www.ijarp.com ISSN 2456-9992 Page: 01-11

International Journal Advanced Research Publications

Research Article

Volume: 02
Issue: 07

"COMPARATIVE ASSESSMENT OF BIOGAS GENERATION POTENTIAL FROM FOOD WASTE AND GARDEN WASTE UNDER SEMI-DRY ANAEROBIC DIGESTION"

***Md. Tahir, Mukul Vijay, Dr. Neetesh Kumar Daheriya**

Department of Chemical Engineering, Faculty of Engineering and Technology, Mewar University Chittorgarh Rajasthan–312901.

Article Received: 24 May 2026, Article Revised: 12 June 2026, Published on: 02 July 2026

***Corresponding Author: Md. Tahir**

Department of Chemical Engineering, Faculty of Engineering and Technology, Mewar University Chittorgarh Rajasthan–312901.

Doi: https://doi-doi.org/101555/ijrpa.6164

ABSTRACT

Rapid urbanization and escalating population growth have led to a surge inmunicipal organic waste (MOW) generation, posing severe environmental risks. Conventional disposal methods, such as land-filling and open dumping, are increasingly problematic due to their significant contribution to anthropogenic greenhouse gas emissions. Anaerobic digestion (AD) serves as a critical mitigation strategy, facilitating the conversion of biodegradable organic fractions into renewable energy in the form of biogas. This study conducts a comparative performance evaluation of food waste (FW) and garden waste (GW) as substrates for biogas production under semi-dry conditions. Experimentaltrialswereexecutedusingbatchreactorsmaintainedatmesophilictemperatures (35 ± 2°C) with a total solids (TS) concentration ranging from 15% to 20%. The study systematically monitored key operational indicators, including pH fluctuations, volatile solids (VS) reduction, cumulative biogas yields, methane (CH_4) concentration, and overall process stability. Findings revealed that food waste achieved superior biogasand methane yields, attributed to its high biodegradability and rich organic density. Conversely, garden waste demonstrated reduced degradation rates and lower methane output, likely due to the structural recalcitrance of its lignocellulosic components. Notably, the co-digestion of FW and GW provided synergistic effects, enhancing process stability, optimizing methanerecovery, and ensuringa more favorable carbon-to-nitrogen (C/N) ratio. Furthermore, the semi-dry AD configuration offered distinct operational benefits, suchas minimized water requirements,

increased solids loading capacity, anda reduction intherequired footprint for reactor infrastructure.

1. INTRODUCTION

The rapid growth of urban populations and industrial activities has led to a significant increase in the generation of municipal solid waste worldwide. Among the various components of municipal waste, organic wasterepresents a substantial proportion and poses serious environmental challenges when not managed properly. Conventional disposal methods such as landfilling and open dumping contribute to greenhouse gas emissions, unpleasant odors, leachate formation, and potential contamination of soil and groundwater resources.

Organic waste mainly consists of food residues and garden waste. Food waste contains high concentrations of readily biodegradable organic matter, including carbohydrates, proteins, and fats, making it an excellent feedstock for biological energy recovery processes. On the other hand, garden waste is primarily composed of lignocellulosic materials such as grass clippings, leaves, and plant trimmings, which exhibit greater resistance to microbial degradation due to their complex structural composition.

Anaerobic digestion has gained widespread attention as an environmentally sustainable technology for the treatment of biodegradable waste while simultaneously generating renewable energy in the form of biogas. Among the various digestion approaches, semi-dry anaerobicdigestion hasemerged asa promising alternativebecauseit can efficiently process substrates with higher total solids content. This technology offers several advantages, including reduced water consumption, lower reactor volume requirements, and improved operational efficiency compared with conventional wet digestion systems.

Previous research has extensively examined the anaerobic digestion performance of food waste and lignocellulosic biomass individually. However, comparative studies evaluatingthe biogas production potential of these two waste streams under semi-dry digestion conditions remain limited. Furthermore, the potential benefitsof co-digestion in enhancing biogasyield and process stability require further investigation.

Therefore,thisstudyaimstoassessand comparethebiogasgenerationcharacteristicsoffood waste and garden waste under semi-dry anaerobic digestion conditions. The investigation focuses on evaluating substrate performance, methane production efficiency, and overall digestion effectiveness to identify suitable organic waste management strategies for sustainable energy recovery.

Objectives of the Study

1. To compare thebiogasproductionpotentialoffoodwaste and gardenwaste under semi-dry anaerobic digestion conditions.
2. Toevaluatemethaneyield,volatilesolidsreduction,andsubstratedegradation efficiency.
3. Toassessthe suitability and performanceof semi-dry anaerobic digestion for organic waste treatment.
4. To investigate the impact of co-digestion on biogas production, methane concentration, and process stability.

2. Literature Review

Previous studies have demonstrated that food waste possesses high methane generation potential because of its readily biodegradable organic matter. However, rapid acidification and process instability may occur due to excessive volatile fatty acid accumulation during digestion.Gardenwaste, ontheotherhand, containshighcellulose, hemicellulose,andlignin content, which reduces biodegradability and biogas yield. Pretreatment methods such as mechanical shredding and thermal pretreatment have been reported to improve methane production from lignocellulosic biomass. Co-digestion of food waste and garden waste has shown promising results by balancing the carbon-to-nitrogen ratio and improving microbial stability.Researchersreportedenhancedmethanerecoveryandimproveddigestionefficiency under semi-dry conditions. Despite these developments, comparative analysis of food waste and garden waste under identical semi-dry digestion conditions remains insufficiently explored. Therefore, this study addresses this research gap through controlled experimental evaluation.

Anaerobic digestion has gained considerable attention in recent years as a sustainable waste management technology. Several researchers have investigated the biogas generation potential of various organic substrates including food waste, agricultural waste, sewage sludge, and lignocellulosic biomass.

Food waste has been widely recognized as an excellent substrate for methane production because of its high moisture content and biodegradability. Researchers observed that food waste digestion can produce high methane yield within a shorter retention period. However, rapid acidification duetoaccumulation of volatile fattyacids can lead to processinstability.

Garden waste, which mainly consists of cellulose, hemicellulose, and lignin, exhibits lower biodegradability compared to food waste. The lignin component acts as a protective barrier and limits microbial access to cellulose fibres. Pretreatment methods such as shredding, grinding, thermal treatment, and alkaline treatment have been reported to improve degradation efficiency.

Co-digestion of food waste and lignocellulosic biomass has been found effective for balancing nutrient composition and improving methane production. The carbon-rich garden waste helps regulate the carbon-to-nitrogen ratio and reduces the risk of acidification associated with food waste digestion.

Semi-dry anaerobic digestion has emerged as a promising alternative to conventional wet digestionsystems.Itoffersadvantagessuchaslowerreactor size,reducedwaterrequirement, and higher organic loading capacity. Researchers have reported that semi-dry systems are suitable for decentralized waste treatment and energy recovery applications.

3. MATERIALS AND METHODS

Collection of Substrates

Food waste samples were collected from local cafeterias, hostel mess facilities, and restaurants. The collected waste primarily consisted of cooked rice, vegetables, bread, fruit peels, and leftover food materials.Garden waste samples including dry leaves, grass clippings, and plant trimmings were collected from parksand institutional gardens.

All non-biodegradable materialssuchas plastics, stones, and metals were manuallyremoved before processing.

Food waste samples were collected from local cafeterias, hostel mess facilities, restaurants, and household kitchens. The collected waste mainly consisted of:

- Cookedrice
- Vegetableresidues
- Fruitpeels

- Breadandbakerywaste
- Leftovercookedfood

Garden waste samples were collected from parks and institutional gardens. The waste included:

- Dryleaves
- Grassclippings
- Plantstems
- Treepruningresidues

Non-biodegradable materials such as plastics, stones, metals, and glass were manually removed before experimentation.

Pre-treatment of Waste

The collected substrates were mechanically shredded to reduce particle size and improve microbial accessibility. Moisture content was adjusted to maintain semi-dry digestion conditions with total solids concentration between 15–20%. The mechanical shredding of substrates is particularly critical for the garden waste fraction. The lignocellulosic matrix of lignin, hemicellulose, and cellulose creates a recalcitrant structure that limits microbial access. Reducing the particle size to below 5–10 mm significantly increases the specific surface area, facilitating enzyme attack during the hydrolysisphase.

Furthermore, size reduction reduces the crystallinity index of cellulose, which is a limiting factorintheinitial degradationrateoflignocellulosicbiomass. For thefoodwaste, shredding ensures homogenous mixing with theinoculum, preventing the formation ofa floating scum layer which can hinder gas release in high-solids digesters.

Experimental Setup

Batch anaerobic digesters with working volume of 5 L were used for experimentation. The reactors were operated under mesophilicconditionsat35 ±2°Cforahydraulicretentiontime of 30 days.

Table1. Experimental Condition susedinsemidry an aerobic Digestion.

Parameter	Value
Digestion Mode	Semi–DryanaerobicDigestion
ReactorWorking Volume	6 L

OperatingTemperature	35 +/-2C
RetentionTime	31 Days
TotalSolids	16 – 21 %
pHRange	6.9 – 7.7
ExperimentalRuns	Foodwaste,Gardenwaste,co–digestion

Table2. Comparison of Substrate Characteristics and Digestion Behaviour.

ATTRIBUTE	FOODWASTE	GARDENWASTE	CO-DIGESTION
Dominant Composition	Carbohydrates, proteins,Lipids	Cellulose, Hemicellulose,lignin	CombinedNutrient profile
Biodegradability	High	Low due to lignocellulosic fraction	Improvedbalanceand stability
ExpectedMethaneyield	Higher	Lower	ModeratetoHighwith Better stability
ProcessStability	RiskofAcidification	StablebutSlower degradation	ImprovedStability
Main Limitation	VFA Accumulation	SlowHydrolysis	Needs Ratio Optimization

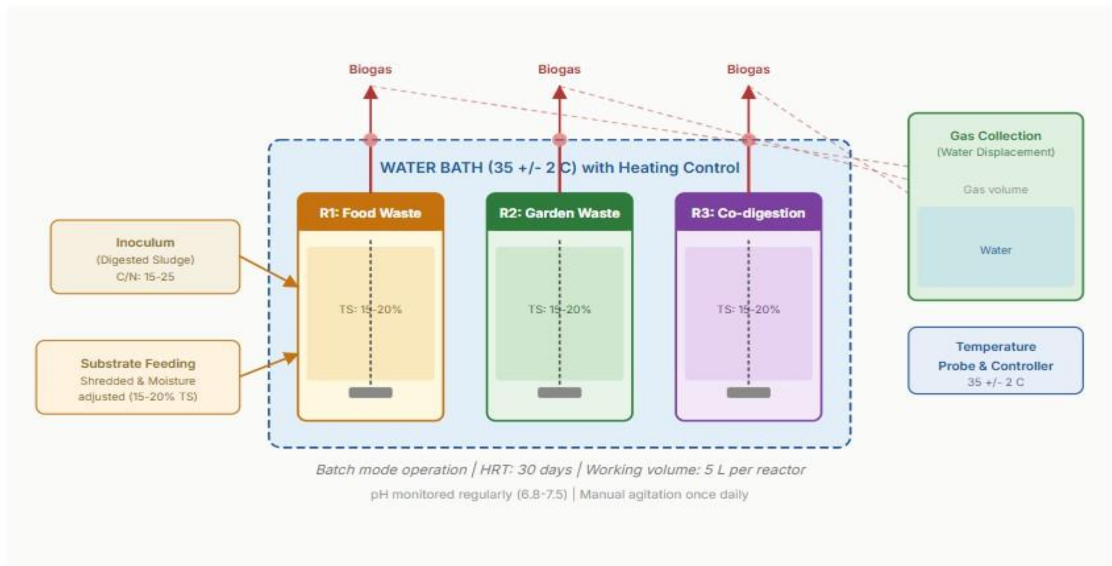

Figure 3: Schematic Diagram of the Experimental Setup for Semi-Dry Anaerobic Digestion

Three parallel batch reactors (R1, R2, R3) operated under mesophilic conditions with water displacement method for biogas volume measurement.

Threeexperimentalsetupswereprepared:

1. Foodwastedigestion
2. Gardenwastedigestion
3. Co-digestionoffoodandgardenwaste

Analytical Methods

Thefollowingparameterswereanalysedduringthedigestionprocess:

- pH
- Totalsolids(TS)
- Volatilesolids(VS)
- Chemicaloxygendemand(COD)
- Dailybiogasproduction
- Methaneconcentration

Biogasvolumewasmeasuredusingwaterdisplacementmethod.

Thebiogasyieldwascalculatedusing:

$$Y_{biogas}=\frac{V_{biogas}}{VS_{added}}$$

Volatilesolidsreductionwasdeterminedby:

$$VSReduction(\%)=\frac{VS_i-VS_f}{VS_i}\times 100$$

4. RESULTS AND DISCUSSION

Biogas Production Performance

Food waste exhibited rapid biogas generation during the initial digestion period because of its high organic biodegradability. Maximum cumulative biogas production was observed within the first 15 days of digestion.

Garden waste produced comparatively lower biogas yield due to the presence of lignocellulosic compounds that resist microbial degradation. However, stable gas production was observed over a longer digestion period.

Co-digestion of food waste and garden waste demonstrated improved digestion stability and enhanced methane recovery due to balanced nutrient composition and improved carbon-to-nitrogen ratio.

Methane Yield Analysis

Food waste showed higher methane concentration because of the presence of carbohydratesandlipids.Garden wastedigestionresultedinlower methaneyieldbecause lignin restricts microbial accessibility to cellulose and hemicellulose. The co-digestion system produced stable methane concentration and minimized acidification problems commonly observed in mono-digestion of food waste. The synergistic effect observedin theco-digestionreactorcanbeattributedtotheregulationofthecarbon-to-nitrogen(C/N) ratio and the dilution ofinhibitory compounds. Mono-digestion of food waste frequently leads to rapid acidification (pH< 6.0) due to the accumulation of Volatile Fatty Acids (VFAs) generated by fast acidogenic bacteria, often outpacing the consumption rate of methanogens. Garden waste, conversely, typically exhibitsa higher C/N ratioand slower acidogenesis. In the co-digestion setup, the lignocellulosic garden waste acts as a structural buffer, physically diluting the readily degradable organic matter andabsorbing excessammonia.ThisbufferingcapacitymaintainedthepHwithintheoptimalrangeof 6.8–7.5 throughout the experiment, preventing the"acid crash" often associated with high-solids food waste digestion. Additionally, the recalcitrant nature of garden waste likely provided a prolonged release of organic carbon, supporting a more stable methanogenic population over the extended retention period.

Volatile Solids Reduction

Highervolatilesolidsreductionwasobservedinfoodwastedigestion,indicatingefficient biodegradation of organic matter. Garden waste exhibited lower volatile solids reduction because of slower hydrolysis kinetics.

Effect of Semi-Dry Digestion

Semi-dryanaerobicdigestiondemonstratedseveraloperationaladvantages:

- Reducedwaterconsumption
- Smallerreactorvolume
- Higherorganicloadingcapacity
- Improvedenergyrecoveryefficiency

These advantages make semi-dry digestion suitable for decentralized waste-to-energy applications.While semi-dry digestion offers distinct volumetric benefits, it presents specific challenges regarding mass transfer compared to wet systems. At total solids concentrations of 15–20%, the viscosity of the substrate increases, which can hinder the diffusion of hydrolytic enzymes and the diffusion of metabolic products out of the microbial aggregates. However, the reduction in free water volume also results in higher concentrations of trace elements (such as Nickel, Cobalt, and Iron) in the liquid phase, which are essential cofactors for methanogenic enzymes. This suggests that under semi-dry conditions, therequirement for external traceelement supplementation may belower than in highly diluted wet systems.The higher organicloadingrate (OLR) utilized in this study also confirms that the microbial consortium adapted well to the high ammonia concentrations typically found in concentrated food waste streams, indicating the process's suitability for decentralized waste treatment.

Future Scope

Futureresearchmayfocuson:

- Pretreatmentofgardenwasteforenhancedbiodegradability
- Kineticmodellingofdigestionprocess
- Microbialcommunityanalysis
- Optimizationofco-digestionratios
- Techno-economicanalysisoflarge-scaleimplementation

5. CONCLUSION

This study comparatively evaluated biogas generation potential from food waste and garden waste under semi-dry anaerobic digestion conditions. Experimental findings revealedthat foodwaste produced significantly higher biogasand methane yieldbecause of its high biodegradability and organic content. Garden waste exhibited lower gas production dueto its lignocellulosic structure and slower degradation characteristics.

Co-digestion of food waste and garden waste improved process stability and methane recovery efficiency by balancing nutrient composition and reducing acidification risk. Semi-dry anaerobic digestion proved to be an effective and sustainable technology for renewable energy generation and organic waste management.

The study demonstrates the potential application of semi-dry anaerobic digestion for municipal organic waste valorisationand supportsthe development of sustainable waste-to-energy systems.

Furthermore,theoperational simplicityofthesemi-dryprocess,whichrequireslesswater management and smaller reactor footprints, makes it a scalable solution for municipal authorities and institutional campuses seeking to implement on-site waste-to-energy systems. Future implementation should focus on optimizing the feedstock mixing ratio based on seasonal variations in garden waste composition (e.g., leaf fall in autumn vs. grass growth in summer) to maximize year-round efficiency.

REFERENCES

1. Zhang, C., Su,H.,Baeyens, J., & Tan,T.(2014).Reviewing the anaerobic digestion offoodwasteforbiogasproduction.*RenewableandSustainableEnergyReviews*,38, 383–392.
2. Li, Y., Park, S. Y., & Zhu, J. (2011). Solid-stateanaerobic digestion for methane productionfromorganicwaste.*RenewableandSustainableEnergyReviews*,15(1), 821–826.
3. Brown,D.,Shi,J.,&Li,Y.(2012).Comparisonofsolid-statetoliquidanaerobic digestion of lignocellulosic feedstocks. *Bioresource Technology*, 124, 379–386.
4. Mata-Alvarez,J.,Dosta,J.,Romero-Güiza,M.S.,Fonoll,X.,Peces,M.,&Astals,S. (2014).A critical review onanaerobic co-digestionachievements between2010 and 2013. *Renewable and Sustainable Energy Reviews*, 36, 412–427.
5. Deepanraj,B.,Sivasubramanian,V.,&Jayaraj,S.(2017).Experimentalandkinetic study on anaerobic digestion of food waste. *Renewable Energy*, 101, 798–805.
6. Mao,C.,Feng,Y.,Wang, X., &Ren,G.(2015).Reviewonresearchachievementsof biogas from anaerobic digestion. *Renewable and Sustainable Energy Reviews*, 45, 540–555.
7. Kothari, R., Tyagi, V. V., & Pathak, A.(2010).Waste-to-energy: A way from renewableenergysourcestosustainabledevelopment.*RenewableandSustainable Energy Reviews*, 14(9), 3164–3170.
8. Tsapekos, P., Kougias, P.G.,Treu, L.,Campanaro, S., & Angelidaki,I. (2017). Process performance and comparative metagenomic analysis during anaerobic digestionofmanureandlignocellulosicbiomass. *AppliedEnergy*,185,126–135.
9. DiMaria,F.,&Sordi, A.(2020).Co-digestionofgardenandfoodwastein an existing anaerobic digestion plant. *Waste Management*, 102, 546-553.
10. Xu,R., &Zhang, K.(2020).Performanceofhigh-solidanaerobicdigestionofcorn straw for methane production: Areview. *Journal of Cleaner Production*, 260, 121112.
11. Nayak,S.S.,&Kalamdhad,A.S.(2020).Pre-treatmentandanaerobicdigestionof municipal solid waste:Areview. *Waste Management&Research*,38(9),956-972.

12. Achinas,S.,&Euverink,G.J.W.(2016).Theoreticalanalysisofbiogasproduction potentialsofagriculturalandfoodprocessing wastesintheNetherlands. *Resources, Conservation and Recycling*, 114, 93-100.
13. Jara-Samaniego,M.,Pérez,M.,&Gutiérrez,M.C.(2017).Compostingofdomestic bio-waste:Effectsofdifferentbulkingagentsonthecompostingprocessandquality of compost. *Waste Management*, 66, 170-178.
14. Wu,X.,Zhu,J.,Dong,C.,Miller,C.,Li,Y., Wang,L.,&Yao,W.(2019).Anaerobic co-digestion of swine manure with corn stover for biogas production. *Energy Procedia*, 158, 2854-2860.
15. Abraham, A.,Mathew, A.K.,Park,H.,Choi,O.,Sindhu,R.,Parameswaran,B.,...& Park, J. H. (2020). Pretreatment strategies for enhanced biogas production from lignocellulosic biomass. *Bioresource Technology*, 301, 122825.