Biomethane potential in anaerobic biodegradation of commercial bioplastic materials

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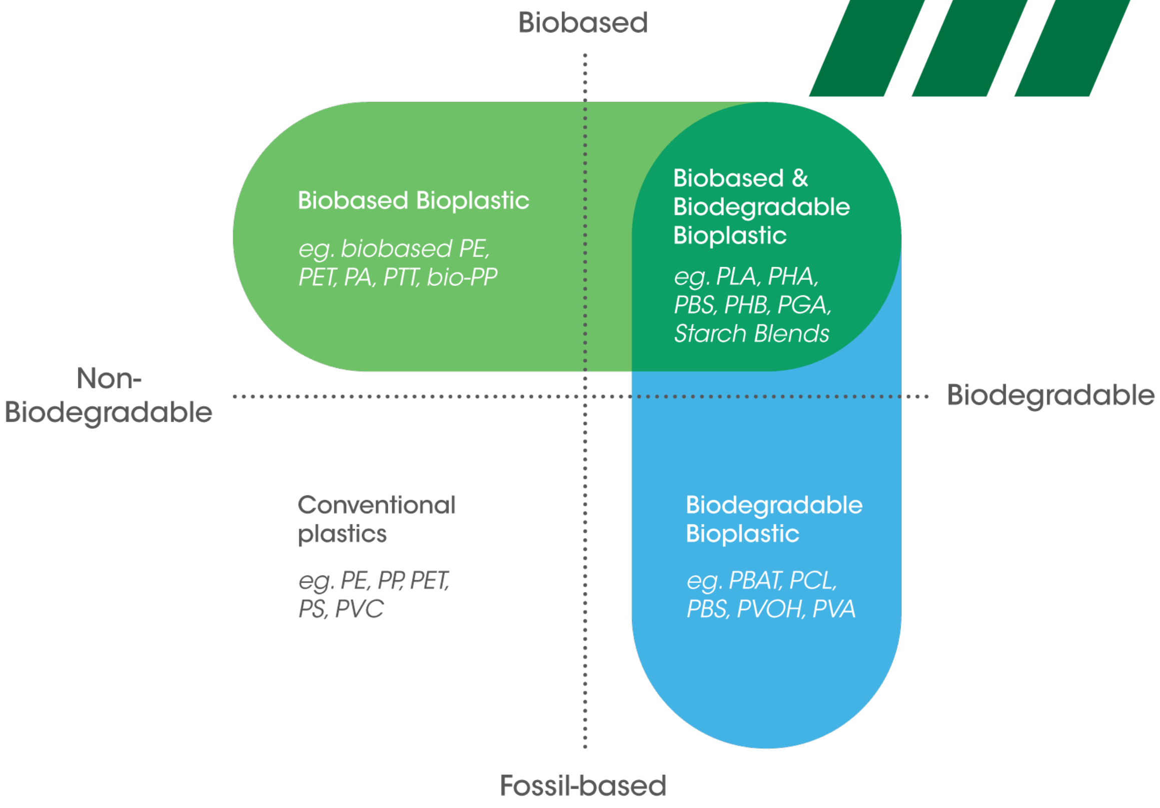
A kutatás a Technológiai és Ipari Minisztérium „A körforgásos gazdaságra történő átállás előkészítési feladatai a mezőgazdasági és zöldhulladékok esetében" című, KEHOP-3.2.1-15-2021-00037 azonosítószámú Környezet és Energiahatékonysági Operatív Program támogatásával valósult meg.

Introduction

- Every year, approximately 300 million tons of plastic waste is generated globally.
- The extensive production and disposal of conventional plastics have raised environmental concerns.
- Bioplastics have emerged as a promising alternative, offering sustainability and efficient waste management.
- End-of-life options: aerobic (composting) and anaerobic (anaerobic digestion)-Biomethane as end-product.
- BMP testing is vital for optimizing anaerobic digestion processes, such as temperature and organic loading rate, to enhance methane production.



SOURCE:

Aims & Objectives

- Assess Chemical Composition: Examine how the chemical composition of commercially available biodegradable plastics affects their behavior under mesophilic conditions.

- Evaluate the Impact of Additives: Determine how various additives influence the biodegradability of these plastics when subjected to anaerobic digestion (AD) conditions.

- Measure Methane Potential (BMP): Quantify the BMP of different biodegradable plastics to understand the rate and extent to which they can generate methane during the anaerobic digestion process.

- By achieving these objectives, the study aims to enhance our understanding of how different biodegradable plastics and their chemical compositions, along with additives, can contribute to the production of methane within anaerobic digestion processes, thus promoting more sustainable waste management practices.

Materials and Methods

- 8 different catering biodegradable polymers
- Certified as biodegradable under industrial composting conditions (EN 13432)
- Black-box samples (names and chemical composition not disclosed)

Inoculum

- Mesophilic inoculum sourced from an operating plant in Hungary, dealing with agricultural materials and industrial food by-products.

Chemical Analysis

- Analysis included elemental analysis, Fourier transform infrared spectroscopy (FT-IR), and inductively coupled plasma - optical emission spectrometry (ICP-OES).

Materials and Methods

Rate of Biodegradation

- Theoretical methane production estimated using Boyle's equation.
- BMP tests conducted in Automatic Methane Potential Test System II instrument

Statistical analysis

- Performed using R Statistical program, involving general linear models and post hoc Tukey's HSD tests to assess significant differences between groups.

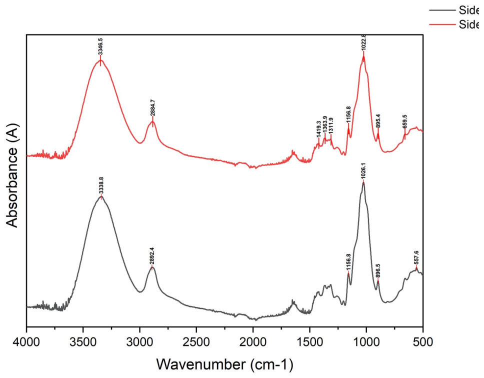
Measured physicochemical parameters

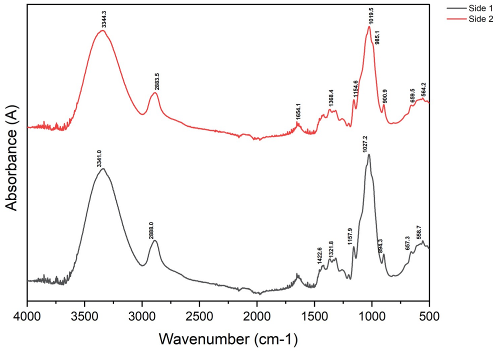
Parameter measured	*Description*	*Test method*
TS	Total solids	Mass measurement, MSZ EN 13040:2008 [32]
VS	Volatile solids	Standard measurement for examination of water and wastewater (APHA,2005) [33]
OM	Organic matter	Loss on ignition (MSZ EN 15935:2013) [34].
pH	Acidity	Potentiometric determination of H^+ ion concentration, MSZ EN 13037:2012 [35]
CHNS	Carbon (C), hydrogen (H), nitrogen (N), and sulfur (S) content	Elemental analysis to measure the conversion of carbon (C) to methane (CH_4) (biodegradability%) MSZ EN ISO 16948:2015 [36] MSZ EN ISO 16994:2017 [37]
Ca	Calcium [HNO_3/H_2O_2]	Inductively coupled plasma optical emission spectrometry (ICP-OES) MSZ 21470-50:2006 [38]
Mg	*Magnesium* [HNO_3/H_2O_2]	Inductively coupled plasma optical emission spectrometry (ICP-OES) MSZ 21470-50:2006 [38]

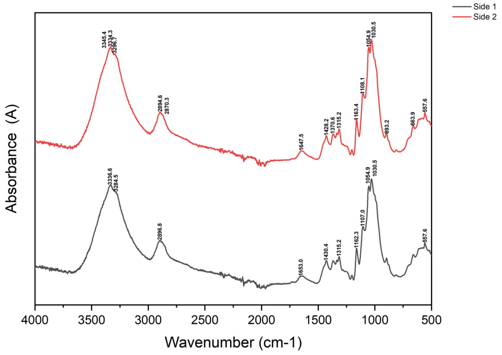
Results

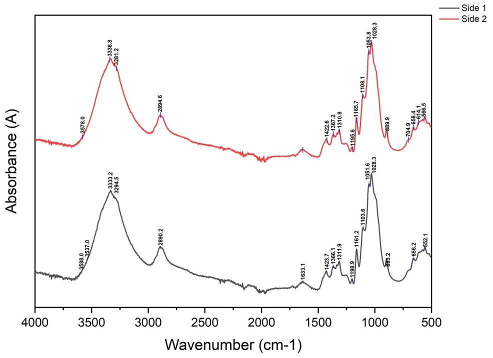
Chemical Composition revealed

Plastics	*Chemical composition* ^{a}	*TS* ^{a,b} (% wm)	*VS* ^{a,b}	*OM* ^{a,b}	*pH*
Product 1	*Cellulose or derivative(s)*	*92.81±0.23* ^{AB*}	*92.01±0.22* ^{A}	*99.14±0.20* ^{A}	*7.3*
Product 2	*Cellulose or derivative(s) with* $CaCO_3$	*93.30±0.22* ^{A}	*88.32±0.22* ^{B}	*64.66±0.18* ^{B}	*7.2*
Product 3	*Cellulose or derivative(s) with* $CaCO_3$	*95.15±0.28* ^{C}	*73.86±0.22* ^{C}	*77.63±0.20* ^{C}	*7.0*
Product 4	*A blend of PLA and PBAT*	*99.16±0.23* ^{D}	*99.14±0.17* ^{D}	*99.98±0.19* ^{D}	*6.9*
Product 5	*The outer side contains cellulose or derivatives(s) and* $CaCO_3$*, the inner side is a blend of PLA and PBAT*	*95.92±0.13* ^{E}	*95.74±0.26* ^{E}	*99.82±0.25* ^{D}	*7.2*
Product 6	*Cellulose or derivative(s) with* $CaCO_3$	*94.45±0.22* ^{F}	*64.57±0.25* ^{F}	*68.37±0.26* ^{E}	*7.0*
Product 7	*Cellulose or derivative(s) with* $CaCO_3$ *and, kaolinite*	*92.54±0.19* ^{B}	*89.01±0.23* ^{G}	*96.19±0.15* ^{F}	*7.3*
Product 8	*Pure PLA*	*85.00±0.26* ^{G}	*82.73±0.20* ^{H}	*97.33±0.20* ^{G}	*6.8*
Inoculum	*Mesophilic inoculum*	*5.87±0.24*	*4.73±0.39*	*80.5±8.1*	*7.9*

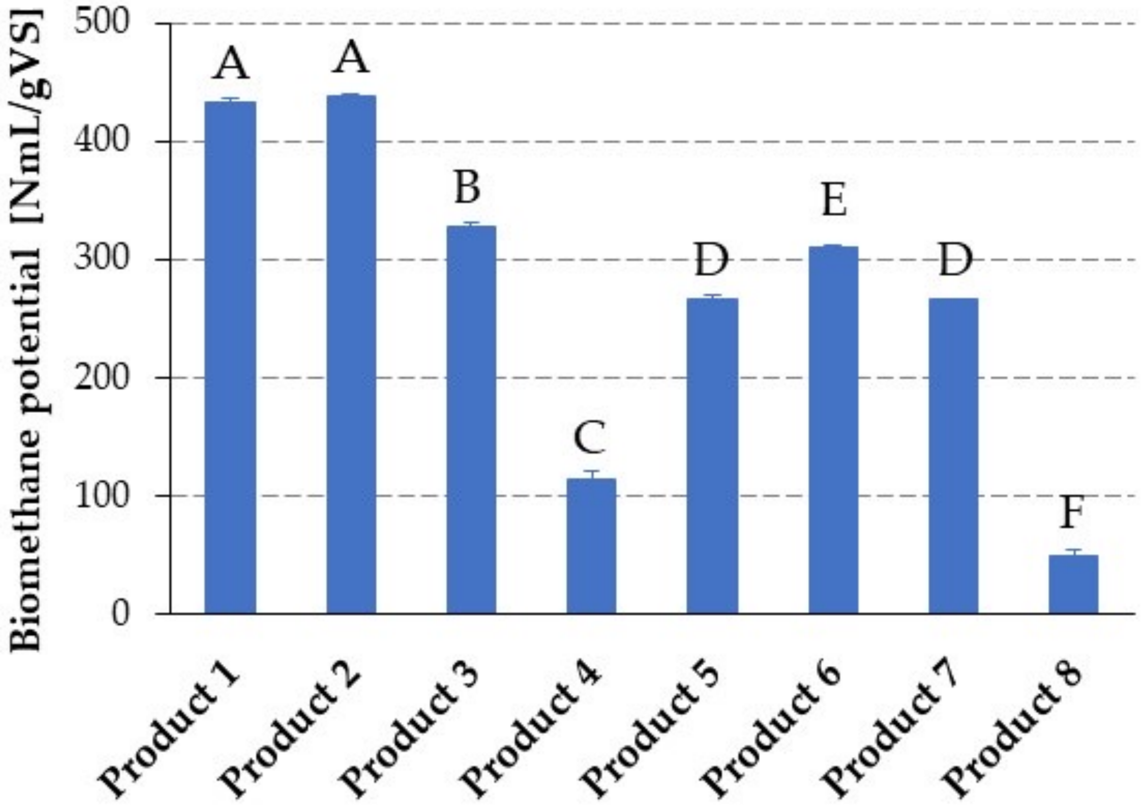






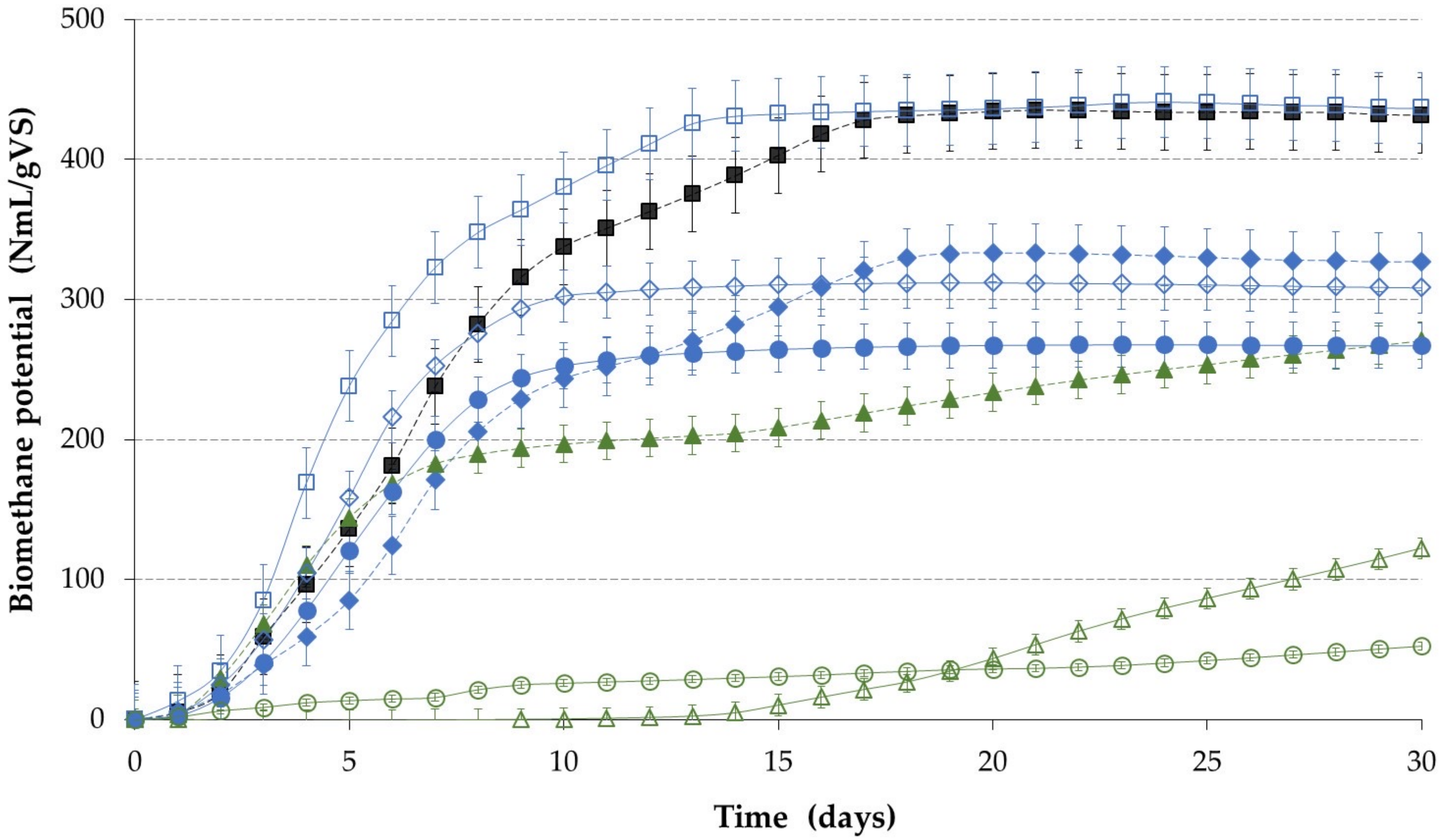


Results_ Biomethane potential (BMP) test



Average biomethane potential of the biodegradable plastics used in the study on the 30th day of the experiment. Different letters indicate significant differences between the investigated products ($p < 0.05$).

Results – BMP curves



Assessment of the biomethane potential of the eight biodegradable plastics (Products 1 to 8) used in the study on the basis of methane (CH_4) development under anaerobic digestion conditions. Product 1 (■, black dashed line), Product 2 (□, blue solid line), Product 3 (♦, blue dashed line), Product 4 (△, green solid line), Product 5 (▲, green dashed line), Product 6 (◊, blue solid line), Product 7 (●, blue solid line), Product 8 (O, green solid line),

Results – Statistical Evaluation

Gradiation values of the initial phase of BMP curves based on the results of linear regression

Plastic	Slope	Y intercept	R^2	p value
Product 1	9.51	-1.46	0.920	<0.001
Product 2	9.10	-1.16	0.936	<0.001
Product 3	17.4	-8.86	0.956	<0.001
Product 4	0.907	0.114	0.964	<0.001
Product 5	30.7	-17.8	0.950	<0.001
Product 6	32.4	-22.4	0.915	<0.001
Product 7	24.4	-18.0	0.899	<0.001
Product 8	2.61	-1.65	0.908	<0.001

Data of polynomial regression tests accomplished on the BMP curves. Values in bold indicate the best fitting model.

Plastic	*Order 1*			*Order 2*			*Order 3*		
	p value	*R^2*	*AIC*	*p value*	*R^2*	*AIC*	*p value*	*R^2*	*AIC*
Product 1	*<0.001*	*0.917*	*974.5*	*<0.001*	*0.920*	*971.9*	***<0.001***	***0.924***	***967.4***
Product 2	*<0.001*	*0.932*	*937.7*	***<0.001***	***0.973***	***854.7***	*<0.001*	*0.972*	*856.5*
Product 3	*<0.001*	*0.975*	*805.5*	*<0.001*	*0.976*	*805.1*	***<0.001***	***0.981***	***781.6***
Product 4	*<0.001*	*0.902*	*754.1*	*<0.001*	*0.901*	*755.4*	***<0.001***	***0.908***	***750.0***
Product 5	*<0.001*	*0.899*	*858.0*	*<0.001*	*0.958*	*777.4*	***<0.001***	***0.968***	***752.2***
Product 6	*<0.001*	*0.900*	*917.2*	***<0.001***	***0.962***	***829.0***	*<0.001*	*0.961*	*830.6*
Product 7	*<0.001*	*0.909*	*883.1*	*<0.001*	*0.953*	*821.0*	***<0.001***	***0.954***	***819.7***
Product 8	*<0.001*	*0.881*	*572.6*	***<0.001***	***0.894***	***562.7***	*<0.001*	*0.893*	*564.0*

Conclusions

- Different biodegradable plastics exhibit varying degrees of biodegradability, with some products readily degrading without a lag phase and others experiencing longer lag phases.
- Methane production patterns differ among the products, with some showing an intensive initial phase, while others have slower kinetics.
- The chemical composition of biodegradable plastics plays a significant role in their biodegradability and methane production. Products with similar compositions can still exhibit different behaviors.
- The PLA/PBAT blend (Product 4) displayed a long lag phase, potentially due to complex compounds and crystalline structures, which may slow down the initial breakdown. However, methane production increased after this phase.
- Statistical analysis showed significant relationships between time (days) and BMP values for the initial phase, highlighting the validity of the findings.

Conclusions

- Comparisons with previous studies in the literature demonstrate that the BMP results for these biodegradable plastics vary based on factors like temperature conditions and specific material compositions.
- Some biodegradable plastics, especially those with readily degradable characteristics, hold promise for efficient methane production under anaerobic digestion conditions.
- The study suggests the need for further analysis to investigate the specific compositions and structures of these biodegradable plastics that might influence biodegradation processes.
- Understanding the biodegradability and methane production characteristics of these plastics is essential for assessing their environmental impact and suitability for various applications.
- The findings can inform decisions regarding the use of biodegradable plastics in anaerobic digestion systems and offer insights into their potential for co-digestion with other organic materials.

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