilience Plan (funded by the European Union, NextGenerationEU).

Challenges/Content

- Linear economy
- Circular economy
- Plastic/Plastic waste
- Biodegradable plastic materials
- Our research realting to PHA/TPS blends
- Conclusions

Linear economy

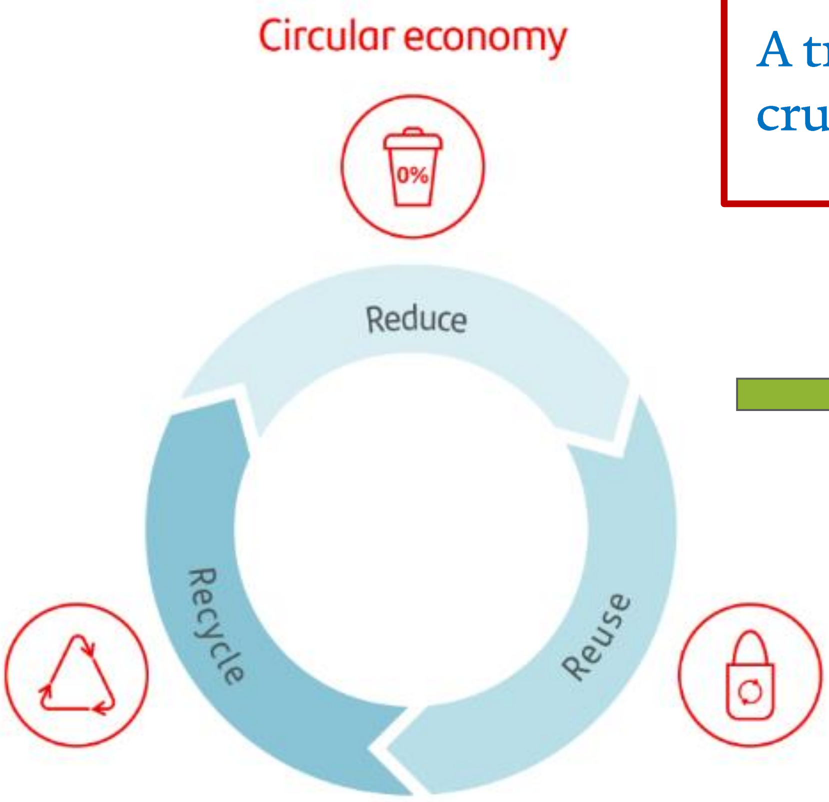


→ PROFITABILITY

Consequences of linear economy

- Polluting system that degrades natural systems
- Is the driver of global challenges (climate change)
- Biodiversity loss

Circular economy



A transition to a circular economy – crucial – progress into the future

→ SUSTAINABILITY

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Plastics

- REVOLUTIONARY MATERIALS – **POLYMERS**
- LAST FOREVER

- their **non-degradability** causes a growing problem of environmental pollution
- increase interest in producing **environmentally friendly materials**

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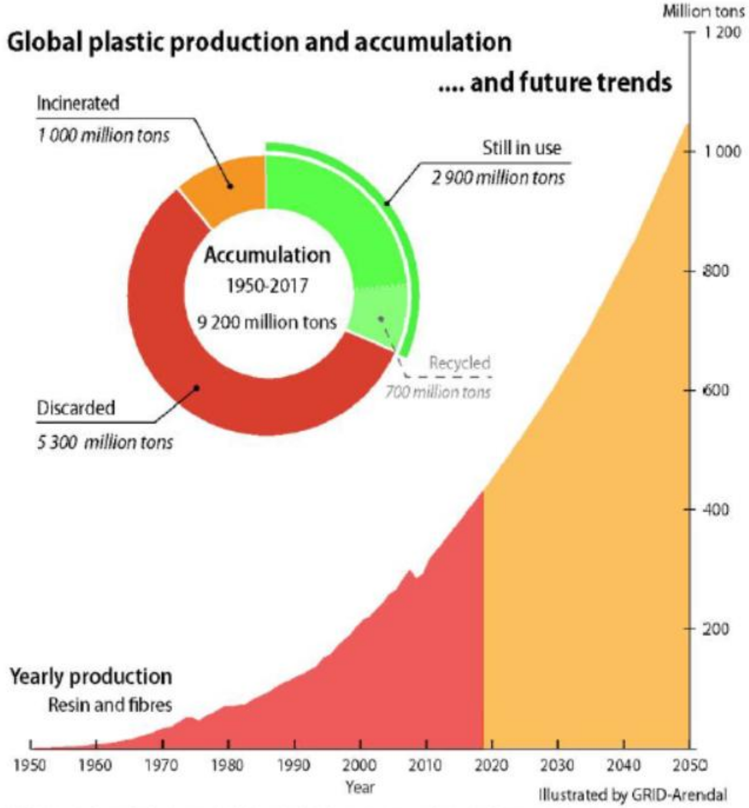
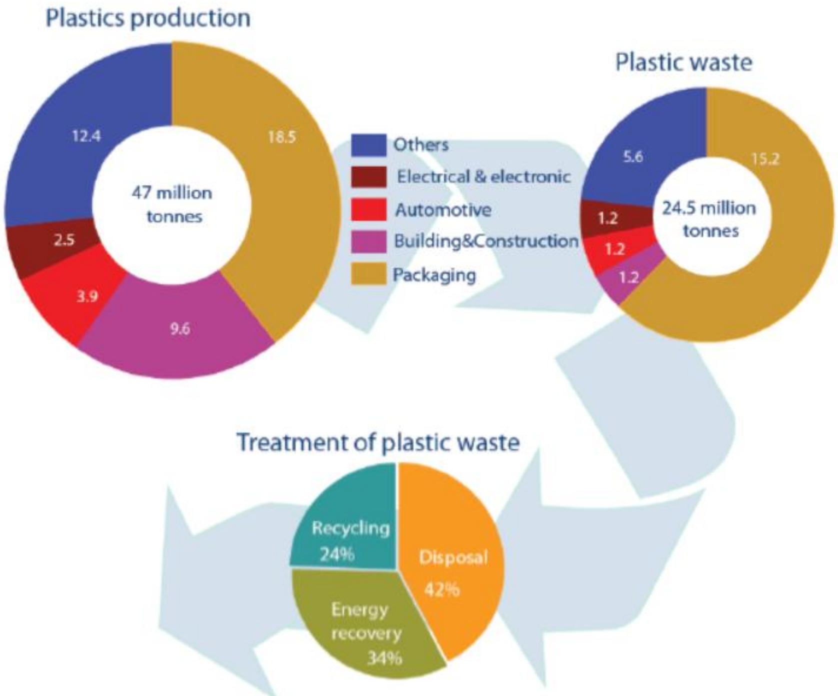
Production of plastics



UNEP (2021). From Pollution to Solution: A global assessment of marine litter and plastic pollution. Nairobi.



- The global production of plastic materials increased tremendously; from ~1.5millions tons in 1950 up to 500 millions tons in 2025
- Projections: in 2050; plastic production will double compare to 2020

Circular economy of plastic

To create a circular economy for plastic we must take three actions:

- **Eliminate**

  Eliminate all problematic and unnecessary plastic items

- **Innovate**

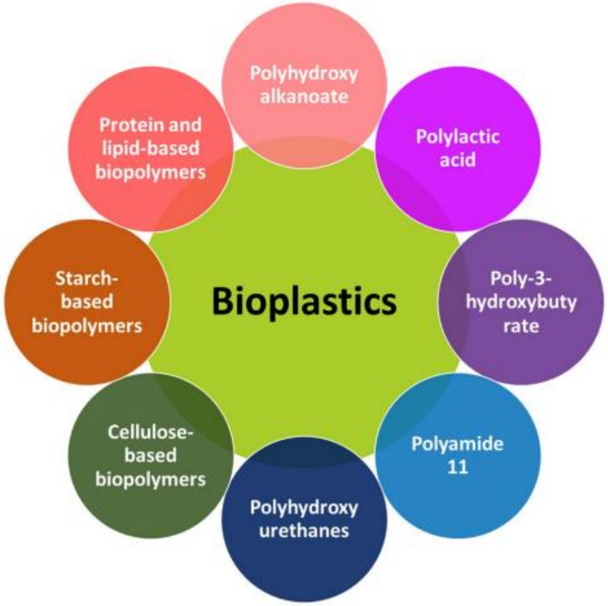
  Innovate to ensure that the plastics we do need are **reusable,** recyclable, and biodegradable

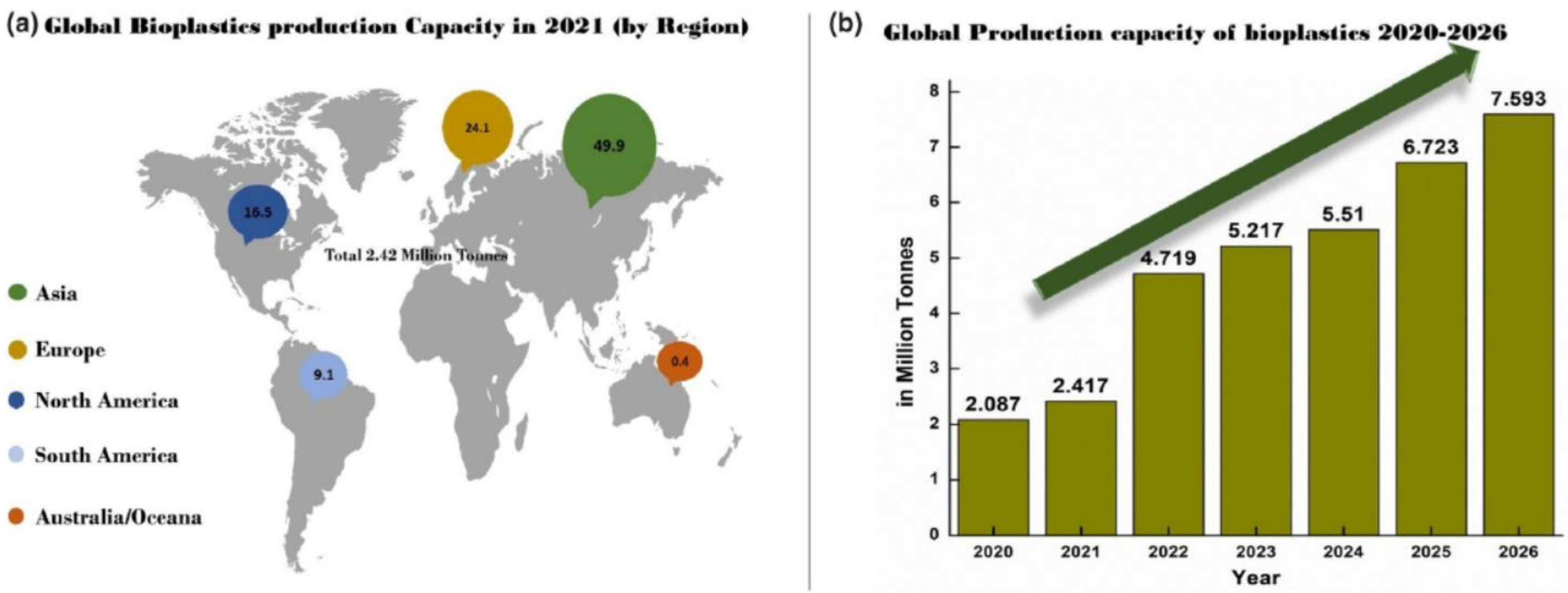
- **Circulate**

  Circulate all the plastic items we use to keep them in the economy and **out of the environment**

Biodegradable plastic

- plastic that decompose naturally in the environment
- decompose into natural compounds such as water, carbon dioxide, methane and other decomposition products consumed microorganisms
- derived from natural sources, e.g. corn and sugar
- less harmful to the environment then traditional plastics





Dynamic rise in production of bioplastics from 2020 to 2026.

(a) Global bioplastic production in 2021 by region,

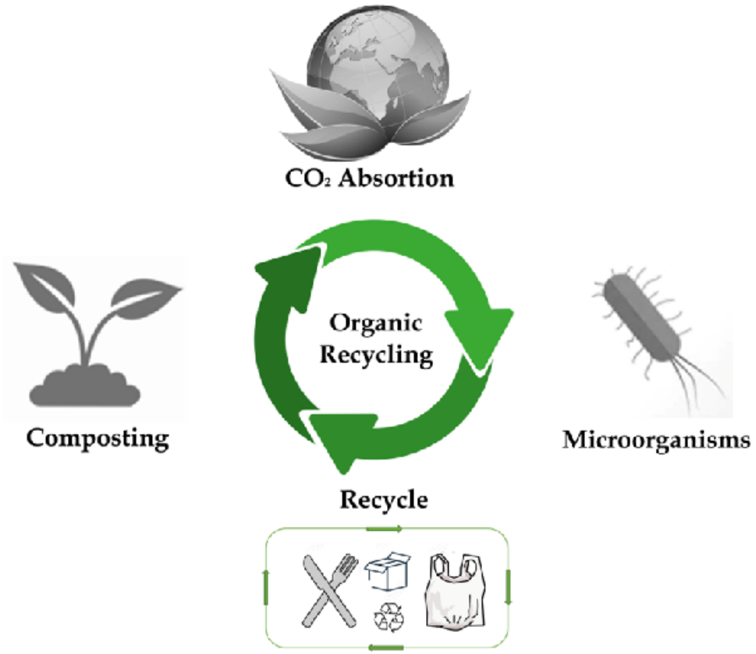
(b) global production capacity of bioplastics 2020–2026

 (redrawn from data;accessd the website “European Bioplastics”)

Polyhydroxyalkanoates (PHAs)

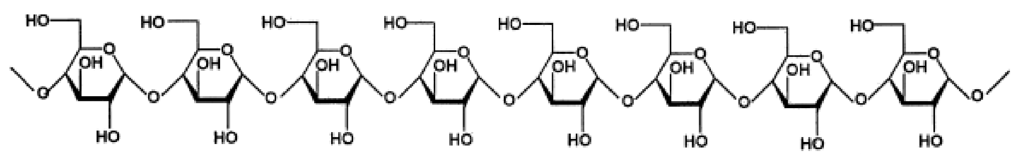
- Linear isotactic biodegradable polyesters that can be obtained from natural resources
- Biopolymer obtained through microbial fermentation
- Biodegradable, compostable
- Inherent biodegradability in natural environments,
- Good barrier properties

- Challenges in PHA Film Development
  - Narrow processing window
  - Brittleness and fragility
  - **Higher production costs**
  - Need for modification or blends

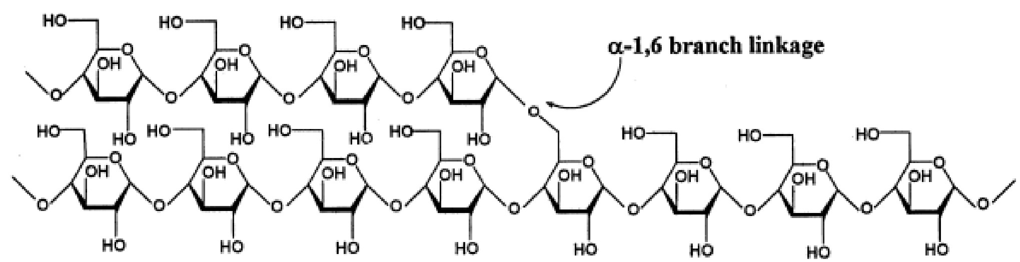


Starch

- A **completely biodegradable** polysaccharide
- On of the **most abundant renewable resources** known to man
- Produce by all **green plants** as an energy store (potatoes, wheat, corn, rice)
- Compose of linear **amylose** and highly branched **amylopectin**
- Native starch is **not a thermoplastic material**
- Temperature melting close to temperature degradation – modification of starch – **PLASTIFICATION -TPS**

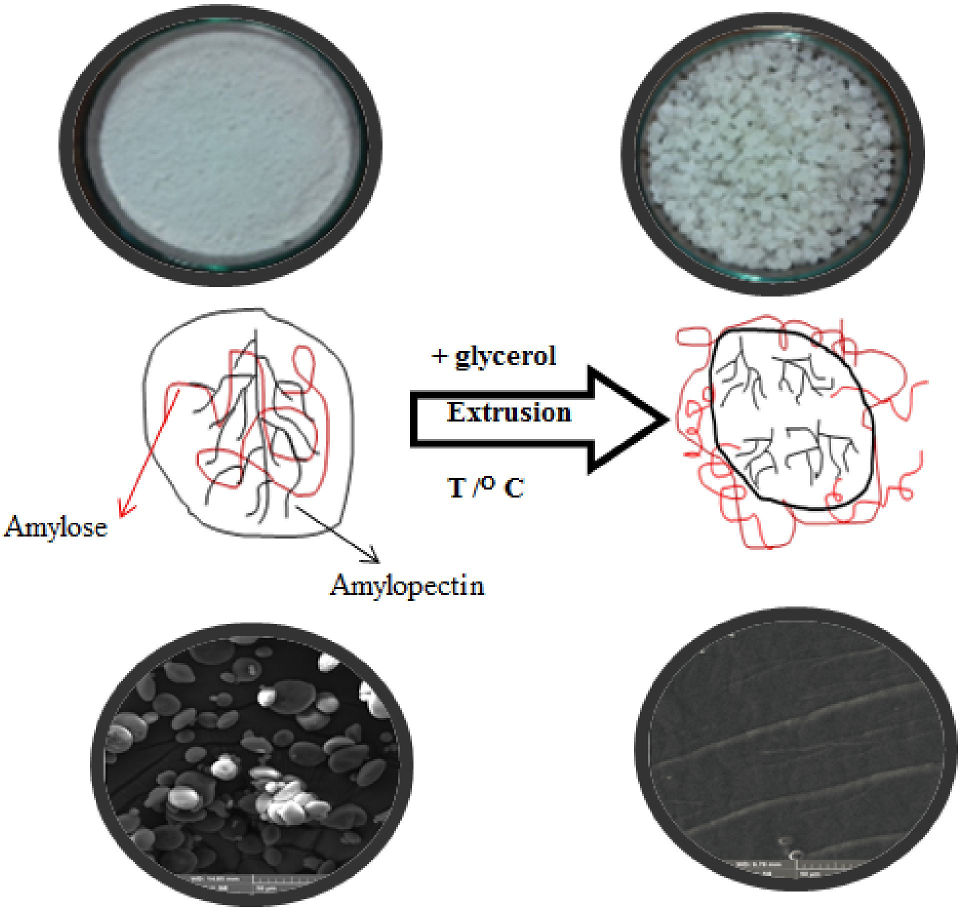


Segment of an amylose molecule



Segment of an amylopectin molecule, showing one α-1,6 branch linkage

Thermoplastic starch



Plastification process of starch

- addition of plasticizer under high pressure and mechanical shear force
- destroy the crystalline structure and hydrogen bonding with starch
- plasticizers get in between the polymer chain and act as lubricants increasing flexibility and movement
- plasticizers decrease the glass and melt temperature of the polymer, leading to more processability of starch

Thermoplastic starch

Disadvantages

- Highly hydrophilic
- Poor mechanical and thermal properties
- Stability - strongly affected by moisture
- Difficult processing

Polymer blends

Obtain materials with the required properties

- enhance the biodegradability, and low cost production
- improve the poor mechanical and thermal properties of TPS
- biodegradable and sustainable plastics with a wide range of desirable properties

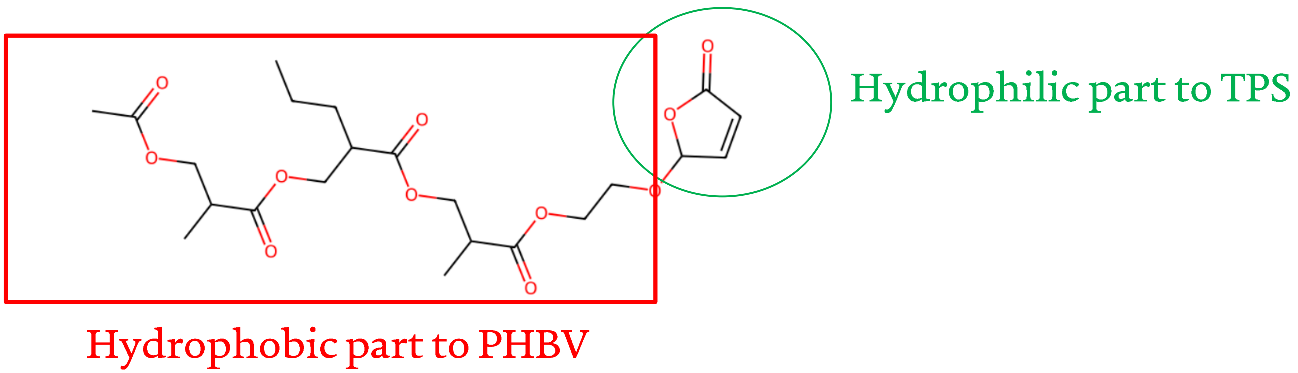
Advantage: Cheap; Tuning properties easily; High property/cost performances

Disadvantage: Immiscibility; Coarse phase morphology

AIM of this study

- Poly(3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV) – EXPENSIVE, HIGH CRYSTALLINITY, HYDROPHOBIC CHARACTER, BIODEGRADES SLOWLY
- Thermoplastic starch (TPS) – LOW COST, HIGHLY HYDROPHILIC
- Compatibilizers (e.g., reactive agents, grafted polymers) – phase compatibility improvement of PHBV/TPS blends

PHBV-g-MA



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Materials

- Wheat varieties "Srpanjka" (harvest 2008) were obtained from Agricultural Institute, Osijek, Croatia. The content of amylose in isolated **wheat starch** ~22.49 ± 2.01 wt %
- Glycerol - supplied by Gram Mol (Zagreb, Croatia); 40 wt. % - **TPS**
- Poly(3-hydroxybutyrate-co-3-hydroxyvalerate) , **PHBV**, ENMAT™ Y1000P, density 1,25 g/cm^3; T_m=165°C; supplied by TianAn Biologic Materials Co., Ltd.
- PHBV-g-MA was synthesized by reactive melt grafting of maleic anhydride onto PHBV using a radical initiator (dicumyl peroxide (DCP)

Prepration of the polymer blends

Thermoplastic starch, TPS

- 40 wt % glycerol; laboratory single-screw extruder (Model 19/20DN; Brabender GmbH, Germany; zone 100/100/130°C; screw speed 40 rpm; dosing speed 15 rpm)

PHBV/TPS blends with and without compatibilzer (PHBV-g-MA; 3 wt.%)

- TPS 10-50 wt. %
- Brabender kneading chamber (170 °C; rotor speed 60 rpm, kneaded for 9 min)
- laboratory hydraulic press Fontune, Holland (SRB 140, EC 320x320NB)

  (150 °C; 25 bar, 6 min)

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CHARACTERIZATION METHODS

MORPHOLOGICAL STRUCTURE

- FTIR-ATR Fourier transform infrared spectroscopy
- SEM Scanning electron microscopy
- LM Light microscopy

THERMAL PROPRETIES

- TGA Thermogravimetric analysis
- DSC Differencial scaning calorimetry

BARIERE PROPERTIES

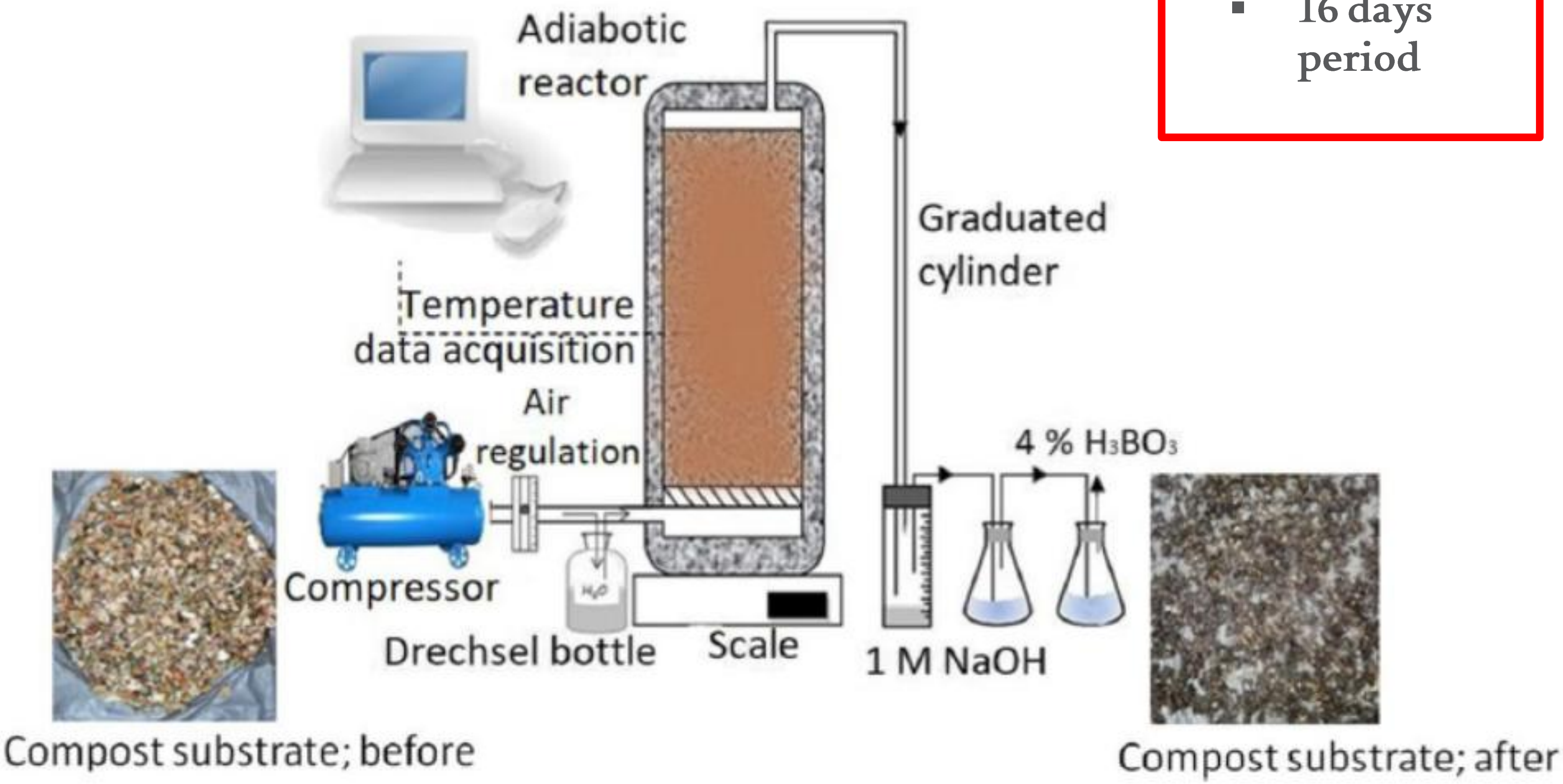
- Water vapor permeability

MECHANICAL PROPERTIES

- Tensile strenght
- Elongation at break
- Youngs modulus

Biodegradability during composting process

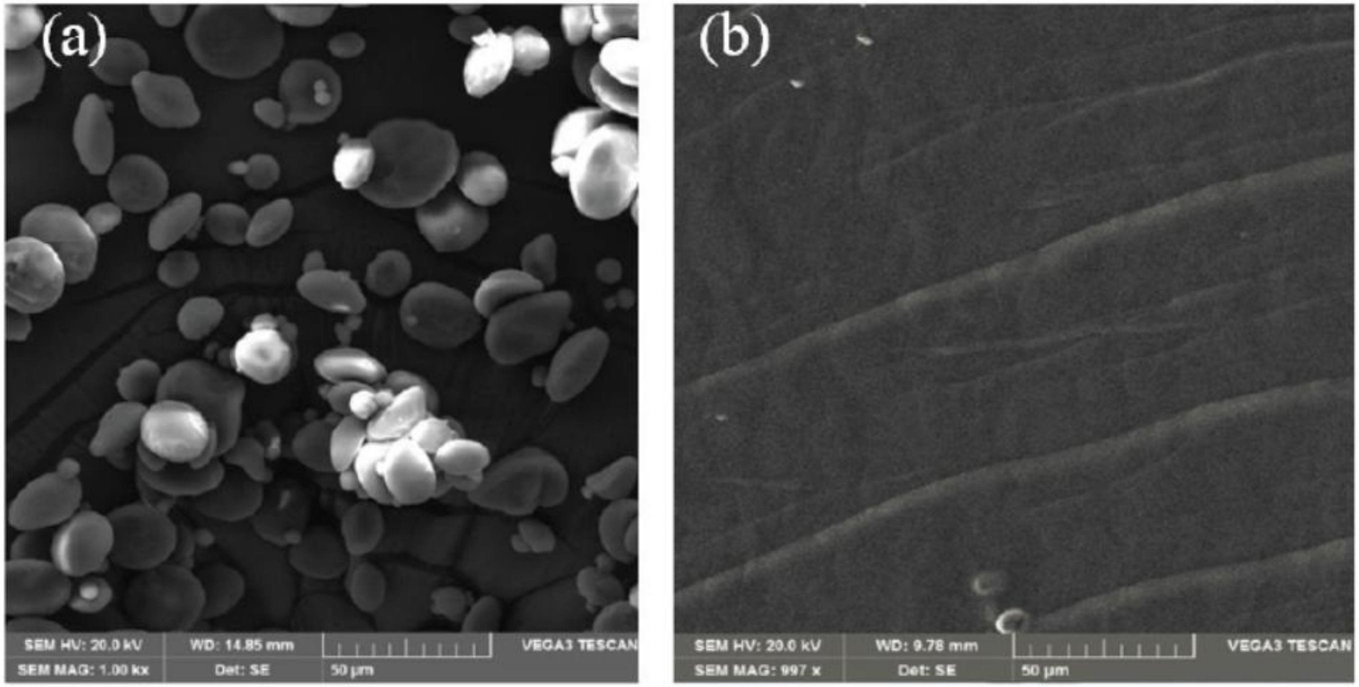
- 16 days period



Schematic diagram of composting process

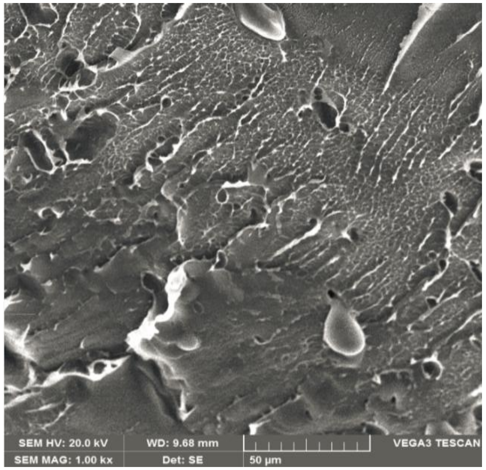
RESULTS AND DISCUSSION

Morphological structure

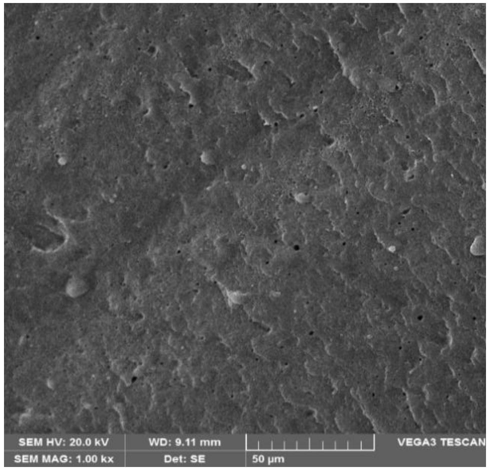


SEM micrographs of (a) native wheat starch, (b) TPS,

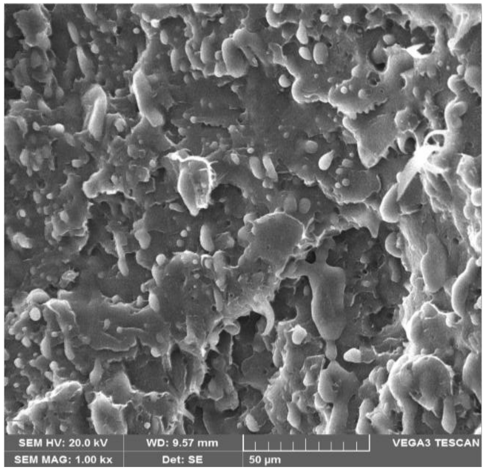
Morphological structure



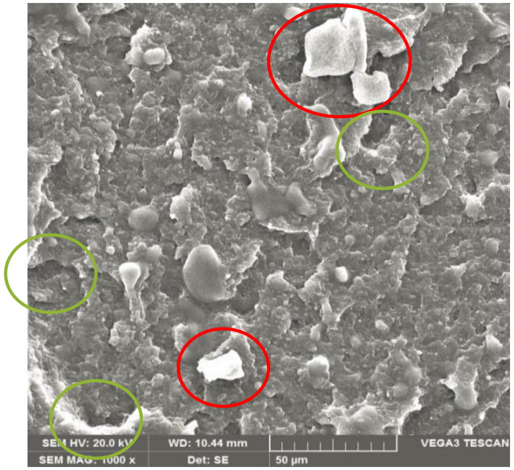
PHBV_TPS30



PHBV_TPS30_PHBV-g-MA



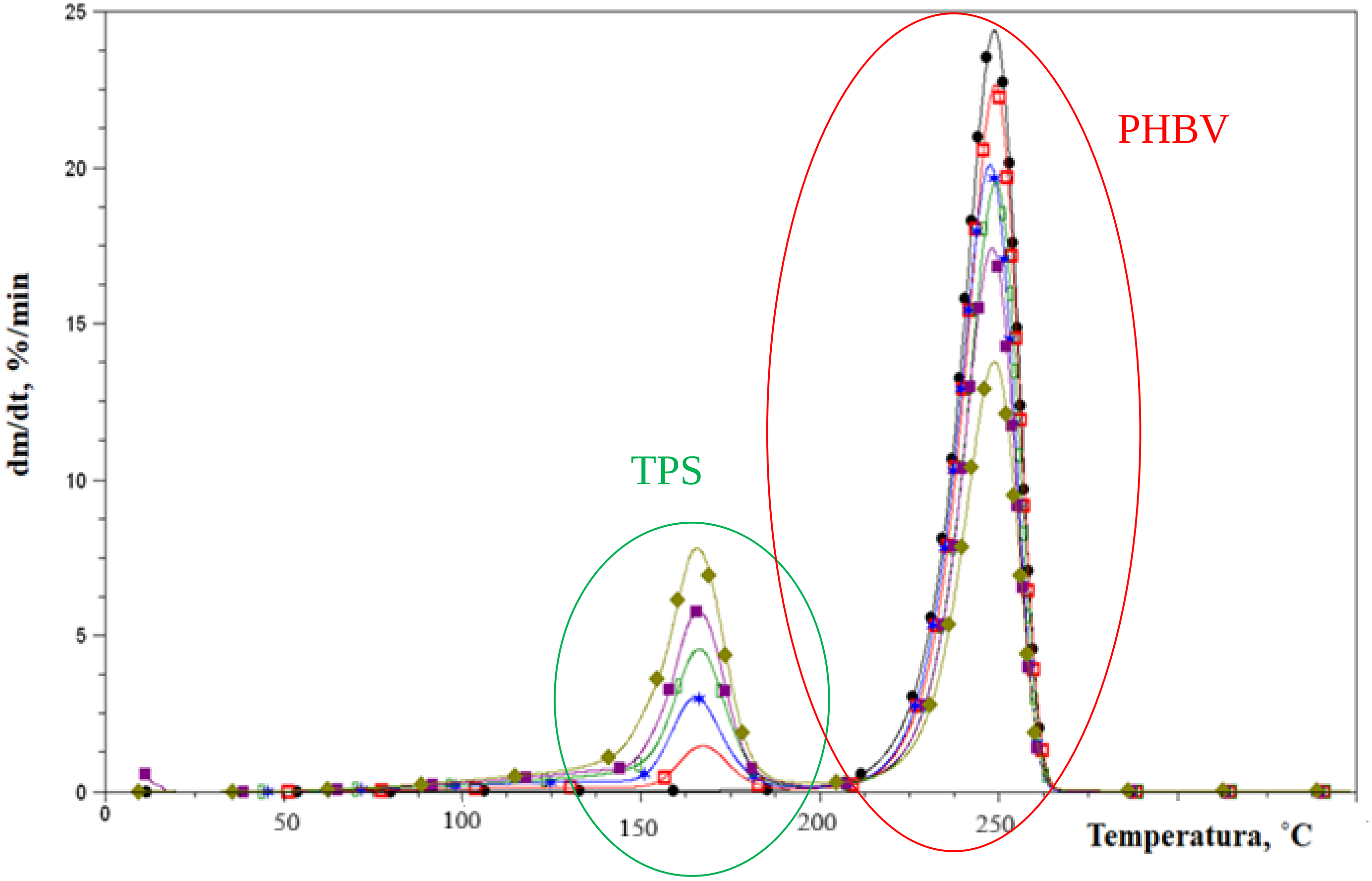
PHBV_TPS50



PHBV_TPS50_PHBV-g-MA

SEM microphotographs

▪ Thermogravimetric analysis



DTG curve of PHBV_TPS blends with compatibilizer

▪ Thermogravimetric analysis

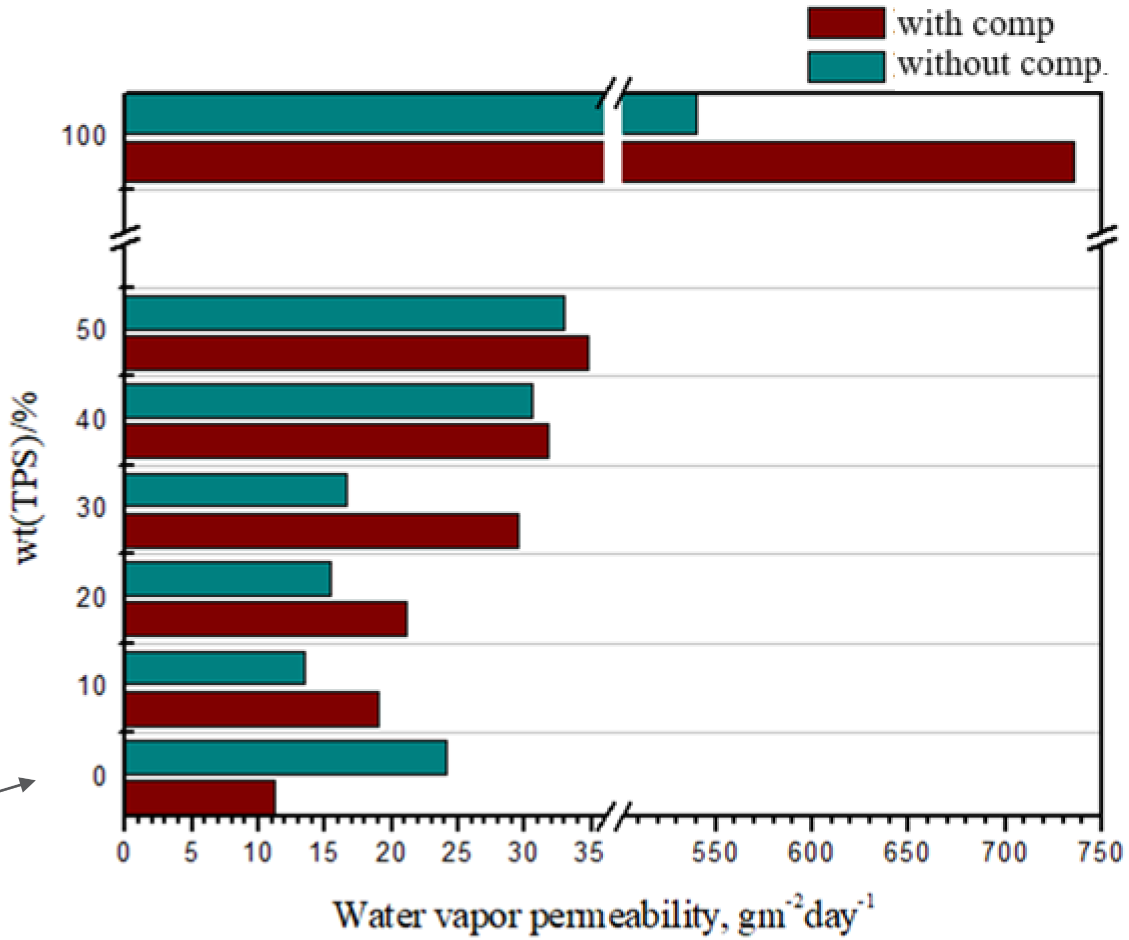
TG/DTG analysis

Sample	$T_{ons.}$/°C	T_1^{max}/°C	Δm_1/%	T_2^{max}/°C	Δm_2/%	T_{end}/°C	$R_{500°C}$/%
PHBV	230,05	234,66	100,00	/	/	295,26	0
PHBV_TPS10	205,65	217,14	9,09	179,86	88,20	291,23	1,03
PHBV_TPS20	200,95	207,04	18,58	174,21	82,82	287,94	0,91
PHBV_TPS30	209,60	209,97	28,48	172,80	69,14	284,86	1,49
PHBV_TPS40	200,90	207,99	36,88	171,91	60,94	284,12	2,03
PHBV_TPS50	202,52	208,78	47,88	170,72	50,26	283,52	3,31

Sample	$T_{ons.}$/°C	T_1^{max}/°C	Δm_1/%	T_2^{max}/°C	Δm_2/%	T_{end}/°C	$R_{500°C}$/%
PHBV_PHBV-g-MA	215,07	247,63	100,00	/	/	362,82	0
PHBV_TPS10_PHBV-g-MA	228,70	254,27	9,56	197,66	88,87	317,19	3,71
PHBV_TPS20_PHBV-g-MA	234,17	250,23	18,00	195,11	79,49	315,45	3,12
PHBV_TPS30_PHBV-g-MA	225,46	252,18	27,68	198,05	68,49	313,50	1,36
PHBV_TPS40_PHBV-g-MA	228,50	251,81	35,53	196,19	59,31	310,66	1,92
PPHBV_TPS50_PHBV-g-MA	223,94	251,06	49,44	197,44	51,73	311,75	3,18

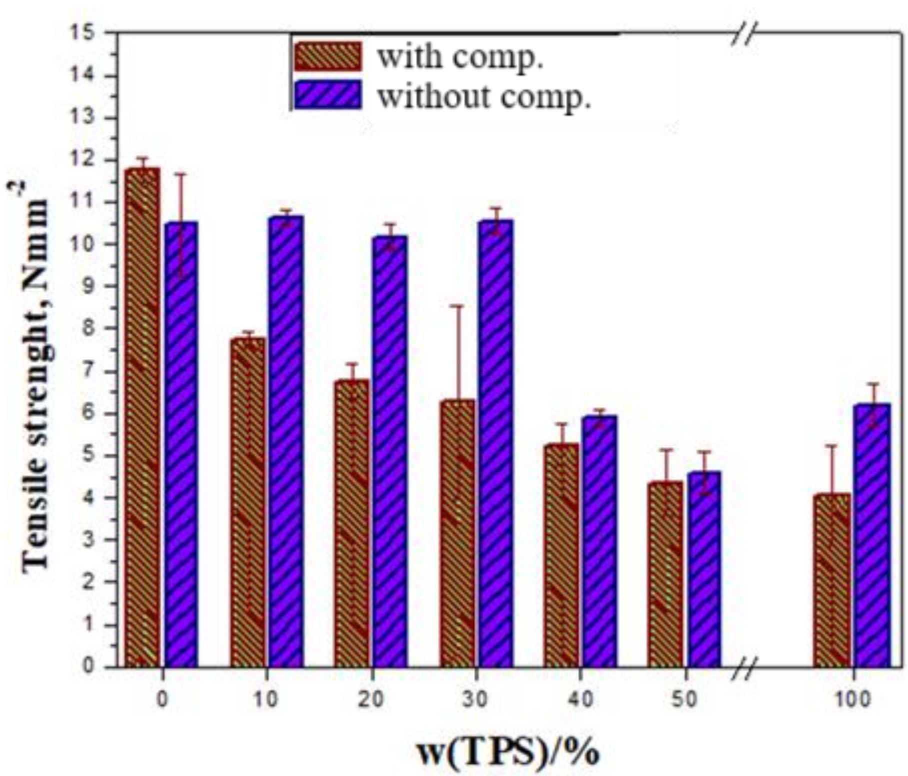
Water vapor permeability

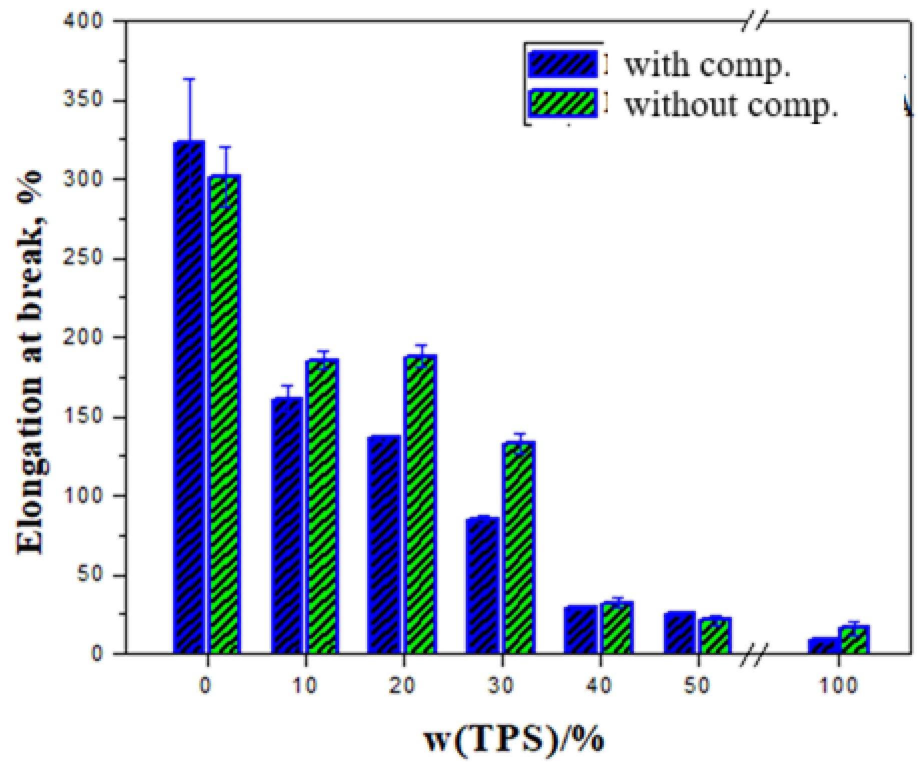
TPS



PHBV

Mechanical properties





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Biodegradability by composting process

The change of mass PPHBV7TPS blends during biodegradation test under composting conditions

Composition	Mass (before degradation) (g)	Mass (after degradation) (g)	Mass loss (%)
PHBV	0.1201	0.1201	0.00
PHBV_TPS10	0.1850	0.1849	0.05
PHBV_TPS20	0.0926	0.0914	1.29
PHBV_TPS30	0.1114	0.1097	1.53
PHBV_TPS40	0.1049	0.0971	7.44
PHBV_TPS50	0.0876	0.0758	13.47

The change of mass PHBVTPS/PHBV-g-MA blends during biodegradation test under composting conditions

Composition	Mass (before degradation) (g)	Mass (after degradation) (g)	Mass loss (%)
PHBV_PHBV-g-MA	0.1110	0.1110	0.00
PHBV_TPS10-PHBV-g-MA	0.1080	0.1080	0.00
PHBV_TPS20-PHBV-g-MA	0.1095	0.1082	1.19
PHBV_TPS30-PHBV-g-MA	0.0808	0.0787	2.61
PHBV_TPS40_PHBV-g-MA	0.1117	0.1053	5.73
PHBV_TPS50_PHBV-g-MA	0.1038	0.0937	9.7

CONCLUSIONS

- A good dispersion was achieved for low TPS contents (< 30 wt %), but agglomeration of the starch particles occurred in the presence of high amounts of TPS (>30 wt %)
- In the presence of PHBV-g-MA, the PHBV/TPS blends have better thermal stability, mechanical and barrier properties (TPS < 30 wt %)
- This research highlights the importance of biodegradable materials based on PHBV and thermoplastic starch (TPS). While PHBV offers excellent mechanical and barrier properties, TPS not only reduces cost but also accelerates biodegradation, creating a new generation of materials that are both high-performing and more environmentally friendly
- It is important to note that the use of PHBV/ TPS blends is essential in reducing the environmental impact caused by the indiscriminate use of conventional plastic in food packaging
- The main challenge with these materials is achieving the right balance between fast biodegradability, barrier properties, and mechanical performance, all while keeping costs reasonable. For certain PHBV/TPS blends, we were able to confirm this balanced performance.
- However, there are still many disadvantages of such blends and further studies are needed before using such blends as an active food packaging


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Projekt „Proizvodnja i razvoj kompostabilne ambalaže iz otpadne biomase za pakiranje industrijski prerađenih prehrambenih proizvoda" se sufinanciran iz Nacionalnog plana oporavka i otpornosti, sredstvima Europske unije – NextGenerationEU kroz poziv Podrška transferu tehnologije (NPOO.C3.2.R3-II.04.0059).
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https://bio-pha-com-f-pack.eu/

Link to our project!

Thanks for your attention !