Anaerobic co-digestion of wheat straw with food waste and cattle manure: Optimization of processing parameters (ISR, C/N, TS %) for enhanced biogas yield

Abstract Presentation at CORFU 2022

BY:

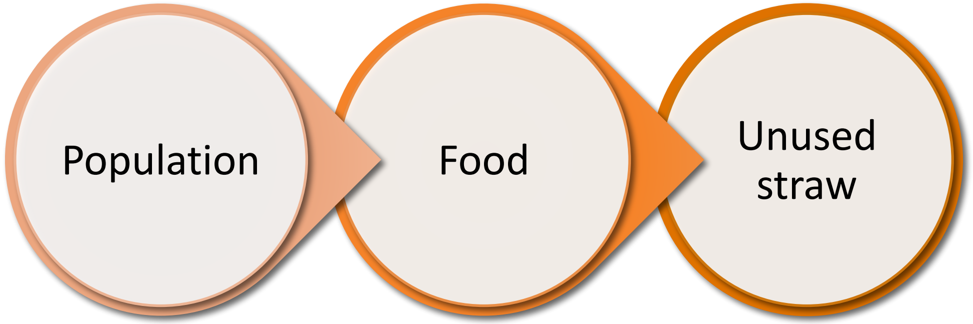
ALI MOHAMMAD RAHMANI,

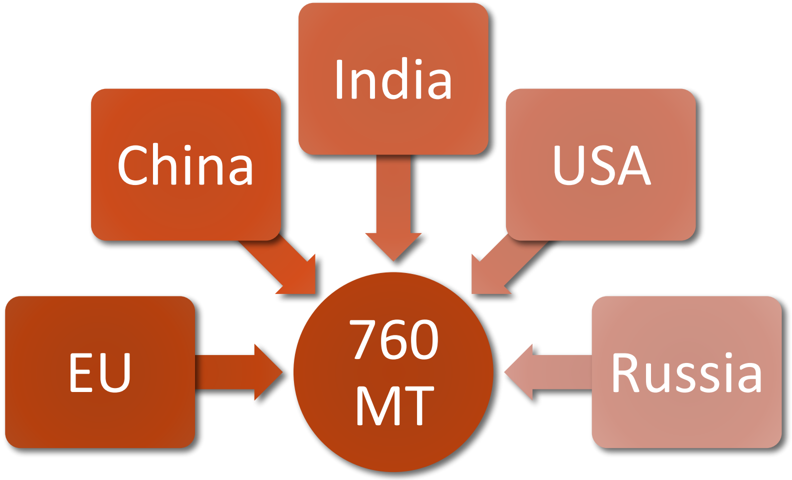
RESEARCH SCHOLAR AT IIT-ROORKEE, INDIA

DATE: 15-JUNE-2022

Contents

Introduction



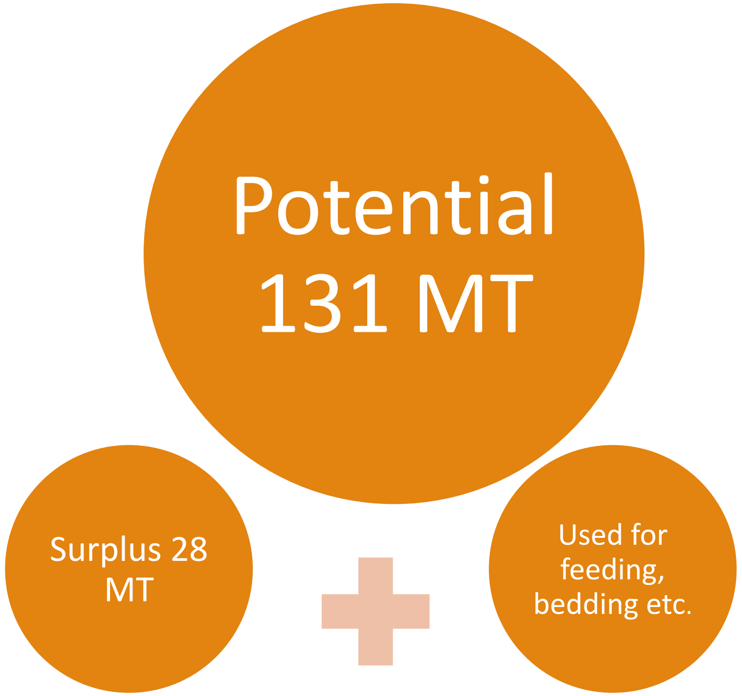


Wheat in World *(FAO, 2019)*

- The major crops grown globally: maize, wheat, and rice (FAO, 2019)
  - Their straws make up 79.5% of the total crop residue
- The residue to crop ratio of wheat varies geographically (0.8 - 1.5)
- In China, 787.4 MT of crop straw was produced in 2015
  - 20.7% of straw is directly combusted (Yu et al., 2019)

Introduction: India

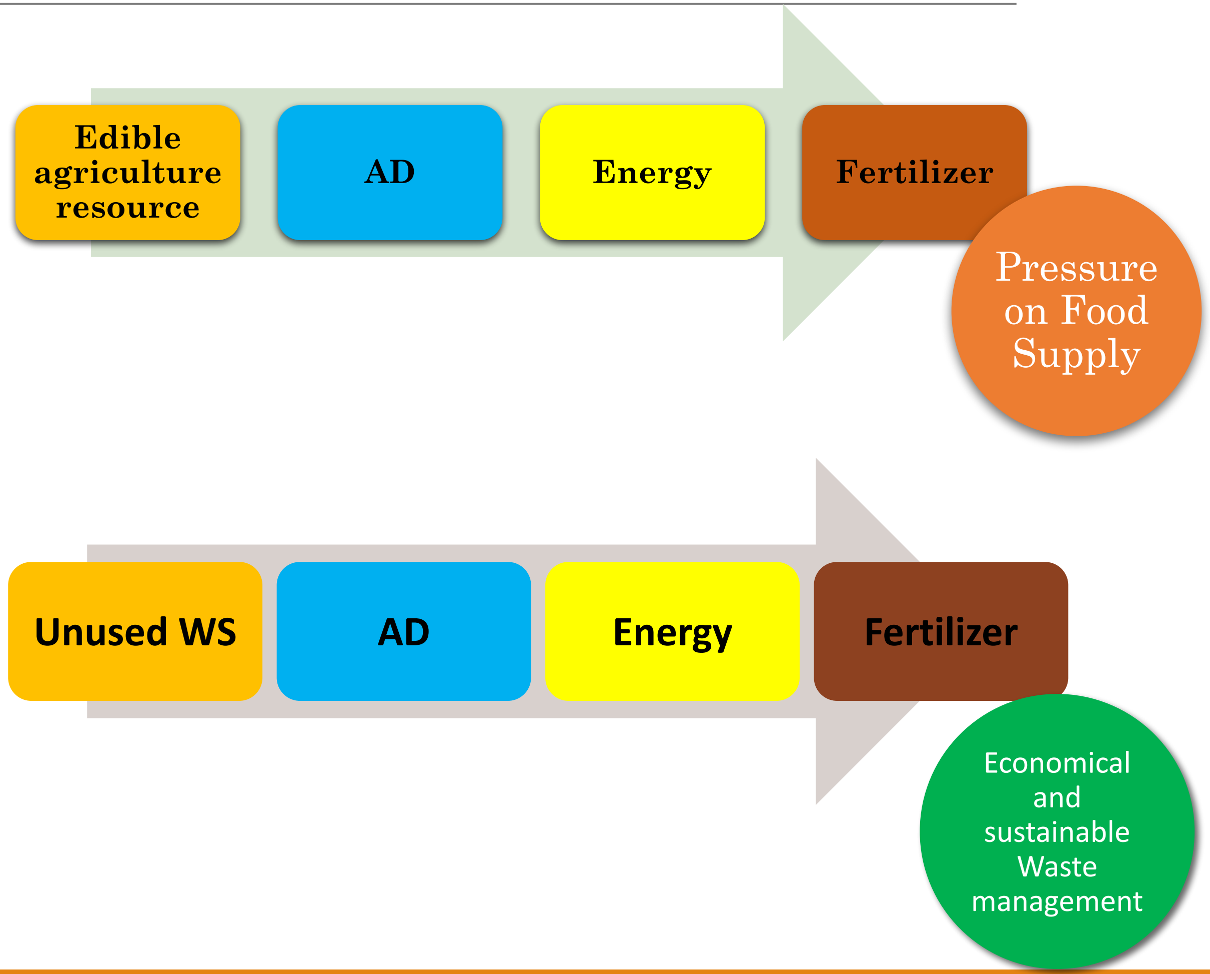
- **Agro-waste Production:** 488 MT, 2017, about 24% burnt at farmlands,
- **Future predictions:** 45% increase in agro-residue emission by 2050



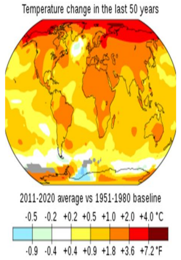
Wheat Straw in India
(Hiloidhari et al., 2014)

Bio-conversion technologies

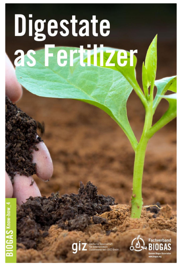
- **Incineration:** high capital and operating costs, generates ash, emit particulate and gaseous pollutants.
- **Pyrolysis and gasification**: require high temperature (>850ºC): energy intensive and expensive; technically challenging, and may not be energy positive since the generated energy may be needed to power the process.
- **Biological solution, i.e., Anaerobic digestion (AD)** of agro-residues is a promising approach: Energy rich biogas (H_2 & CH_4) & Nutrient rich Digestate as end products



AD advantage



Prevent 80 to 90% GHGs compared to natural gas *(Cherubini & Ulgiati, 2010)* which in turn prevent global warming and air pollution

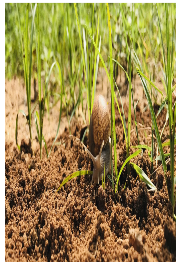


It allows closing the nutrient and humus cycle in agriculture *(Andersen et al., 2020).*

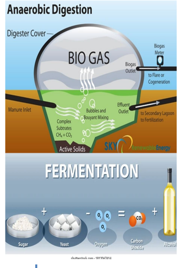
Fulfill the United Nations' sustainable development goal *(Cakir, 2018)*

renewable energy sources be 77% by 2050.

Wheat straw is a cheap and promising feedstock for bioenergy production *(Zheng et al., 2014)*

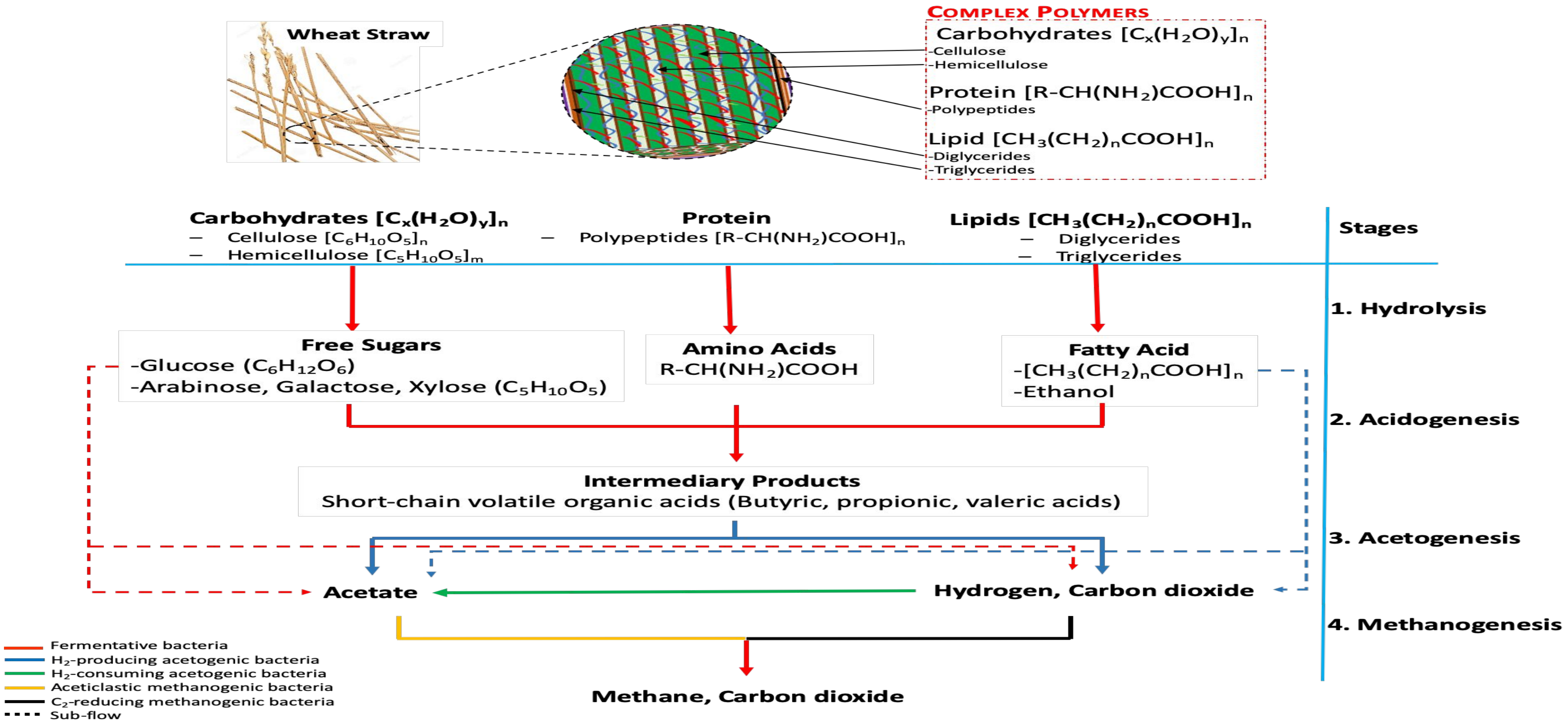


AD converts cellulose and hemicellulose to biogas but not lignin which is vital for increasing topsoil organic matter, microbial diversity and crop yield *(Hao et al., 2019).*



The process of AD allows more biomass utilization than alcoholic fermentation (Chandra et al., 2012). Moreover, AD is relatively simple and robust *(Chandel et al., 2018).*

AD Process


Wheat Straw
COMPLEX POLYMERS
Carbohydrates $[C_x(H_2O)_y]_n$
-Cellulose
-Hemicellulose
Protein $[R\text{-}CH(NH_2)COOH]_n$
-Polypeptides
Lipid $[CH_3(CH_2)_nCOOH]_n$
-Diglycerides
-Triglycerides
Carbohydrates $[C_x(H_2O)_y]_n$
– Cellulose $[C_6H_{10}O_5]_n$
– Hemicellulose $[C_5H_{10}O_5]_m$
Protein
– Polypeptides $[R\text{-}CH(NH_2)COOH]_n$
Lipids $[CH_3(CH_2)_nCOOH]_n$
– Diglycerides
– Triglycerides
Stages
1. Hydrolysis
Free Sugars
-Glucose ($C_6H_{12}O_6$)
-Arabinose, Galactose, Xylose ($C_5H_{10}O_5$)
Amino Acids
$R\text{-}CH(NH_2)COOH$
Fatty Acid
-$[CH_3(CH_2)_nCOOH]_n$
-Ethanol
2. Acidogenesis
Intermediary Products
Short-chain volatile organic acids (Butyric, propionic, valeric acids)
3. Acetogenesis
Acetate
Hydrogen, Carbon dioxide
4. Methanogenesis
Methane, Carbon dioxide
Fermentative bacteria
H_2-producing acetogenic bacteria
H_2-consuming acetogenic bacteria
Aceticlastic methanogenic bacteria
C_2-reducing methanogenic bacteria
Sub-flow

Problem statement

1. Addressing the challenge of waste management of surplus wheat straw *(Rena et al., 2020).*

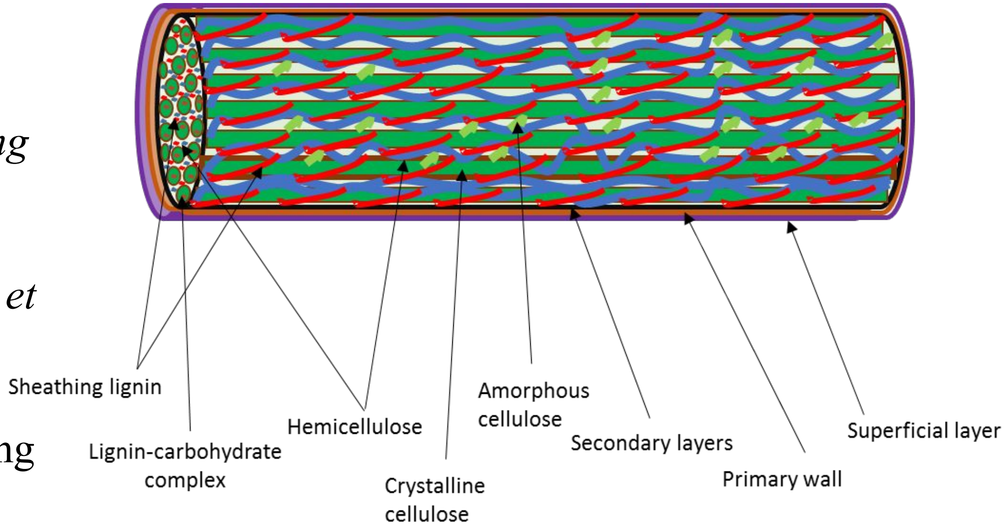
   uncontrolled incineration (low cost)

   - inhabit the agricultural field as ash,
   - GHG, VOC, PM *(Andersen et al., 2020)*
   - leading to global warming and air pollution.
   - reduce the organic carbon within the topsoil up to 70% *(J. H. Zhang et al., 2015).*

2. In addition, fossil fuel is being exhausted leading to energy insecurity *(Hyväkkö et al., 2020).*

Challenges with AD of straw

1. low biodegradability (Dell'Omo & Spena, 2020).
2. Lignin acting as a physical barrier to cellulolytic enzymes,
3. adsorbs some of enzymes thus removing them from the reaction zone *(Chang & Holtzapple, 2000)*.
4. the (C/N) is sometimes higher than 90 (w/w) *(Ferreira et al., 2013) (Rajput et al., 2021)*.
5. Cellulose crystallinity and degree of polymerization (DP) negatively affecting the degradation process *(Hendriks & Zeeman, 2009)*

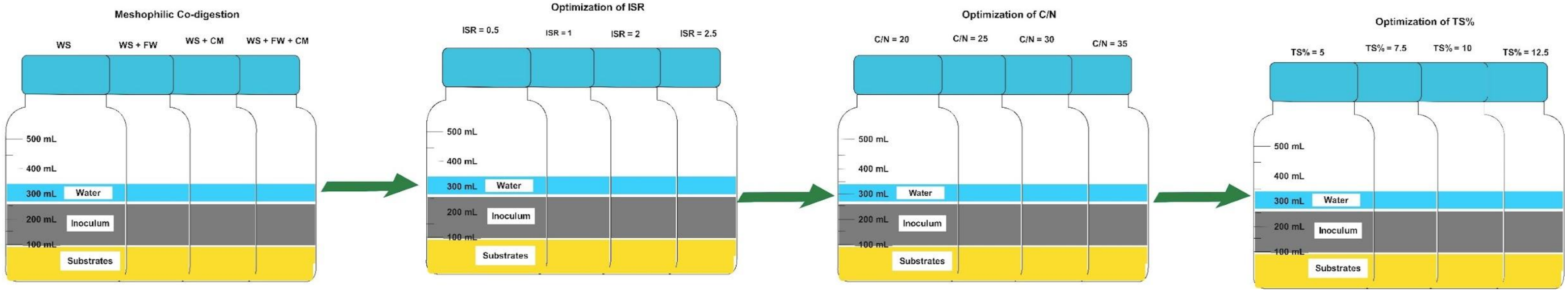


Strategies to increase the biodegradability are:

1. thermophilic anaerobic digestion (needs more energy, short fluctuation range)
2. **co-digestion**

   At what mixture ratio? What should be the ISR? What should be the C/N What should be the TS%
3. pretreatment

Methodology



- The ISR of 2 (VS basis)
- mixing ratio among the WS, FW, and CM was 1:1:1 (VS basis) for the co-digestion.
- working volume was fixed to 350 mL

- mixing ratio between the WS, FW, and CM was kept 1:1:1 (VS basis),
- the ISRs were 0.5, 1.0, 2.0, and 2.5.
- working volume was fixed to 350 mL

- The ISR 2
- Inoculum 50 g (VS basis)
- FW fraction 0.25 g (VS basis)
- Working volume 350 mL,
- The WS and CM fractions varied to make up different C:N ratios of 20, 25, 30, and 35.

- The ISR 2
- Inoculum 50 g (VS basis)
- FW fraction 0.25 g (VS basis)
- C/N 35
- The water content was varied to achieve the desired TS% of 5, 7.5, 10, and 12.5%.

Batch Assays setups

Inoculum

Reactors

Caps with Septa

Mixture with FW, CM and inoculum

Triplicate

N2 purging

Mesophilic incubation and rotation

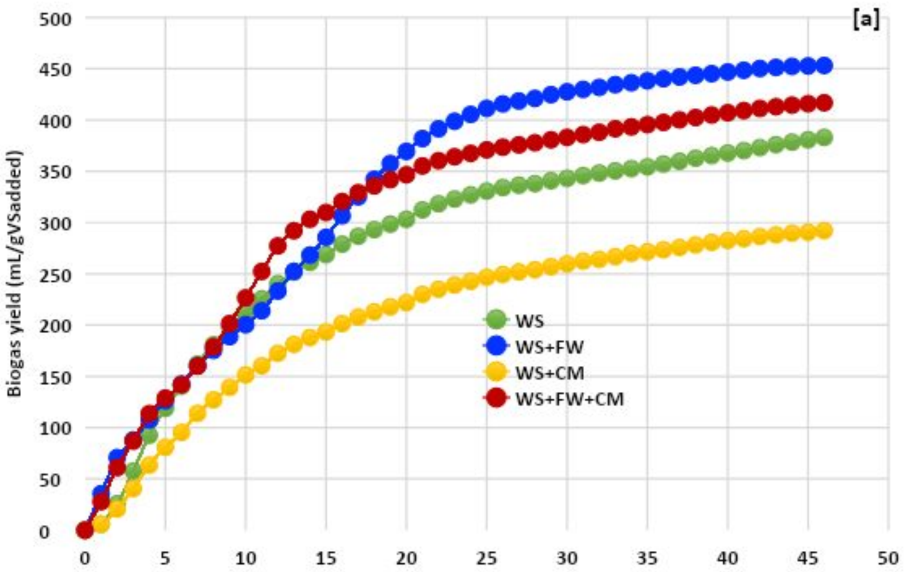
Biogas measurement

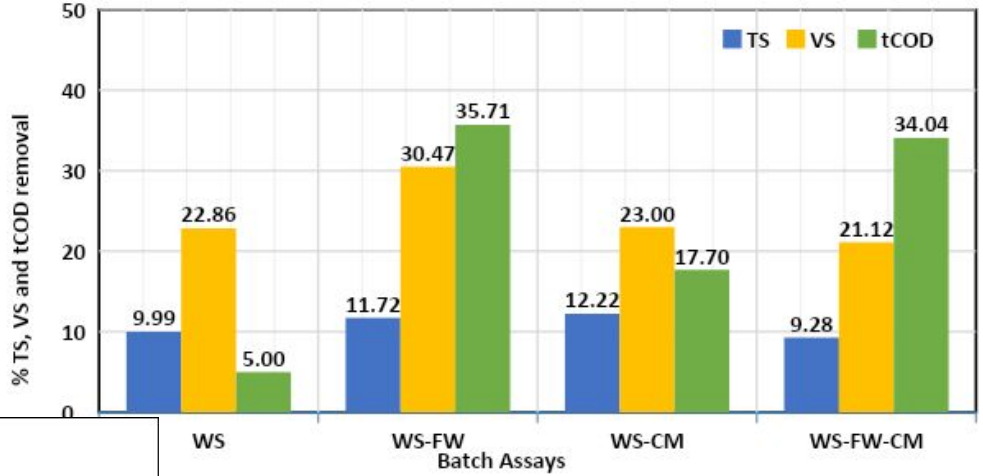
Raw waste characterization

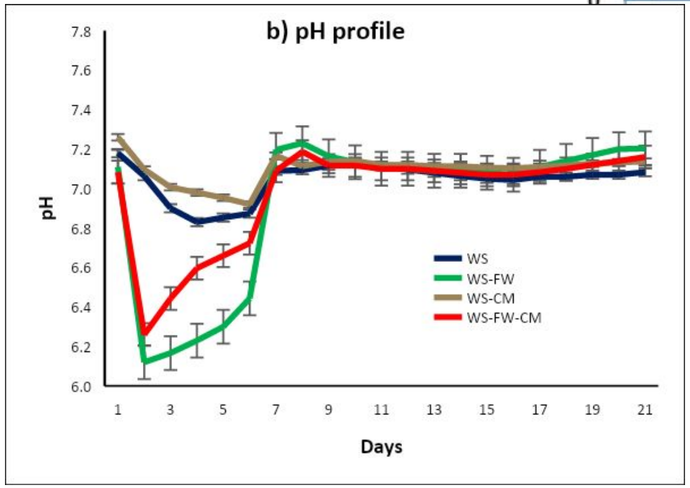
Parameters	***WS***	***FW***	***CM***	***Inoculum***
pH	7.1	5.3	7.3	7.4
TS%	89.64	28.96	13.77	3.19
VS (% TS)	86.66	91.29	87.53	53.3
Organic Carbon (% TS)	48.15	50.72	48.63	29.61
Density (kg/l)	0.10	1.07	0.95	1.05
Nitrogen (TKN) (% TS)	0.83	2.12	2.66	-
C/N	58.01	23.94	18.28	-
NH_4-N (dry g/kg)	0.19	2.89	3.15	-
sCOD (dry g/kg)	76	287	56	-
tCOD (dry g/kg)	811	942	715	-
Alkalinity (dry g/kg)	20.08	19.45	43.57	-
VFA (dry g/kg)	88.13	26.75	55.91	-
Cellulose (% TS)	39.2	-	-	-
Hemicellulose (% TS)	28.6	-	-	-
Lignin (% TS)	14	-	-	-
Extractives (% TS)	4.9	-	-	-
Ash (% TS)	13.3	-	-	-

Batch Assay 1 (Mixture optimization)

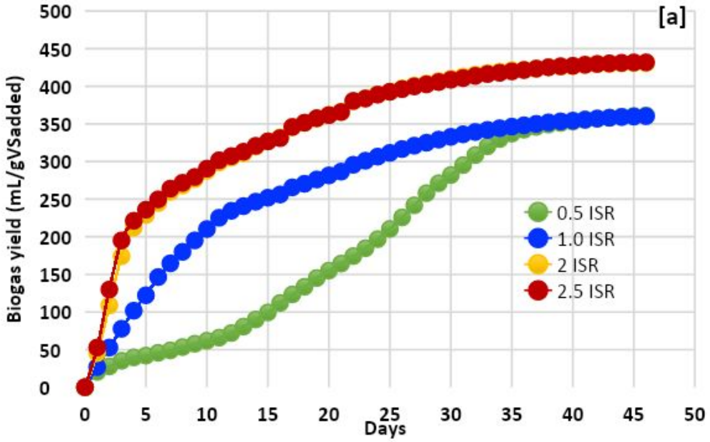
20%

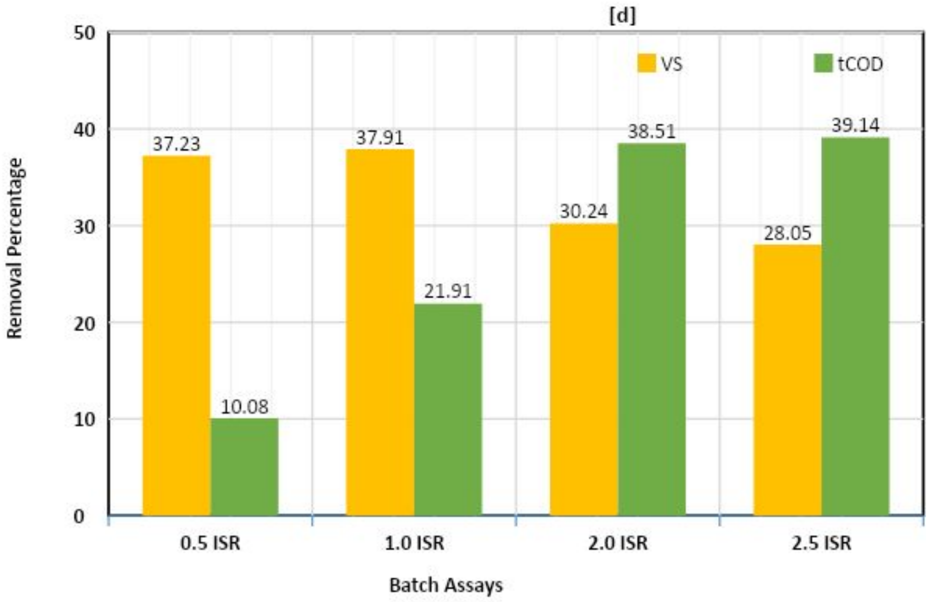


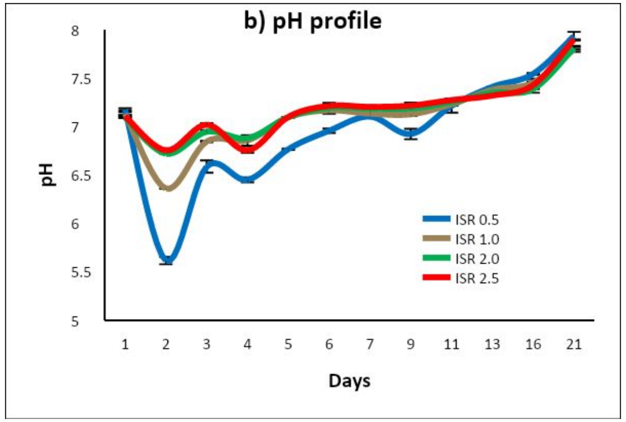


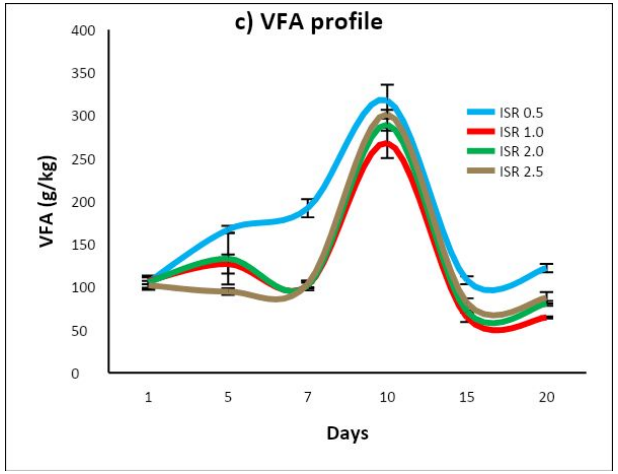


Batch Assay 2 (ISR Optimization)

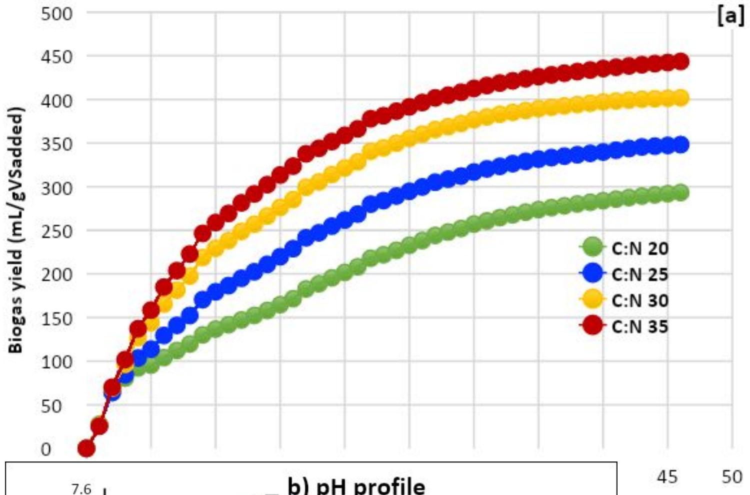




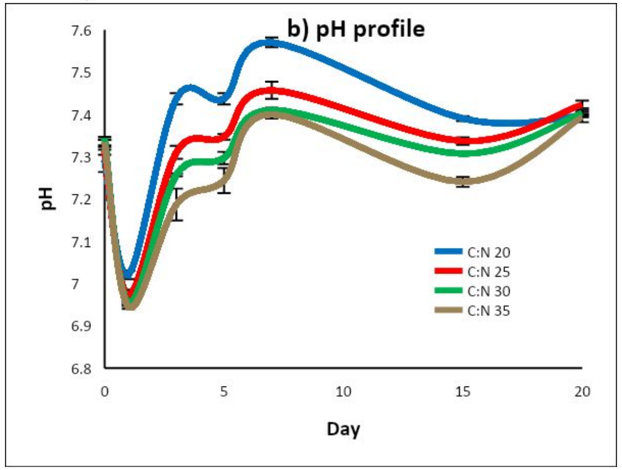


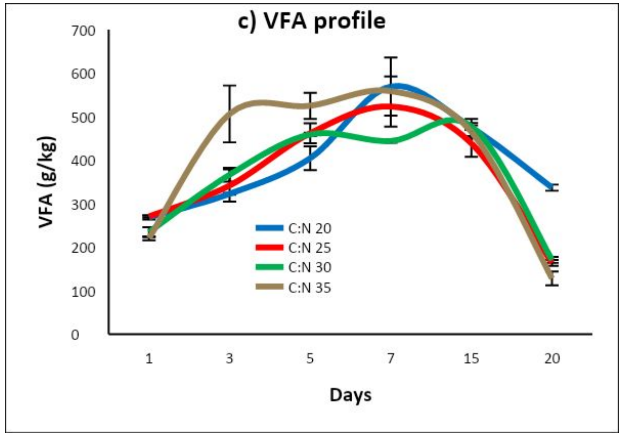


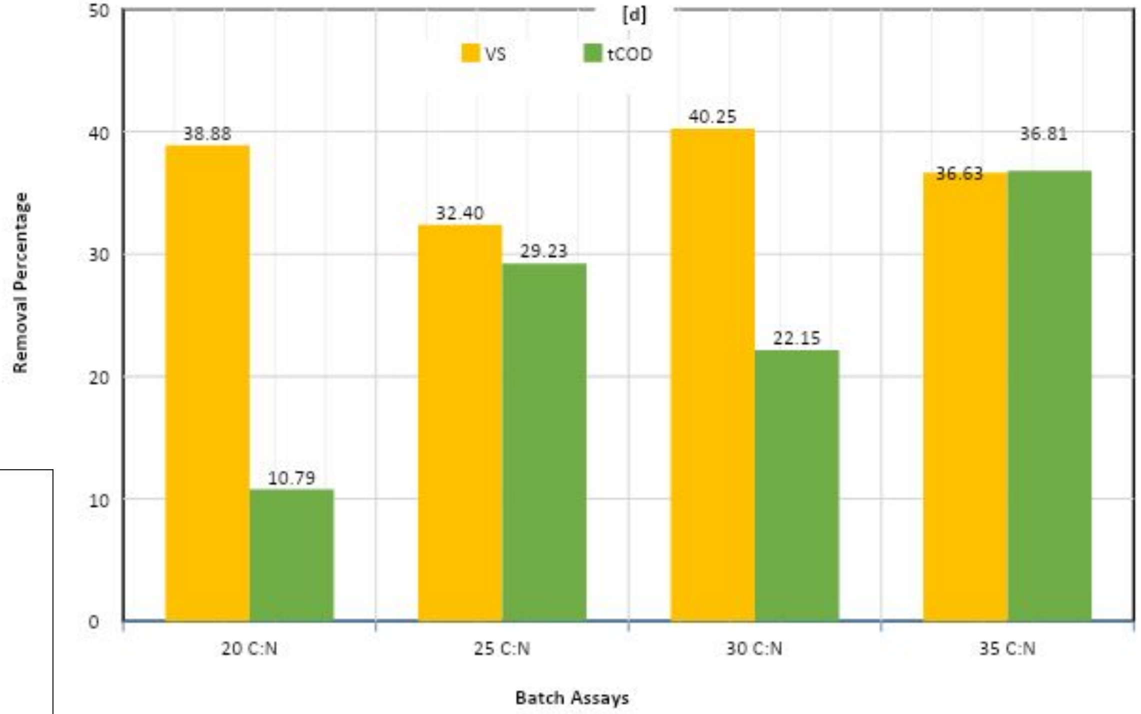
Batch Assay 3 (C/N Optimization)



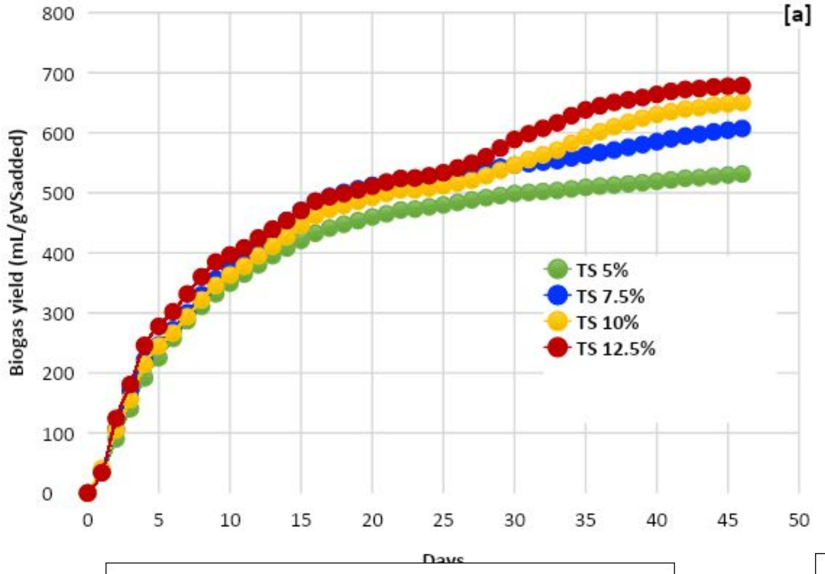
18%



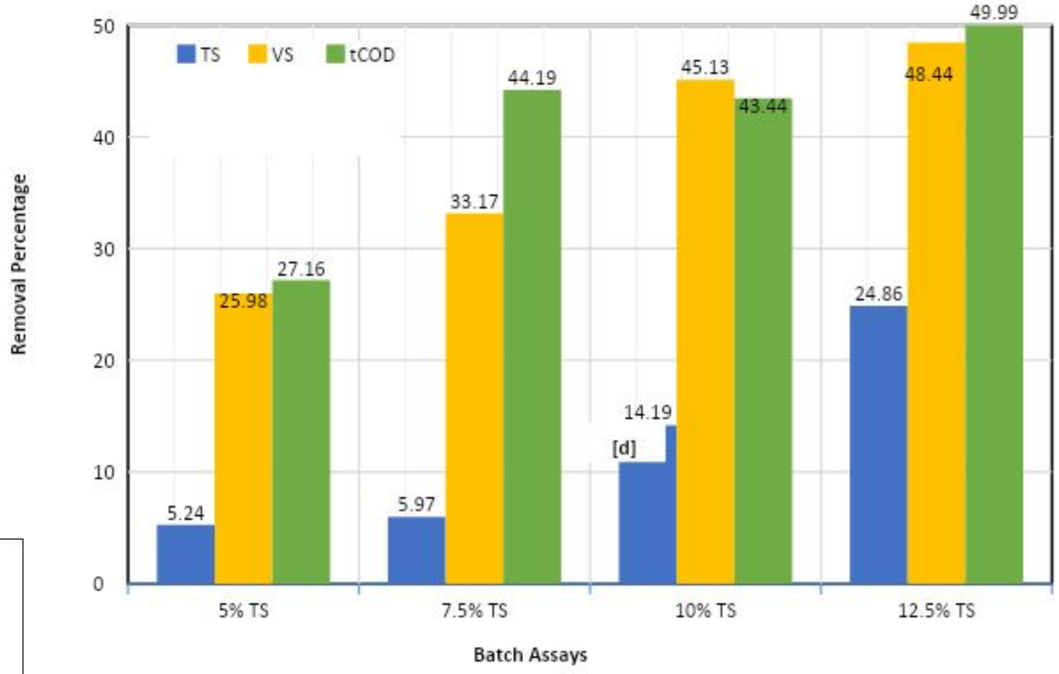


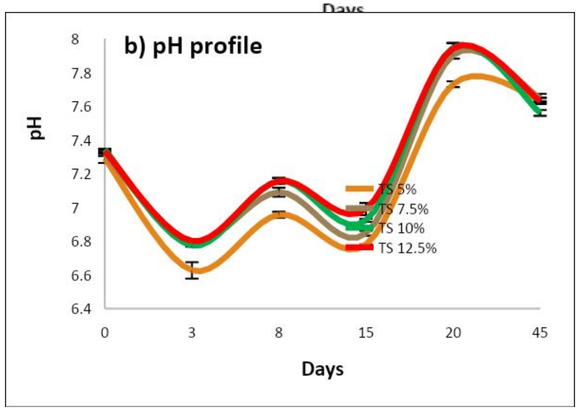


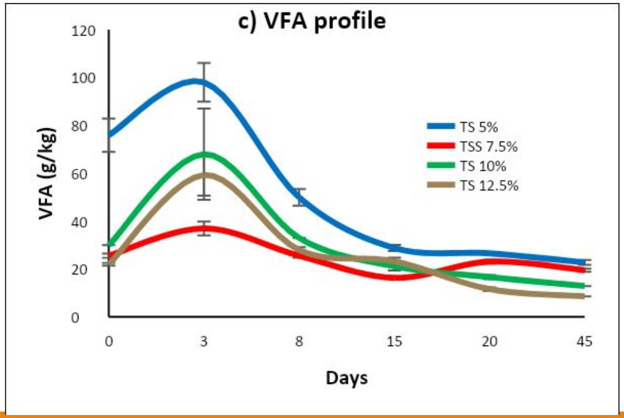
Batch Assay 4 (TS% Optimization)



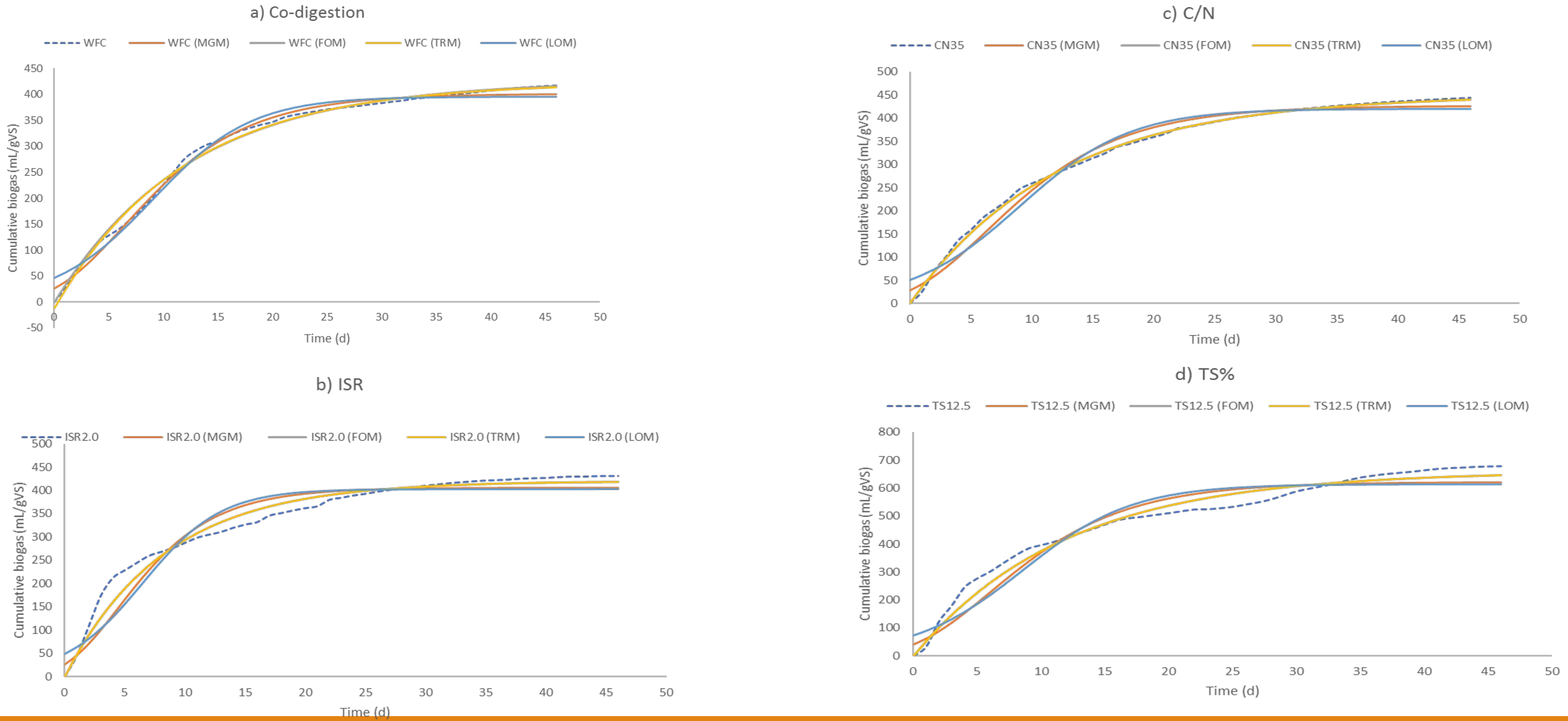
80%







Kinetics Study



Kinetics Study

Batch assays	Modified Gompertz model				First-order model			Transference model				Logistic model				Experimental	
	Bm	Rm	λ	R^2	Bm	k	R^2	Bm	Rm	λ	R^2	Bm	Rm	λ	R^2	Bm	Rm
WS	361.063	20.383	0.000	0.986	385.927	0.077	0.996	380.608	32.055	0.590	0.997	355.299	19.355	0.000	0.971	383.021	34.860
FW	565.229	22.138	0.087	0.986	699.778	0.042	0.973	698.095	29.262	0.034	0.973	534.682	22.858	1.025	0.991	514.898	56.532
CM	144.270	7.562	0.000	0.995	161.011	0.067	0.995	159.820	10.961	0.180	0.995	140.594	7.226	0.000	0.989	147.360	16.747
WS+FW	457.394	20.815	0.000	0.995	500.207	0.060	0.989	496.407	31.029	0.266	0.989	447.713	19.784	0.000	0.994	453.156	35.562
WS+CM	278.840	13.988	0.000	0.987	303.551	0.066	0.998	298.976	21.429	0.533	0.998	273.536	13.280	0.000	0.973	292.104	22.984
WS+FW+CM	401.708	23.035	0.000	0.993	426.101	0.080	0.994	422.981	35.629	0.348	0.995	395.450	21.922	0.000	0.986	416.798	33.214
ISR 0.5	453.612	11.594	5.826	0.991	5426.333	0.002	0.973	19018.851	9.172	1.496	0.973	390.364	12.962	7.931	0.997	361.189	20.330
ISR 1	345.019	19.637	0.000	0.977	366.937	0.079	0.997	366.937	29.133	0.000	0.997	340.342	18.491	0.000	0.960	360.316	26.767
ISR 2	406.040	33.303	0.000	0.925	420.033	0.120	0.974	420.033	50.522	0.000	0.974	403.396	30.997	0.000	0.901	430.845	65.315
ISR 2.5	403.517	35.082	0.000	0.907	416.797	0.127	0.963	416.797	53.019	0.000	0.963	401.110	32.633	0.000	0.882	431.850	77.081
C:N 20	288.634	11.779	0.000	0.973	318.258	0.054	0.987	318.259	17.221	0.000	0.987	283.941	11.007	0.000	0.969	293.294	37.556
C:N 25	338.705	16.267	0.000	0.981	365.624	0.066	0.996	365.624	24.072	0.000	0.996	333.814	15.220	0.000	0.971	348.176	37.955
C:N 30	390.055	21.598	0.000	0.979	413.638	0.078	0.998	413.639	32.434	0.000	0.998	385.483	20.184	0.000	0.966	401.782	42.754
C:N 35	426.072	24.812	0.000	0.981	450.427	0.083	0.999	450.428	37.201	0.000	0.999	420.944	23.282	0.000	0.966	443.499	44.620
TS 5%	503.659	37.396	0.000	0.981	522.489	0.109	0.987	521.725	57.499	0.089	0.998	498.952	35.265	0.000	0.965	531.279	56.299
TS 7.5%	563.555	40.092	0.000	0.976	586.418	0.104	0.994	586.417	60.705	0.000	0.994	558.100	37.777	0.000	0.962	607.143	70.605
TS 10%	592.121	34.493	0.000	0.948	632.369	0.080	0.982	632.369	50.538	0.000	0.982	583.525	32.644	0.000	0.927	650.266	64.705
TS 12.5%	621.509	37.915	0.000	0.931	660.887	0.084	0.974	660.886	55.713	0.000	0.974	613.440	35.765	0.000	0.908	678.574	90.092

Conclusion

1. Anaerobic co-digestion of the three substrates had synergetic effects on biogas production (20% higher yield) compared to mono-digestion and 21% VS removal.
2. The ISR 2 and 2.5 produced identical biogas of 431 mL/gVS, but ISR 2 was considered as optimum one to achieve economically viability of process. In ISR 2 assay, the VS degradation of 30.24% has been achieved.
3. The CN35 (ISR 2) attained the highest biogas yield among the C/N studied with increase of 17.4% compared to mono-digestion of WS and 36.6% VS removal. Higher process stability was achieved for VFA, alkalinity and pH over previous batch assays.
4. In the fourth assay, 12.5% TS yielded 80% higher biogas compared to WS mono-digestion (control) and ≈ 50% VS destruction, highest among the TS% studied.
5. Additional improvement in substrate biodegradation and biogas yield could be obtained by pretreatment of the recalcitrant WS.
6. The experimental data of all batch assays were compared with MGM, FOM, TRM and LOM. All batch assays were fit well with all models, especially CN35 with TRM having R^2=0.999.

References

Ben'Ko, Elena M., Dmitriy G. Chukhchin, and Valeriy V. Lunin. 2020. "Changes in Wheat Straw Cell Walls during Ozone Pretreatment." *Holzforschung* 74(12):1157–67. doi: 10.1515/hf-2019-0168.

Korai, Rashid Mustafa, and Xiujin Li. 2020. "Effect of Ultrasonic Assisted KOH Pretreatment on Physiochemical Characteristic and Anaerobic Digestion Performance of Wheat Straw." *Chinese Journal of Chemical Engineering* 28(9):2409–16. doi: 10.1016/j.cjche.2020.06.022.

Kumar, Subodh, Paras Gandhi, Monika Yadav, Kunwar Paritosh, Nidhi Pareek, and Vivekanand Vivekanand. 2019. "Weak Alkaline Treatment of Wheat and Pearl Millet Straw for Enhanced Biogas Production and Its Economic Analysis." *Renewable Energy* 139:753–64. doi: 10.1016/j.renene.2019.02.133. (*Reprinted with permission from Elsevier*).

Victorin, Mirjam, Åsa Davidsson, and Ola Wallberg. 2020. "Characterization of Mechanically Pretreated Wheat Straw for Biogas Production." *Bioenergy Research* 13(3):833–44. doi: 10.1007/s12155-020-10126-7.

Yadav, Monika, and Vivekanand Vivekanand. 2021. "Combined Fungal and Bacterial Pretreatment of Wheat and Pearl Millet Straw for Biogas Production – A Study from Batch to Continuous Stirred Tank Reactors." *Bioresource Technology* 321(December 2020):124523. doi: 10.1016/j.biortech.2020.124523

Thank You!