BUKTI KORESPONDENSI

ARTIKEL JURNAL INTERNASIONAL BEREPUTASI

Judul artikel : Theoretical biochemical methane potential generated by the anaerobic digestion of mustard green residues in different dilution volumes.

Jurnal : Polish Journal of Environmental Studies (PJOES), Vol. 32, No. 5, Tahun 2023, Hal. 4799–4804

Penulis : Lukhi Mulia Shitophyta, Septia Riskillah Putri, Zienmy Ayu Salsabiella, Gita Indah Budiarti, Fatima Rauf, Azim Khan

Penerbit : HARD Pub. Co.

ISSN : 1230-1485; E-ISSN: 2083-5906

SJR : 0,

Kronologi Korespondensi Artikel di Jurnal Internasional Bereputasi

No	Tanggal	Aktivitas
1	19 Februari 2023	Notifikasi article submission
2	23 Februari 2023	Notifikasi pengiriman artikel ke reviewer oleh editor
3	24 Maret 2023	Notifikasi revisi artikel
4	26 Maret 2023	Konfirmasi penerimaan revisi artikel
5	27 Maret 2023	Notifikasi pengiriman artikel yang telah direvisi ke reviewer
6	27 Maret 2023	Notifikasi penerimaan artikel
7	27 Maret 2023	Notifikasi publishing fee
8	27 Juni 2023	Notifikasi penerimaan publishing fee
9	27 Juni 2023	Notifikasi penerbitan artikel
10	24 Juli 2023	Verifikasi manuskrip
11	1 Agustus 2023	Notifikasi penetapan DOI
12	8 September 2023	Notifikasi artikel telah diterbitkan

Article submission (Bukti dari email dan OJS, 19 Februari 2023)

- **Bukti dari email**

New manuscript received by Editorial Office (PJOES-00225-2023-01) Inbox ×

Polish Journal of Environmental Studies <kontakt@editorialsystem.com> Sun, Feb 19, 3:21 PM

to me

Dear Lukhi Shitophyta,

Thank you for your manuscript: Theoretical biochemical methane potential generated by the anaerobic digestion of mustard green residues in different dilution volumes.
The following number has been assigned to it: PJOES-00225-2023-01.

The manuscript will be checked by Editors and then sent to the Reviewers.
You will be informed by email about any further decisions on this article.

Thank you for submitting your work to our journal.

With kind regards,

Professor Hanna Radecka
Editor – in – Chief
Polish Journal of Environmental Studies
www.pjoes.com

Editorial System is available here: https://www.editorialsystem.com/pjoes/

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- **Bukti dari OJS**

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With kind regards,

Professor Hanna Radecka
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Journal Website

PJOES-00225-2023-01

Theoretical biochemical methane potential generated by the anaerobic digestion of mustard green residues in different dilutio...

Lukhi Shitophyta

INSERTED:
2023-02-18

SUBMITTED:
2023-02-19

DECISION:
2023-03-24

TITLE AND TYPE

1

Title

Theoretical biochemical methane potential generated by the anaerobic digestion of mustard green residues in different dilution volumes

Type

Original research

ABSTRACT

2

The mustard green residues can be converted into biogas through anaerobic digestion. In this study, different dilution volumes (1 L, 1.5 L, 2 L) were observed to determine the effect of dilution volumes on biogas yield. Three kinetic models (first-order, Fitzhugh, modified Gompertz model) were used to simulate the methane potential, kinetic constants and lag phase time. The experiment was carried out in 5 L digesters at room temperature. The results showed that modified Gompertz is the best model for simulating the AD process. Dilution volume affected biogas production ($p < 0.05$) with the highest biogas yield of 4372.58 mL/gVS (dilution volume of 2 L). The statistical analysis showed a significant correlation between the COD total, different dilution volumes and theoretical methane potential ($p < 0.05$).

AUTHORS

3

CORRESPONDING AUTHOR

Master Lukhi Mulia Shitophyta (mulia.lukhi@gmail.com)

Department of Chemical Engineering, Faculty of Industrial Technology, Universitas Ahmad Dahlan, Yogyakarta, 55191, Indonesia, Indonesia

Country	Indonesia
ORCID iD	0000-0003-3434-1893
Scopus ID	57189732512
Researcher ID	AAQ-4576-2021

es

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PJOES-00225-2023-01

Theoretical biochemical methane potential generated by the anaerobic digestion of mustard green residues in different dilutio...

Septia Putri (septia1800020042@webmail.uad.ac.id)

Department of Chemical Engineering, Faculty of Industrial Technology, Universitas Ahmad Dahlan, Yogyakarta, 55191, Indonesia, Indonesia

Country Indonesia

Zienmy Salsabiella (zienmy1800020046@webmail.uad.ac.id)

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Country Indonesia

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Fatima Rauf (fatimarauf240101@gmail.com)

Department of Biochemistry, Faculty of Sciences, Superior University, Pakistan

Country Pakistan

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Theoretical biochemical methane potential generated by the anaerobic digestion of mustard green residues in different dilutio...

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Country India

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4

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AUTHOR'S STATEMENTS

5

I declare that this manuscript has not been submitted for publication in any other journal

CHECKED

I declare that this manuscript has not been published

CHECKED

The authors declare no conflict of interest

CHECKED

KEYWORDS

6

biogas, chemical oxygen demand, kinetic model, mustard green, regression model

es

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PJOES-00225-2023-01

Theoretical biochemical methane potential generated by the anaerobic digestion of mustard green residues in different dilutio...

TOPICS
7

Solid waste engineering
Environmental management
Bioenergy from biomass

SUGGESTED REVIEWERS
8

Dr. Aster Rahayu • aster.rahayu@che.uad.ac.id
Indonesia
Spectrophotometric, Chromatographic

Master Ajeng Lestari • aydlestari@uii.ac.id
Indonesia
Water treatment, Wastewater engineering

Master Yayuk Mundriyastutik • yayukmundriyastutik@umkudus.ac.id
Indonesia
Medical countermeasures for chemical toxicity, Heavy metals

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PJOES-00225-2023-01

Theoretical biochemical methane potential generated by the anaerobic digestion of mustard green residues in different dilutio...

COVER LETTER
9

February 18, 2023

Dear Hanna Radecka
Editor-in-chief Polish Journal of Environmental Studies

On behalf of my co-authors, I am pleased to submit our manuscript, "Theoretical biochemical methane potential generated by the anaerobic digestion of mustard green residues in different dilution volumes", for consideration for publication as original research in the Polish Journal of Environmental Studies.

We confirm that this work is original. The manuscript was not previously submitted to the Polish Journal of Environmental Studies and has not been published elsewhere nor is it currently under consideration for publication elsewhere.

In the manuscript, we report on the effect of dilution volumes on the anaerobic digestion of mustard green and estimate biomethane potential by comparing three kinetic models (the first-order model, the Fitzhugh model and the modified Gompertz model). This is significant because the results can help to enhance biogas production and determine the most optimal parameters for the anaerobic digestion of mustard green residues.

We believe the manuscript is appropriate for publication in the Polish Journal of Environmental Studies because the manuscript concerns the topic of renewable energy that your journal is interested in.

Thank you for your consideration

Sincerely

Lukhi Mulia Shitophyta

es

Pengiriman artikel ke reviewer oleh editor (Bukti dari email dan OJS, 23 Februari 2023)

- **Bukti dari email**

Manuscript has been sent to Reviewers (PJOES-00225-2023-01) Inbox ×

Polish Journal of Environmental Studies <kontakt@editorialsystem.com>
to me

Feb 23, 2023, 9:40 PM

Dear Lukhi Shitophyta,

Your manuscript: Theoretical biochemical methane potential generated by the anaerobic digestion of mustard green residues in different dilution volumes (PJOES-00225-2023-01) was sent to the Reviewers.

You will be informed by email about any further decisions on this article.

Dorota Radecka PhD
Executive editor
Polish Journal of Environmental Studies
www.pjoes.com

Editorial System is available here: https://www.editorialsystem.com/pjoes/

Reply | Forward

- **Bukti dari OJS**

Manuscript has been sent to Reviewers (PJOES-00225-2023-01)

Dear Lukhi Shitophyta,

Your manuscript: Theoretical biochemical methane potential generated by the anaerobic digestion of mustard green residues in different dilution volumes (PJOES-00225-2023-01) was sent to the Reviewers.

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Dorota Radecka PhD
Executive editor
Polish Journal of Environmental Studies
www.pjoes.com

Editorial System is available here: https://www.editorialsystem.com/pjoes/

Notifikasi revisi artikel (Bukti dari email dan OJS, 24 Maret 2023)

- **Bukti dari email**

Decision on manuscript PJOES-00225-2023-01 Inbox ×

Polish Journal of Environmental Studies <kontakt@editorialsystem.com> Mar 24, 2023, 11:42 PM
to me

March 24, 2023
PJOES-00225-2023-01
Theoretical biochemical methane potential generated by the anaerobic digestion of mustard green residues in different dilution volumes

Dear Lukhi Shitophyta,

I am pleased to inform you that your manuscript, entitled: Theoretical biochemical methane potential generated by the anaerobic digestion of mustard green residues in different dilution volumes, might be accepted for publication in our journal, pending changes suggested by reviewers (see below).

Please revise your manuscript strictly according to the attached Reviewers' comments as well as Editor's remarks. Your manuscript won't be taken into consideration without the revisions made according to the recommendations.

Please, check all Editor's remarks when revising your manuscript:
- R e f e r e n c e s should be indicated in the text by consecutive numbers and the full references should be listed in the same order at the end of the article according to Journal way
- In references all authors name must be included
- E-mail address of Corresponding Author must be provided
- Manuscript should be divided into the sections: Abstract, Keywords, Introduction, Material and Methods (could be omitted in Reviews), Results and Discussion, Conclusions, Acknowledgements, References

Please, provide the following items:
1) copy of the fully revised manuscript that has all the changes highlighted in red colour, along with high–quality figures. Each figure prepared in colour will be charged 60 EURO
2) answers to all the Reviewer comments

Authors of our journal are requested to prepare a revised version of their manuscript as soon as possible. This may ensure fast publication if an article is finally accepted.

Thank you for submitting your work to our Journal and fruitful co-operation.

With kind regards,

Dorota Radecka PhD
Executive editor
Polish Journal of Environmental Studies
www.pjoes.com

Please note that this email may not include all details of your article's evaluation. The full decision is available here:
https://www.editorialsystem.com/pjoes/article/336404/view/#showDecisionLetter330829

Review 1:
Paper can contribute the related field by the revision.

1. Originality of the study can be described wth one more sentences at the end of introduction section.
2. Conclusion section can be rewritten with details of the methodology
3. One more paper can be cited to support the aim of study such as:

http://jestec.taylors.edu.my/Vol%2010%20issue%206%20June%202015/Volume%20(10)%20Issue%20(6)%20722-729.pdf

https://www.mdpi.com/1996-1073/15/9/2989

https://dergipark.org.tr/en/pub/jotaf/article/730915

Reply Forward

- **Bukti dari OJS**

Decision on manuscript PJOES-00225-2023-01

March 24, 2023
PJOES-00225-2023-01
Theoretical biochemical methane potential generated by the anaerobic digestion of mustard green residues in different dilution volumes

Dear Lukhi Shitophyta,

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Please revise your manuscript strictly according to the attached Reviewers' comments as well as Editor's remarks. Your manuscript won't be taken into consideration without the revisions made according to the recommendations.

Please, check all Editor's remarks when revising your manuscript:
- R e f e r e n c e s should be indicated in the text by consecutive numbers and the full references should be listed in the same order at the end of the article according to Journal way

Decision on manuscript PJOES-00225-2023-01

- In references all authors name must be included
- E-mail address of Corresponding Author must be provided
- Manuscript should be divided into the sections: Abstract, Keywords, Introduction, Material and Methods (could be omitted in Reviews), Results and Discussion, Conclusions, Acknowledgements, References

Please, provide the following items:
1) copy of the fully revised manuscript that has all the changes highlighted in red colour, along with high–quality figures. Each figure prepared in colour will be charged 60 EURO
2) answers to all the Reviewer comments

Authors of our journal are requested to prepare a revised version of their manuscript as soon as possible. This may ensure fast publication if an article is finally accepted.

Thank you for submitting your work to our Journal and fruitful co-operation.

With kind regards,

Dorota Radecka PhD
Executive editor

Decision on manuscript PJOES-00225-2023-01

Executive editor
Polish Journal of Environmental Studies
www.pjoes.com

Please note that this email may not include all details of your article's evaluation. The full decision is available here:
https://www.editorialsystem.com/pjoes/article/336404/view/#showDecisionLetter330829

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Paper can contribute the related field by the revision.

1. Originality of the study can be described wth one more sentences at the end of introduction section.
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3. One more paper can be cited to support the aim of study such as:

http://jestec.taylors.edu.my/Vol%2010%20issue%206%20June%202015/Volume%20(10)%20Issue%20(6)%20722-729.pdf

https://www.mdpi.com/1996-1073/15/9/2989

- **Authors' response**

March 26, 2023

Dorota Radecka PhD
Executive Editor
Polish Journal of Environmental Studies

Dear editors, Polish Journal of Environmental Studies

We thank you for the letter dated 24/03/2023 and the opportunity to resubmit a revised copy of this manuscript. We also want to thank the reviewers for the positive feedback and helpful comments for correction or modification.

The manuscript has been revised to address the reviewer's comments and the editor's remarks, which are appended alongside our responses to this letter. Revisions in the manuscript are shown in red font.

We hope that the revisions in the manuscript and our accompanying responses will be sufficient to make our manuscript suitable for publication in the Polish Journal of Environmental Studies

Sincerely yours,

Lukhi Mulia Shitophyta
on behalf of the authors
Department of Chemical Engineering
Universitas Ahmad Dahlan, Yogyakarta, 55164
Indonesia
lukhi.mulia@che.uad.ac.id

Reviewer's comments	Author's response
Originality of the study can be described with one more sentences at the end of introduction section.	Thank you for pointing this out. We have added the originality of the study at the end of the introduction section, where the change can be found in the revised manuscript
Conclusion section can be rewritten with details of the methodology	Thank you. We have rewritten the conclusion with details of the methodology, where the change can be found in the revised manuscript.
One more paper can be cited to support the aim of study such as: http://jestec.taylors.edu.my/Vol%2010%20issue%206%20June%202015/Volume%20(10)%20Issue%20(6)%20722-729.pdf https://www.mdpi.com/1996-1073/15/9/2989 https://dergipark.org.tr/en/pub/jotaf/article/730915	Thank you for this suggestion, unfortunately, the suggested papers are not relevant to our study, thus, we cannot cite the papers.

Notifikasi pengiriman artikel yang telah direvisi ke reviewer (bukti dari email dan OJS, 27 Maret 2023)

- **Bukti dari email**

Manuscript has been sent to Reviewers (PJOES-00225-2023-02) Inbox ×

Polish Journal of Environmental Studies <kontakt@editorialsystem.com> Mar 27, 2023, 5:48 PM

to me

Dear Lukhi Shitophyta,

Your manuscript: Theoretical biochemical methane potential generated by the anaerobic digestion of mustard green residues in different dilution volumes (PJOES-00225-2023-02) was sent to the Reviewers.

You will be informed by email about any further decisions on this article.

Prof. Hanna Radecka
Editor in Chief
Polish Journal of Environmental Studies
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Editorial System is available here: https://www.editorialsystem.com/pjoes/

Reply Forward

- **Bukti dari OJS**

Manuscript has been sent to Reviewers (PJOES-00225-2023-02)

Dear Lukhi Shitophyta,

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Editor in Chief
Polish Journal of Environmental Studies
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- **Bukti dari email**

Decision on manuscript PJOES-00225-2023-02 Inbox ×

Polish Journal of Environmental Studies <kontakt@editorialsystem.com> Mon, Mar 27, 7:55 PM
to me

March 27, 2023
PJOES-00225-2023-02
Theoretical biochemical methane potential generated by the anaerobic digestion of mustard green residues in different dilution volumes

Dear Lukhi Shitophyta,

I am pleased to inform you that your manuscript, entitled: Theoretical biochemical methane potential generated by the anaerobic digestion of mustard green residues in different dilution volumes, has been finally accepted for publication in our journal.

Thank you for submitting your work to our Journal and fruitful co-operation.

Prof. Hanna Radecka
Editor in Chief
Polish Journal of Environmental Studies
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Reply Forward

- **Bukti dari OJS**

Decision on manuscript PJOES-00225-2023-02

March 27, 2023
PJOES-00225-2023-02
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Prof. Hanna Radecka
Editor in Chief
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- **Bukti dari email**

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Bank wire transfer:
Name of Payee: Firma Wydawnicza HARD s.c. Jerzy Radecki, Hanna Radecka, Dorota Radecka
Address of Payee: ul. Wengris 71, 10-718 OLSZTYN, POLAND
Bank Name: Bank Polska Kasa Opieki SA
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PL19124015901111000014317981
Swift Reference: PKOPPLPW

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Publishing fee has been received Inbox ×

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Thank you very much for selecting of our Journal and fruitful co-operation.

With kind regards,

Professor Hanna Radecka
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Polish Journal of Environmental Studies
www.pjoes.com

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Polish Journal of Environmental Studies <kontakt@editorialsystem.com> Tue, Jun 27, 7:29 PM
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https://www.editorialsystem.com/dl/pay/32745/4a4276edbef21112c954cd5563d15480/

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Jun 27, 2023, 7:29 PM

June 27, 2023
PJOES-00225-2023-02
Theoretical biochemical methane potential generated by the anaerobic digestion of mustard green residues in different dilution volumes

Dear Lukhi Shitophyta,

I am pleased to inform you that your manuscript PJOES-00225-2023-02, entitled Theoretical biochemical methane potential generated by the anaerobic digestion of mustard green residues in different dilution volumes is considering for publication in Polish Journal of Environmental Studies, issue: Manuscripts accepted.

With kind regards,

Professor Hanna Radecka
Editor – in – Chief
Polish Journal of Environmental Studies
www.pjoes.com

Reply Forward

Verifikasi manuskrip (Bukti dari email dan OJS, 24 Juli 2023)

- **Bukti dari email**

Verification requested (PJOES-00225-2023-02) Inbox ×

Editorial System <kontakt@editorialsystem.com>
to me

Jul 24, 2023, 3:04 AM

Dear Lukhi Shitophyta,

Theoretical biochemical methane potential generated by the anaerobic digestion of mustard green residues in different dilution volumes (PJOES-00225-2023-02) requires verification.

Verification deadline: 2023-07-29

Theoretical Biochemical Methane Potential
Generated by the Anaerobic Digestion of Mustard
Green Residues in Different Dilution Volumes

Dear Corresponding Author,

Please, find below link with the proof of your article, to be published in "Polish Journal of Environmental Studies" Vol. 32, No.5, 2023 and a list of queries.

Please use this proof only for checking the typesetting, editing,
completeness and correctness of the text, tables and figures.
The comments included serve the purpose of suggesting changes. If you do not agree with any of the comments, please, feel free to acknowledge that. If you wish to make any other comments, please do not hesitate to mark them using sticky notes on the same pdf document.

To ensure fast publication of your paper, please return your proof and the answers to all queries (BOTH DOCUMENTS MUST BE UPLOADED IN THE PJOES EDITORIAL SYSTEM) within 3 days.
These are conditions allowing us to proceed to the next step of publication procedure of your manuscript.

WE WOULD BE VERY GRATEFUL IF YOU COULD USE THE PJOES EDITORIAL SYSTEM AS THE MAIN COMMUNICATION TOOL.

PLEASE DO NOT SEND YOUR REVISED PDFs OR QUERIES TO OUR E-MAIL ADDRESS.

THANK YOU.

Best regards,

Anastazja Każmir
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Editorial System Team

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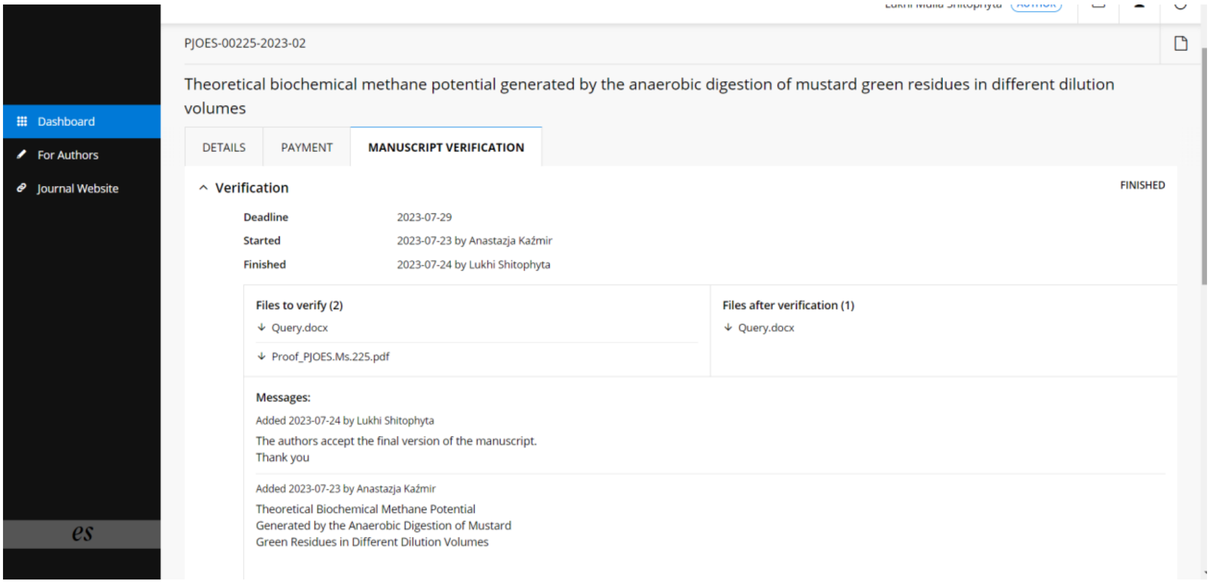

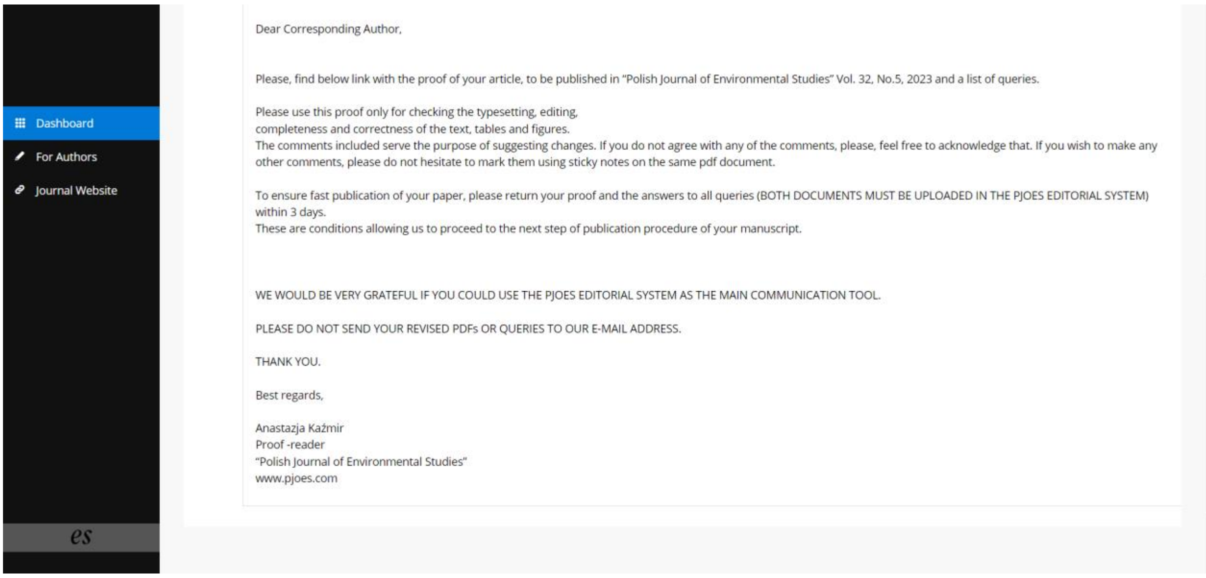

Notifikasi penetapan DOI (1 Agutus 2023)

A DOI number has been assigned (PJOES-00225-2023-02)

We would like to inform you that manuscript Theoretical Biochemical Methane Potential
Generated by the Anaerobic Digestion of Mustard
Green Residues in Different Dilution Volumes (PJOES-00225-2023-02) has been indexed in CrossRef.

Assigned DOI: 10.15244/pjoes/162690

Link: https://doi.org/10.15244/pjoes/162690

Article view:
https://www.editorialsystem.com/pjoes/article/336404/view/

Please, notice that the number of pages will be assigned after the printing of hard copy.
We would like to thank you for selecting our journal and for the fruitful co-operation.

Looking forward to your next submission.

Editorial Office of Polish Journal of Environmental Studies

Notifikasi artikel telah diterbitkan (8 September 2023)

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Polish Journal of Environmental Studies <kontakt@editorialsystem.com> Sep 8, 2023, 12:54 PM
to me

September 08, 2023
PJOES-00225-2023-02
Theoretical Biochemical Methane Potential
Generated by the Anaerobic Digestion of Mustard
Green Residues in Different Dilution Volumes

Dear Lukhi Shitophyta,

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Generated by the Anaerobic Digestion of Mustard
Green Residues in Different Dilution Volumes is considering for publication in Polish Journal of Environmental Studies, issue: 5/2023 vol. 32.

With kind regards,

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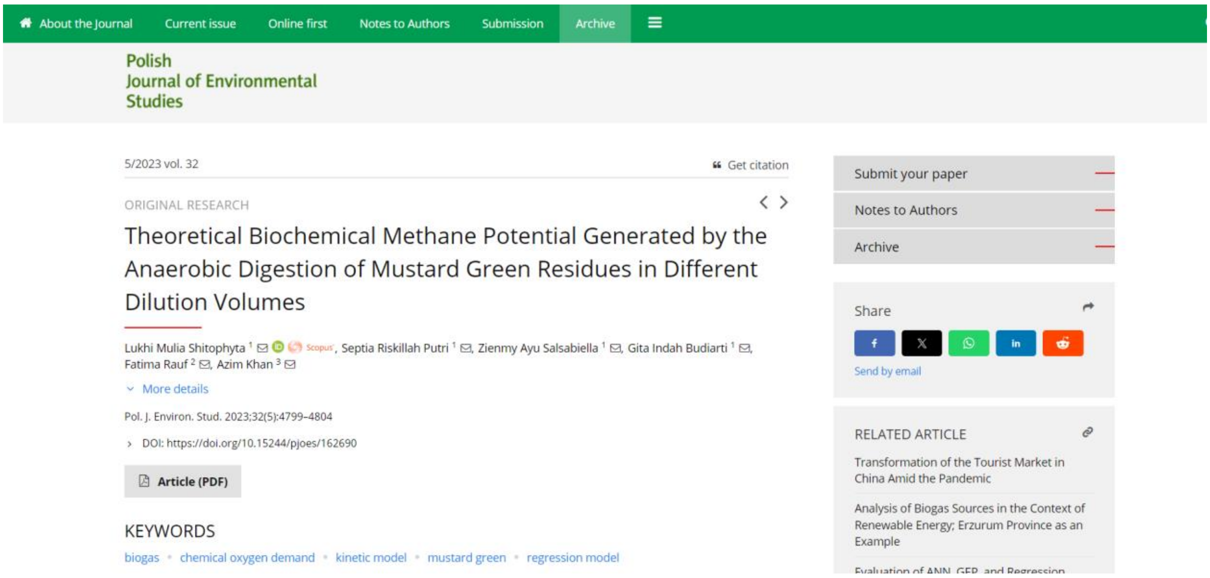

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Lukhi Mulia Shitophyta [1], Septia Riskillah Putri [1], Zienmy Ayu Salsabiella [1], Gita Indah Budiarti [1], Fatima Rauf [2], Azim Khan [3]

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Pol. J. Environ. Stud. 2023;32(5):4799–4804

DOI: https://doi.org/10.15244/pjoes/162690

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KEYWORDS

biogas • chemical oxygen demand • kinetic model • mustard green • regression model

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Pol. J. Environ. Stud. Vol. 32, No. 5 (2023), 4799-4804
DOI: *10.15244/pjoes/162690* ONLINE PUBLICATION DATE: 2023-08-01

Original Research

Theoretical Biochemical Methane Potential Generated by the Anaerobic Digestion of Mustard Green Residues in Different Dilution Volumes

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Received: 19 February 2023
Accepted: 27 March 2023

Abstract

The green mustard residues can be converted into biogas through anaerobic digestion. In this study, different dilution volumes (1 L, 1.5 L, 2 L) were observed to determine the effect of dilution volumes on biogas yield. Three kinetic models (first-order, Fitzhugh, modified Gompertz model) were used to simulate the methane potential, kinetic constants, and lag phase time. The experiment was carried out in 5 L digesters at room temperature. The results showed that modified Gompertz is the best model for simulating the AD process. Dilution volume affected biogas production ($p<0.05$) with the highest biogas yield of 4372.58 mL/gVS (dilution volume of 2 L). The statistical analysis showed a significant correlation between the COD total, different dilution volumes and theoretical methane potential ($p<0.05$).

Keywords: biogas, chemical oxygen demand, kinetic model, mustard green, regression model

Introduction

Anaerobic digestion (AD) is a biochemical reaction consisting of the hydrolysis stage, acetogenesis stage, and methanogenesis stage [1]). The AD process generates two main products: biogas and digestates [2]. The compositions of biogas are 50-70% of methane (CH_4), 30-45% of carbon dioxide (CO_2), and other impurities of hydrogen sulfide, ammonia, and water vapour [3].

The raw material of biogas can be obtained from organic materials such as the residue and by-products of vegetables since it has high organic content and moisture [4]. Mustard greens (*Brassica juncea*) are plentiful plants in Indonesia. Nevertheless, after harvesting, the farmers are inclined to waste the mustard greens due to the imbalanced market price and cultivation cost [5].

The potential biogas production assay, also called biochemical methane potential (BMP), is the primary parameter for describing the wastes and determining

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the optimal variables of the anaerobic digestion process [6]. The BMP also determines the fraction of organic carbon in each substrate that can be converted to methane [7].

The mathematical models can represent the potential of digester performance and provide the theoretical biogas yield [8]. Numerous methods for calculating theoretical methane potential are based on chemical oxygen demand (COD), primary composition, and kinetic models [9]. Most studies have focused on determining biogas potential using chemical composition and substrate COD [10-12]. However, no study has investigated the relationship between dilution volumes and biochemical methane potential by determining a regression model. Therefore, this study aimed to evaluate the effect of dilution volume on biochemical methane potential and determine the kinetic parameters by simulating different kinetic models. The study provides originality by adding new knowledge based on our hypotheses which find a significant correlation between dilution volume and kinetic results during anaerobic digestion of mustard green residues.

Material and Methods

Feedstock and Inoculum Preparation

Mustard green was collected from vegetable sellers in Yogyakarta, Indonesia. The green mustard residuals were shredded and stored at 20°C. Yeast was used as inoculum containing 44% carbohydrates, 44% protein and 12% fat.

Anaerobic Digestion Experimental Set-up

The substrate and 50 g yeast were fed in batch digesters. The experiment was performed in different water dilution volumes of 1 L, 1.5 L, and 2 L. The substrate-to-inoculum ratio (S/I ratio) was maintained at 5 (based on the dry matter content). The anaerobic digestion test was conducted for 40 days.

Analytical Method

Volatile solids (VS) and chemical oxygen demand (COD) were analyzed according to standard methods. Biogas volume was measured using the water displacement method. Corrected biogas volumes were calculated using the equation below [13]:

$$V_{STP} = \frac{V_T \times 273 \times (760 - P_w)}{760 \times (273 + T)} \quad (1)$$

Where V_{STP} is biogas volume of standard temperature and pressure (L); V_T is a volume of biogas measured at temperature T (L); T is the temperature of biogas or ambient space (°C); P_w is saturated vapor pressure at the ambient temperature (mmHg).

MS Excel performed the analysis of variance (ANOVA). The significant results were checked with a p-value less than 0.05. The kinetic parameters were determined using regression analysis by Solver in MS Excel.

The theoretical methane yield was performed according to the following equation [14].

$$CH_4\ yield = COD_{total} \times V_{sample} \times (0.36\ LCH_4/g\ COD) \quad (2)$$

Kinetic Models

The first-order, Fitzhugh, modified Gompertz models fit the measured biogas yields. Model equations are presented in Table 1.

M_t represents the cumulative methane production (CMP), mL/gVS; t represents for anaerobic digestion time, day; M_0 represents the simulated methane potential (mL/gVS); R_m is the maximum methane production rate, mL/gVS/day; e equals to 2.7183; n is a dimensionless shape factor, and λ represents the lag phase time, day.

Results and Discussion

Effect of Dilution Volumes on Biogas Production

The influence of dilution volumes on biogas production is presented as daily and cumulative biogas yields in Fig. 1 and Fig. 2, respectively. Biogas production was initiated on day 4 with biogas yields of 261.44 mL/gVS, 411.76 mL/gVS, and 392.16 mL/gVS at dilution volumes of 1 L, 1.5 L, and 2 L, respectively. Biogas production then increased gradually until reaching peak yields of 372.55 mL/gVS, 931.37 mL/gVS, and 1490.20 mL/gVS on day 12 at

Table 1. The kinetic model to express biogas production from batch anaerobic digestion of mustard green wastes.

Model	Equation	References
First-order	$M_t = M_0 \times \left(1 - exp^{(-kt)}\right)$	[15]
Fitzhugh	$M_t = M_0 \times \left(1 - exp^{(-kt)^n}\right)$	[16]
Modified Gompertz	$M_t = M_0 \times exp\{-exp[(R_m.e/M_0) \times (\lambda - t) + 1]\}$	[17]

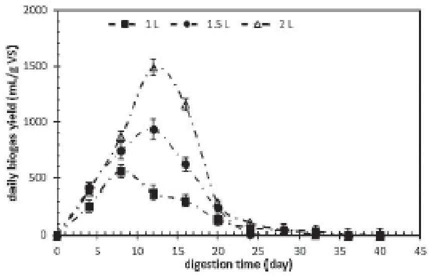

Fig. 1. Daily biogas yields during anaerobic digestion of mustard green residues.

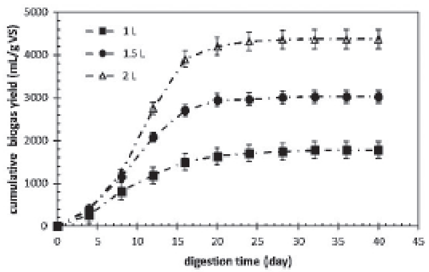

Fig. 2. Cumulative biogas yields during anaerobic digestion of mustard green residues.

dilution volumes 1 L, 1.5 L, and 2 L. Biogas production then dropped progressively with the lowest yield obtained on day 40.

Fig. 2 illustrates an enormous cumulative yield of 4372.58 mL/gVS was obtained at a dilution volume of 2 L, followed by cumulative yields of 1781.70 mL/gVS and 3026.85 mL/gVS for dilution volumes of 1 L and 1.5 L, respectively. An increase in dilution volumes gained a positive effect on biogas production. Statistical analysis performed that dilution volumes affected biogas production significantly with a p-value of 0.008 ($p<0.05$).

The prior study conducted by Jeppu et al. [18] reported that as dilution increased, the biogas production also increased during the anaerobic digestion of cow dung. A similar result exposed that the highest dilution generated high methane [19].

Kinetic Results

Table 2 presents the relevant results of model parameters. Among the three kinetic models used in this experiment, the modified Gompertz model performs the slightest difference (0.29-0.9%) between the calculated and measured biogas yield (M_o) followed by the Fitzhugh model (0.69-4.17%), whereas a tremendous difference (4.62-7.28%) between the calculated and measured biogas yield is obtained in the first-order kinetic model. For the Fitzhugh and first-order model, the values of k were almost constant for all substrates in each dilution volume. However, the Fitzhugh model provided a higher k than the first-order model. The R^2 obtained by the Fitzhugh model was also

Table 2. Kinetic parameters of first-order, Fitzhugh, and modified Gompertz models.

Model	Parameters	Dilution volumes		
		1 L	1.5 L	2 L
First-order	Mo (mL/gVS)	1960.54	3383.57	5102.59
	k (1/day)	0.076	0.076	0.065
	R^2	0.9185	0.9196	0.9397
	difference	4.62%	6.00%	7.28%
Fitzugh	Mo (mL/gVS)	1707.43	2977.15	4342.38
	k (1/day)	0.096	0.092	0.084
	n	3.00	3.00	3.00
	R^2	0.9976	0.9974	0.9976
	difference	4.17%	1.64%	0.69%
modified Gompertz	Mo (mL/gVS)	1779.00	3055.07	4414.37
	Rm (mL/gVS/day)	130.19	255.06	402.86
	l (day)	2.04	3.17	4.68
	R^2	0.9995	0.9992	0.9992
	difference	0.29%	0.86%	0.90%

higher than the first-order kinetic model. Therefore, the Fitzhugh model is more appropriate for calculating the rate constants (k). The higher k indicated the rapid degradation rate and fast biogas production [20]. The lower dilution volume (1 L) obtained a higher k which denoted the enhanced substrate degradation and biogas yield.

The ultimate methane yield (M_r) could be calculated from the Fitzhugh, modified Gompertz and first-order kinetic model. For all models, the value of the ultimate biogas yield of substrates increased with dilution volume increased. For the modified Gompertz model, the maximum methane production rate (R_m) increased with increasing dilution volumes; however, the lag phase (λ) was more extended as dilution volumes increased. This phenomenon might imply that the Gompertz model is inaccurate enough to predict the lag phase under the studied circumstances. The prolonged lag phase might occur due to the long hydrolysis time and slow methanogenesis [21]. The previous study also reported that the lag phase increased as the biogas production rate increased in the anaerobic co-digestion of Thai rice noddle wastewater and chicken manure [11].

Fig. 3 shows the regression fitting of the experimental data following first-order, Fitzhugh and modified Gompertz models. According to the results, all three models could simulate the anaerobic digestion of mustard green wastes well due to the R^2>0.9 for all models. However, the experimental data fit very well with the modified Gompertz. Furthermore, the values of R^2 show that the modified Gompertz model prediction to the experimental value is statistically higher than the first-

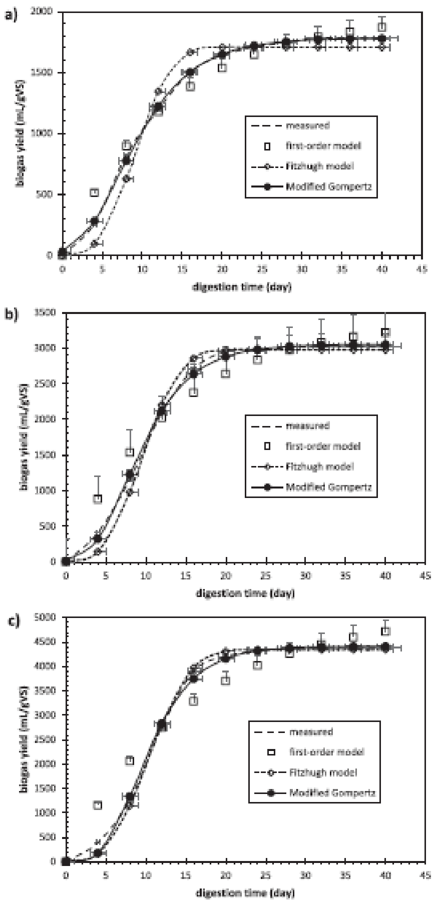

Fig. 3. Regression fitting of cumulative biogas yield following first-order, Fitzhugh, and modified Gompertz models in different dilution volumes: a) 1 L; b) 1.5 L; c) 2 L.

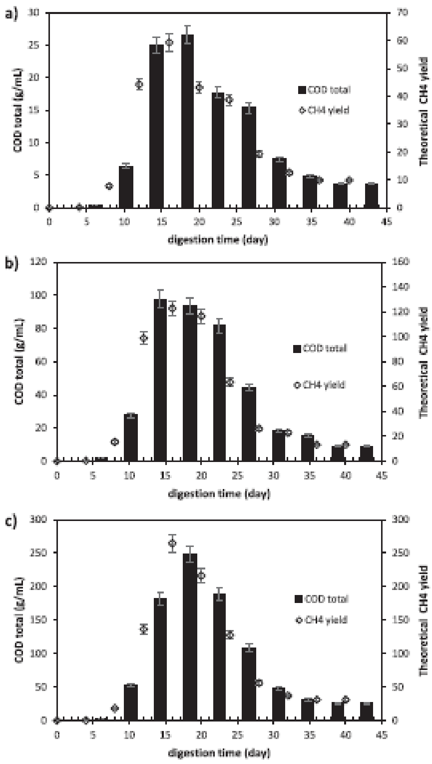

Fig. 4. Correlation between COD total and theoretical methane yield for different dilution volumes: a) 1 L; b) 1.5 L; c) 2 L.

order and Fitzhugh models (see Table 2). The dilution volume of 2L had the highest M_0 (4414.37 mL/gVS) and R_m (402.86 mL/gVS/day), respectively.

According to previous literature, the modified Gompertz model had higher R^2 (0.985-0.999) than first-order (R^2 0.813-0.992) and Fitzhugh (R^2 0.813-0.992) models during the anaerobic digestion of vegetable wastes [22]. Ajayi-banji [23] reported that modified Gompertz was the best-fit model to depict the kinetic of solid-state anaerobic co-digestion of corn stover with dairy manure among two other models of Fitzhugh and first-order.

Correlation between COD Total, Dilution Volume and Theoretical Methane Yield

COD represents the quantity of organic material in a substrate [24]. The efficiency of the process can be evaluated by the COD content in the digester [25]. The correlation between theoretical methane yield and COD total is illustrated in Fig. 4.

The theoretical methane yield was calculated using the COD total in each dilution volume. From Fig. 4, it can be seen that high COD contents obtained high methane yields for all dilution volumes. The dilution volume of 2 L got the most methane yield of 264.70 mL/gVS on day 16, followed by dilution volumes of 1.5 L and 1 L with the highest methane yields of 92.02 mL/gVS and 24.41 mL/gVS, respectively. The lowest methane yield was obtained at the lowest COD total for all dilution volumes. From the results, it can be inferred that the COD total affected theoretical methane yields. The statistical analysis also proved the significant impact of COD total towards the theoretical methane yield with a p-value of 0.01 ($p<0.05$). Tang et al. [26] obtained a methane yield of 276±34 mL/gVS for the digestion of mustard residuals. Yan et al. [27] reported cauliflower residues generated a methane yield of 249.61 mL/gVS. Czubaszek et al. [28] found the highest methane yield of 297.81±0.65 L/kgVS during the anaerobic digestion of cabbage leaves. Compared to the previous literature, the theoretical methane yield obtained in this study is almost close to the experimental methane yield obtained by the anaerobic digestion of mustard residuals, with a yield difference of 4.27%.

Conclusions

This study investigated the effect of different dilution volumes on biogas production and the correlation between dilution volumes and theoretical methane yield. The results showed that the modified Gompertz model is the best-fit model for anaerobic digestion of green mustard residuals with R^2 of 0.9992-0.9995. The highest cumulative yeast of 4372.58 mL/gVS was obtained at a dilution volume of 2 L. According to the analytical method, dilution volumes significantly affect biogas production with a p-value of 0.008 ($p<0.05$) and correlate with theoretical methane yield by obtaining a p-value of 0.01 ($p<0.05$).

Acknowledgments

We thank all persons who had any contributions to this research.

Conflict of Interest

The authors declare no conflict of interest.

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