Original Research Article

Energy recovery from poultry droppings in farming environments in the context of climate change

Abstract

The poultry sector has grown significantly in the recent years. Certainly, the rise in the global population, particularly in developing nations, has prompted the expansion of the agricultural sector to fulfill the growing demand for food. The activity produces organic waste and the management of which can pose problems in the breeding sites. Poultry farming requires energy for the production processes. It is in this context, his study aims to examine the energy potential of poultry waste depending on whether its origin is industrial or domestic. The methanogenic potential of these wastes was determined using the BMP test on industrial manure, household manure and other wastes such as cow and horse dung as controls. The tests showed that the industrial manure had higher gas content and higher CH_4 than the control cow and horse dung. The link between biogas production and the chemical composition of the dung, such as its C/N ratio, was also demonstrated. The findings indicates that the industrial manures are favorable methanogenic substrates for methane production. Utilizing Industrial poultry droppings for energy recovery has the potential to make poultry farms energy independent. The energy autonomy of these industries can be a significant advantages to these agricultural enterprises, and is an excellent technique to combat or limit climate change.

Key words: Biogas, Methanation, Poultry droppings, Energy.

1) Introduction

Fossil fuels are commonly regarded as the backbone of our society's energy supply. The environmental pollution caused by the use of fossil fuels and their progressive depletion make it necessary to find alternative, environmentally friendly and renewable sources of energy and chemicals.

Furthermore, as the global population continues to grow, there is an escalating demand for both energy and food [1] leading to increased waste generation. Most of these activities produce methane, which is a potent greenhouse gas. Methane has been categorized as one of the GHG with its global warming potential, 21 times more potent than CO2 [2] [3].

Thus, in order to meet the high demand for both food and energy, and imperative to mitigate climate impacts, hydrocarbons derived from biomass or bio-fuels have aroused a great deal of interest and are emerging as an alternative to the use of fossil fuels. Methanizationrepresents one of the prominentprocesseswithinthisemergingfield[3]. Certainly, methanisation or the anaerobic digestion for the production of methane-containing biogas is a classic example of a resource recovery process, that combines the treatment and stabilization of particulate organic matter with the production of a valuable end product [4].

The anaerobic decomposition of organic matter, under the action of microorganisms, into biogas, is considered a viable alternative source of energy. However, the energy efficiency of biogas depends on the composition of different constitutive gases. There is a positive correlation between the CH_4 composition of biogas, its calorific value and the composition of the organic matter. In addition, the byproduct generated from anaerobic digestion (compost or biodigestate) could be used as an alternative organic fertilizer[5]. This product is rich in nitrogen and could be used to fertilize food crops, such as sorghum, in Senegal [6].

Methanisation provides an efficient approach to pollution reduction, surpassing the effectiveness of conventional aerobic processes [3]. While methanization or anaerobic fermentation has been in practice for decades, it is only in recent times that significant attention has been directed towards its utilization in economically recovering fuel gas from industrial and agricultural surpluses [7]. The anaerobic processes has considerable advantages over aerobic active sludge system such as (a) less energy demand (b) minimal sludge formation (c) minimization of unpleasant odour (d) efficient break down of organic substances by anaerobic bacteria to methane.

One of the raw materials producing sectors is poultry breeding farm. The global poultry sector is characterized by faster growth in consumption and trade than any other major agricultural sector [8]. The consumption of poultry meat is increasing, since it is considered a convenient product that is readily available on the market. World poultry production increased from 9 to 133 million tonnes between 1961 and 2020, and egg production increased from 15 to 93 million tonnes[9]. Today, chicken production is a global industry with a projected meat protein intake of 17% by 2031 [10]. Chicken meat and eggs are the best source of quality protein and are essential for millions of people living in poverty.

This increase in poultry production leads to a large-scale accumulation of waste, especially manure and litter, and is one of the major problem for the poultry industry. This poses a significant challenge for the poultry industry, raising concerns about environmentally and economically sustainable waste management solutions to address disposal and pollution issues [4]. Most of the litter produced by the poultry industry is currently directly applied in agricultural lands as a source of nutrients and soil amendment. However, environmental pollution can be generated due to nutrient and contaminant leaching when poultry litter is applied directly onto soil under climatic conditions that are not conducive to the efficient agronomic utilization of the nutrients contained in the manure. Thus, this context will justify the choice of our study material which is chicken droppings from the peri-urban area of Sangalkham of Dakar, where chicken farming activities are developed to meet the food needs of the city. Poultry farming results in the production of significant amount of organic matter in the form of manure waste mixed with different proportions of rearing media (peanut shells, shells, rice straw, etc.). The quantities are significant and ~~are~~ estimated at 41 tons of poultry waste per month [11] with different valorization outcomes (energetic, agronomic, calorific) [12].

The aim of this study is to characterize poultry manure waste according to the nature of the farm substrate and to evaluate its methanogenic potential. For this purpose, a semi-industrial farm in the Sangalkam area was chosen to carry out a complete sampling of poultry droppings. In addition to these samples, droppings were collected off-site to serve as a reference. Dung (cow dung and horse dung) were chosen for control.

The study explores anaerobic digestion as a recycling method for poultry excrement. Specifically, the study assess the energy potential of poultry droppings within the broader context of poultry industry growth and environmental management.

2)MATERIALS AND METHODS

2.1) Sampling condition

The materials used are mainly poultry waste from a company in the peri-urban area of Dakar that we call "poultry industry". The chickens were raised on the floor, resulting in the production of waste in the form of droppings, sometimes mixed with litter. It was observed that shavings were used as bedding material, although the precise quantities varied according to requirements. To collect samples, visits were conducted to multiple farms belonging to the company "poultry industry". These samples were subsequently crushed and coded. Detailed farm characteristics were obtained through information sheets displayed at each farm site.

In this study, the substrates employed included poultry droppings, cow dung, and horse dung. A total of 20 samples were used, comprising 16 samples from industrial poultry production, 2 from non-industrial sources, 1 from cow dung, and 1 from horse dung. The 16 samples from industrial farms adhered to specific standards and were designated with codes ranging from B1 to B16 based on their respective building numbers. Meanwhile, the two samples obtained from non-industrial sources were labeled with the letter D followed by a letter indicating their domestic origin ((DMixr: Domestic origin mixed with rice litter and DMixw: Domestic origin mixed with wood).

2.2) Biochemical characterization of poultry

Collected samples were systematically weighed (1g) and packaged before storage at low temperature (4–8°C). Total carbon, total nitrogen, soluble phosphorus, exchangeable cations (Ca, Mg, K and Na) and ash contents were analysed by a quality-certified chemical analysis laboratory (LAMA lab, Dakar, https://imago.ird.fr/moyens-analytiques/dakar).

Other chemical analyses of chicken droppings included total solids (TS), fresh matter (FM), volatile solids (VS) and chemical oxygen demand (COD) [13]. Total solids (TS) were determined by incubating a sample at 104°C until no further weight change was evident, and volatile solids (VS) were measured by the loss of weight upon ignition of the dried sample at 550°C. COD was determined by a chemical method, and the calorific value was determined in a bomb calorimeter.

The pH of the samples was determined in advance, and the values were observed to be close to neutral pH (Table 1). The pH of the manure samples collected from the site had values between 5.87 and 7.29. Manure collected off-site (DMixr: Domestic origin mixed with rice litter and DMixw: Domestic origin mixed with wood) had pH values of 7.24 and 7.29, respectively, while fermented feed (B1) had 6.83. The Cow dung (DC) had a pH value of 5.87, the most acidic of all samples.

Table 1: Representation of pH values;

Samples	B1	B2	B3	B4	B5	B6	B7	B8	B9	HD	B10	B11	B12	CD	DMixw	DMixr	B13	B14	B15	B16
pH	6.83	6.9	7.25	7.29	7.18	7.34	7.3	7.25	6.85	6.9	6.85	7.25	7.34	5.9	7.29	7.24	7.28	7.26	6.9	7.07

B: Industrial Batiment (followed by the number); DMixr: Domestic origin mixed with rice litter; DMixw: Domestic origin mixed with wood shavings litter CD:Cow Dung; HD: Horse Dung

2.3) Measurement of biochemical methane potential

The principle of methane potential BMP (BMP: Biochemical Methane Potential) assay is to incubate a small amount of organic substrate, to monitor the amount of biogas and the proportion of methane produced. Digestion process was studied in batch reactors to develop an appropriate technology for the production of biogas from the solid waste obtained from poultry farms. A known amount of substrate, containing a mixture of waste was transferred into wide mouth glass bottle. All of the bottles were sealed with air tight rubber stoppers. Biogas produced by anaerobic digestion was collected and measured by the water displacement method.

For the experiment, the inoculum was introduced in a 10L bioreactor containing 400g (fresh weight) sediments, taken from Lake Retpa [a highly salty environment that is rich in extremophilic microorganisms [14], 800 g cow dung and filled with water to maintain a volume of 2 L in total. The experimental conditions were tested, including a positive control and negative control (solution and inoculum alone). Each experiment was repeated three times for reliability. All bottles were placed in an oven (38°C) and shaken (two to three times per day). The produced CH_4 and CO_2 were measured using micro-chromatography (ICG).

2.4) Data analysis and statistical tests

Statistical analyses were performed on different parameters that were measured on the composition of the samples to assess their energy potential. The analysis of variance "ANOVA" was employed, followed by a comparison test (Tukey HSD) using XLSTAT software (version 2010.3.02; Addinsoft Inc, Long Island City, NY, USA).

3)RESULTSAND DISCUSSION

3.1) Chemical composition of chicken droppings

The table table 2 represents total solid (TS) and volatile solid (VS) of the substrates.

Regarding the total solid (TS) of the samples from the company "poultry industry" site, the values obtained were all above 50% TS, with the exception of B13 (with 46.16% TS). Samples B2, B3 had higher TS contents than the off-site samples, i.e., DMixr (86.57% TS) and DMixw (77.25% TS). The dry matter content of horse dung (HD) was among the richest (93.45% TS) while that of cow dung was intermediate with an average value of 77.25% TS. These results suggest that the samples collected were relatively dry with the exception of B13 (with 46.16% TS).

For volatile solids, the results obtained showed that the average volatile solids value of the study site samples was 65.85%. The sample B13 had the highest VS (82.07% VS) and significantly different from all the samples, B8 had the lowest value (51.94% VS). The off-site samples (DMixw and DMixr) had VS values of 74.73% and 77.87% were significantly not different from the majority of the samples collected from the company site "poultry industry". Cow dung had a value of 72.54% and significantly higher than horse dung (57.67%).

3.2) Composition of the produced biogas

In terms of biogas quality (percent CH_4), the methane values produced ranged from 39 to 60% for all poultry droppings. The biogas produced by the B15 droppings had a significantly higher methane value than the off-site DMixr droppings and highly significant compared to the off-site DMixw droppings. A total of 11 droppings from the company site "poultry industry" out of 14 produced methane with significantly higher methane value than the off-site DMixw droppings. Among this batch of poultry droppings, 7 had significant ($p<0.001$) mean values, while 4 were slightly higher than the amount of methane in the off-site DMixw sample biogas.

All the substrates have a common characteristic: they all are originated from animal. However, they exhibit variations on multiple fronts, including the animal species, age, and the farming practices involved. Specifically, the substrates consist of waste materials from poultry, non-ruminant animals (hair), and ruminant animals (beef).

Following the production kinetics, samples of poultry droppings were performing well compared to cow dung which is the most used substrate. This trend in biogas quantity is maintained with the biogas quality showing a good methane percentage 60.01% for B15 followed by HD 56.41% CH_4. Except DMixw (39.01%), DMixr (47.41%) and DC (45.21%), all other substrates show CH_4 proportions above 50%. The XLSTAT ANOVA software did not show any significant difference between the control and the samples with CH_4 percentages above 50% except for B11, B13 and B16.

Regarding the unidentified gases, there is notable variability in their percentage composition. This can be observed across three different batches: The first batch is made up of 11 samples including B8, B10, B16, B11, B6, B1, HD, B7, B12, B16, B5 and it's noteworthy that within this group, the samples demonstrate the highest CH_4 percentages.; then the second batch consists of B9, B3, B14, B13, B3, B2, DC, DMixr, B4, and finally a third batch of DMixw and DC have the CH_4 % respectively. The quality of biogas has a direct influence on the calorific value of the substrate. Indeed, the proportion of methane is closely related to the calorific value and this is demonstrated by the calorific value formula: PCI (calorific value) = $9.42*CH_4\%$ at 15°C at atmospheric pressure. The correlation between volatile total solid (TS) and biogas richness is negative.

The production of methane depends on the composition and availability of mineral elements, such as nitrogen, carbon, phosphorus and other trace elements. During anaerobic digestion, bacteria use ambient CO_2 and various nutrients present in the substrate (in this case poultry dropping, cow and horse dung) to produce methane.

The energy potential, which is reflected in the quality of the biogas, is strongly related to the chemical quality of the substrate, such as volatile solids and Chemical Oxygen Demand (COD), and also physical factors such as pH. In this study, the pH is around neutrality (pH 6.5 and 7.3) for all the samples at the start of methanisation, which agrees well with the results of Ferry, (1993) [15]. This pH close to neutrality is ideal for micro-organisms which are very sensitive to the ionic balance of the environment [4]and at a certain threshold the pH becomes toxic. For total solid (TS) and volatile solid (VS), overall, the samples have proportions above 50% except for B13 which is 22 weeks old laying hen droppings, has a 46.16% TS. These findings are not in line with the work of Quideau, et al., (2014)[16], whose research on pig manure typically yielded TS percentages ranging from 4.97% to 7.8% [16]. It's worth noting that the TS percentages in the current samples are more in line with the results reported by Tahri et al. (2012)[17], where the TS content for poultry waste was recorded at 96.16% [17]. Volatile solids provide information on the availability of organic matter, but not on the nature of the substrate. This explains the negative correlation we have between VS and biogas quality (CH_4) (Table 4). In fact, the substrate used in this study is made up mainly of wood shavings, so there is a large quantity of wood fibre, which takes longer times to degrade.

The high rate of total solid in the samples can be explained by the way chickens are reared compared to pigs. Indeed, poultry farms are generally dry environments to limit diseases, especially in chicks whose mortality is mainly high and can reach 90%[18] [19], whereas pigs evolve in humid places due to the heating of their body. Notably, B13 has a volatile total solid of exceeding 80% which among the highest values recorded. This shows that total solids (TS) and volatile solids (VS) are not necessarily directly correlated. TS is crucial in determining the appropriate digestion method (dry or wet), while VS provides insights into the organic matter content[4], making it a valuable indicator for substrate suitability. The importance or high value of this organic matter does not necessarily mean the digestibility of the elements that compose the substrate. This digestibility is explained by the COD values, which evaluate the concentration of the nature of the organic matter of the substrates and is closely related to the biodegradability of the sample.

Thus, sample B13 has the highest percentage total solid (TS) [20] and the lowest DOC. The B13 sample is mainly made up of poultry feed and droppings from 22-week-olds, so the vegetal fibre content is high. This was the case for the two off-site droppings (DMixr and DMixw) which had high volatile mass (VS) percentages, as DMixr and DMixw are mainly made of rice straw and wood chips. The composition of these samples must be balanced for the micro-organisms that need mineral elements to synthesise methane as nitrogen is the limiting factor [3].

If Nitrogen levels are too low compared to carbon, bacterial metabolism is hindered, with an inadequate conversion of carbon to produce methane. On the other hand, if nitrogen levels are too high, this will result in the production of ammoniacal-nitrogen which in turn inhibits the activity of the micro-organisms. This explains the reduction of methane production for substrates with higher amounts of nitrogen (the relationship of nitrogen to CH_4). Nitrogen plays a crucial role in effective anaerobic digestion. The high level of nitrogen implies a low carbon/nitrogen ratio (C/N), which ideviates from the recommended optimum range of of 25-30 [21]. Despite this, the trials achieve high quality biogas with CH_4 proportions above 50% for almost all samples. Notably, biogas production diminishes after 30 days, which could correspond to the depletion of mineral elements in the substrate in the BMP test[3]. The calorific value of the biogas is strongly correlated with the CH_4 content. Intriguingly, when comparing biogas produced from poultry feces to that from cows, the former demonstrated a higher quality, approaching the quality of biogas derived from leachate, which had a methane content of 77% (as observed in the study by Imen et al. in 2009)[22].

The assessment of biogas quality reveals a favorable methane (CH_4) content, with substrates consistently having methane proportions exceeding 50%. Importantly, statistical ANOVA tests did not reveal any significant differences among the samples. Specifically, one sample, B15, derived from layer droppings without litter and collected from individuals aged 57 weeks at the study site, exhibited a methane content of 60.01%. These findings align with the research conducted by Dupont in 2010[23], where methane percentages in the range of 60 to 75% were reported for cattle. Most of the sample samples have exibit CH_4 percentages above 50% except for B11, B13 and B16. The results on methane are consistent with the work of Imen et al, 2009 which shows a significant production of CH_4 from the 15th day (more than 50% CH_4 for almost all substrates). Notably the percentage of HD sample is 56.41%, higher than 50%. In contrast, the other samples, such as DMixw (39.01%), DMixr (47.41%), and DC (45.21%), have CH4 percentages lower than 50%. This proportion of CH_4 for B15 sample, can be explained by the fact that, firstly the B15 sample is made up of pure droppings without any added litter, so the amount of fibre is not high and secondly, the age of the individualchickens in thissample, whichis over 50 weeksold and shavings used as layers, can alsocontribute to the highermethane production, as olderchickensmayproducemanurewithdifferentcharacteristicsthatfavormethane production. However, it's important to note that while methane content is a significant factor in biogas quality, it doesn't necessarily correlate directly with cumulative biogas production. The calorific value of biogas, which represents its energy content, is influenced by multiple parameters, including methane, carbon dioxide (CO_2), and water (H_2O) levels. In this study, it was observed that CO_2 levels can decrease the calorific value of biogas, which is reflected in the lower calorific values of substrates like DMixr and DMixw. This study showed a difference in energy potential depending on the age and origin of the manure collected from our study site compared with off-site manure, cow and horse dung.

4) CONCLUSION

This study shows that industrial poultry droppings have a high biogas production potential in the presence of external methanogenic microorganisms, compared to non-industrial samples such as DMixw and DMixr, which may be linked to the high presence of plant fibres in these non-industrial samples. This potential was higher than that reported for the control substrate, cow dung.

Overall, we believe that these new bioprocessing pathways to convert low-value feedstocks into higher value-added products will contribute to a sustainable future and change the economic status of organic waste, but also allow poultry industries to be energy self-sufficient. This method of recovering energy from poultry droppings limits the release of methane into the atmosphere, and is an excellent response to the fight against climate change.

Table 2: Total Solid (TS) and volatile Solid (VS) of the samples, Values form the same column are compared and when not sharing identical letters were significantly different (P-value <0.05).

Samples	TS %	VS%
B1	$60,66^{g}$	$65,11^{bcde}$
B2	$91,36^{b}$	$73,19^{abc}$
B3	$96,08^{a}$	$73,61^{abc}$
B4	$75,87^{e}$	$70,17^{abcd}$
B5	$58,17^{gh}$	$62,55^{cdef}$
B6	$79,55^{de}$	$58,73^{def}$
B7	$80,00^{de}$	$64,36^{bcdef}$
B8	$76,66^{e}$	$51,94^{f}$
B9	$61,61^{g}$	$72,33^{abc}$
HD	$93,45^{ab}$	$57,67^{def}$
B10	$55,11^{h}$	$65,78^{bcde}$
B11	$86,75^{c}$	$54,53^{ef}$
B12	$71,59^{f}$	$58,15^{def}$
CD	$83,13^{cd}$	$72,54^{abc}$
DMixw	$77,25^{e}$	$74,73^{abc}$
DMixr	$86,57^{c}$	$77,87^{ab}$
B13	$46,16^{i}$	$82,07^{a}$
B14	$76,25^{e}$	$69,17^{abcd}$
B15	$85,36^{c}$	$73,09^{abc}$
B16	$71,72^{f}$	$58,78^{def}$

B: Industrial Batiment (followed by the number); DMixr: Domestic origin mixed with rice litter; DMixw: Domestic origin mixed with wood shavings litter CD:Cow Dung; HD: Horse Dung.

Table 3: Chemical composition of substrates; Values form the same column are compared and when not sharing identical letters were significantly different (P-value <0.05).

Samples	N %	C %	H%	S%	C/N ratio
B12	10.2433^{a}	33.3333^{e}	4.2740^{d}	0.5153^{ghi}	3.2557^{l}

B14	5.5933^{b}	26.4400^{j}	3.3953^{e}	0.5483^{fgh}	4.7363^{kl}
B5	4.5933^{c}	33.530^{e}	4.4900^{cd}	0.4447^{ij}	7.3137^{ij}
B15	4.3167^{c}	26.4667^{j}	3.7207^{e}	0.6450^{de}	6.1323^{jk}
B1	3.7233^{d}	35.7000^{d}	5.1757^{ab}	0.5633^{efg}	9.5883^{FGHI}
B10	3.4333^{d}	31.4000^{f}	4.3020^{d}	0.6527^{d}	9.1567^{GHI}
B4	3.4033^{d}	27.3133^{h}	3.7463^{e}	0.6697^{bcd}	8.0363^{HIJ}
B9	2.9200^{e}	37.4933^{b}	4.7767^{bc}	0.7477^{b}	12.8427^{cde}
B6	2.8767^{e}	36.3333^{c}	5.2637^{a}	0.6280^{def}	12.6407^{CDE}
B13	2.8167^{e}	27.1833^{hi}	3.4230^{e}	0.7383^{bc}	9.6953^{FGH}
B8	2.5833^{ef}	27.4267^{h}	3.4567^{e}	0.6567^{cd}	10.6213^{EFG}
B11	2.5433^{ef}	37.4400^{b}	4.7143^{c}	0.5677^{efg}	14.7713^{c}
B2	2.4733^{efg}	28.7233^{g}	4.2000^{d}	0.4667^{hi}	11.6333^{DEF}
B16	2.2833^{fgh}	28.2867^{g}	3.6413^{e}	0.6413^{de}	12.3900^{DE}
B3	2.2600^{fgh}	27.4167^{h}	3.7863^{e}	0.9420^{a}	12.1340^{DE}
B7	2.0833^{gh}	27.5200^{h}	3.5343^{e}	0.5280^{ghi}	13.2173^{cd}
DC	1.8500^{hi}	43.2567^{a}	5.5083^{a}	0.3627^{j}	23.4717^{a}
DMixw	1.4100^{i}	26.7333^{ji}	3.6233^{e}	0.6737^{bcd}	18.9600^{b}
DMixr	0.8767^{j}	11.6067^{k}	1.5813^{f}	0.5513^{fg}	13.2620^{cd}
HD	0.3333^{k}	3.5133^{l}	0.3633^{g}	0.2480^{k}	10.7803^{EFG}

B: Industrial Batiment (followed by the number); DMixr: Domestic origin mixed with rice litter; DMixw: Domestic origin mixed with wood shavings litter CD:Cow Dung; HD: Horse Dung

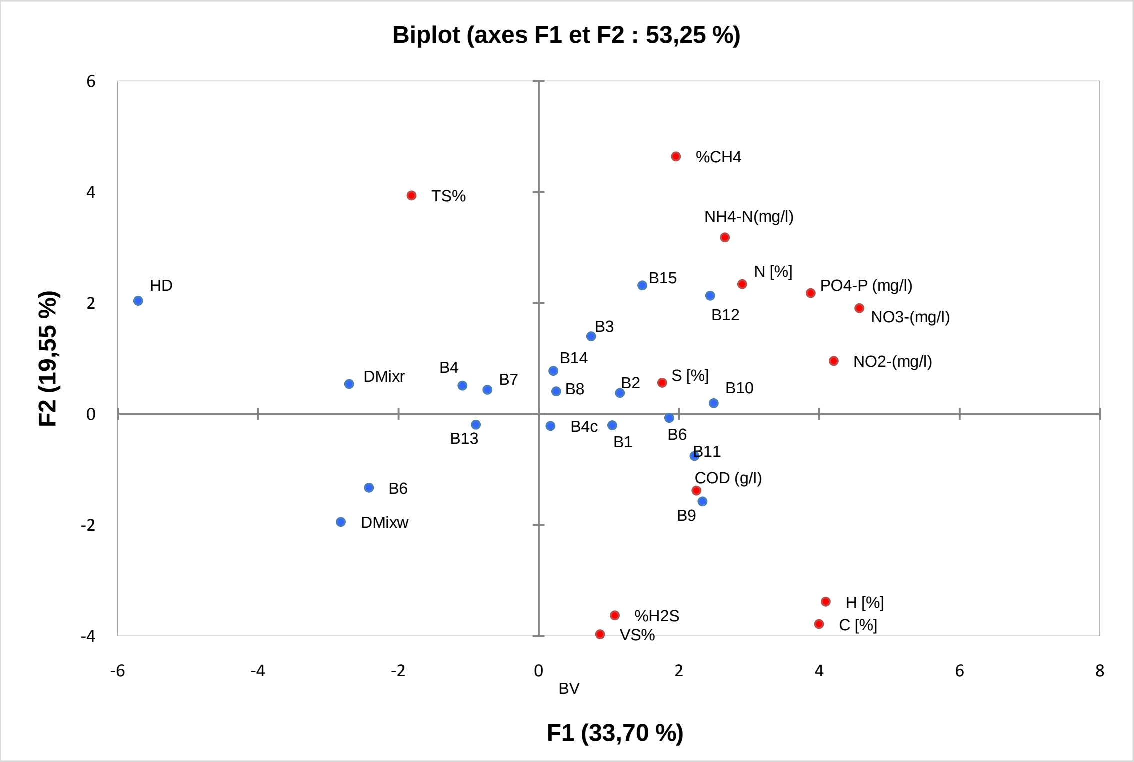

Fig1:Comparison by PCA of the chemicalelements essential for methanisationwith the quality of the biogas in the samples

Table 4: Correlation coefficients (r) between Chemical Oxygen Demand (COD), percentage of methane, percentage of dry matter and volatile dry matter

Variables	$\%CH_4$	COD (g/l)	TS%	VS%
$\%CH_4$	1			
COD (g/l)	0.1364	1		
TS%	0.2925	-0.2307	1	
VS%	-0.3230	-0.0941	-0.1020	1

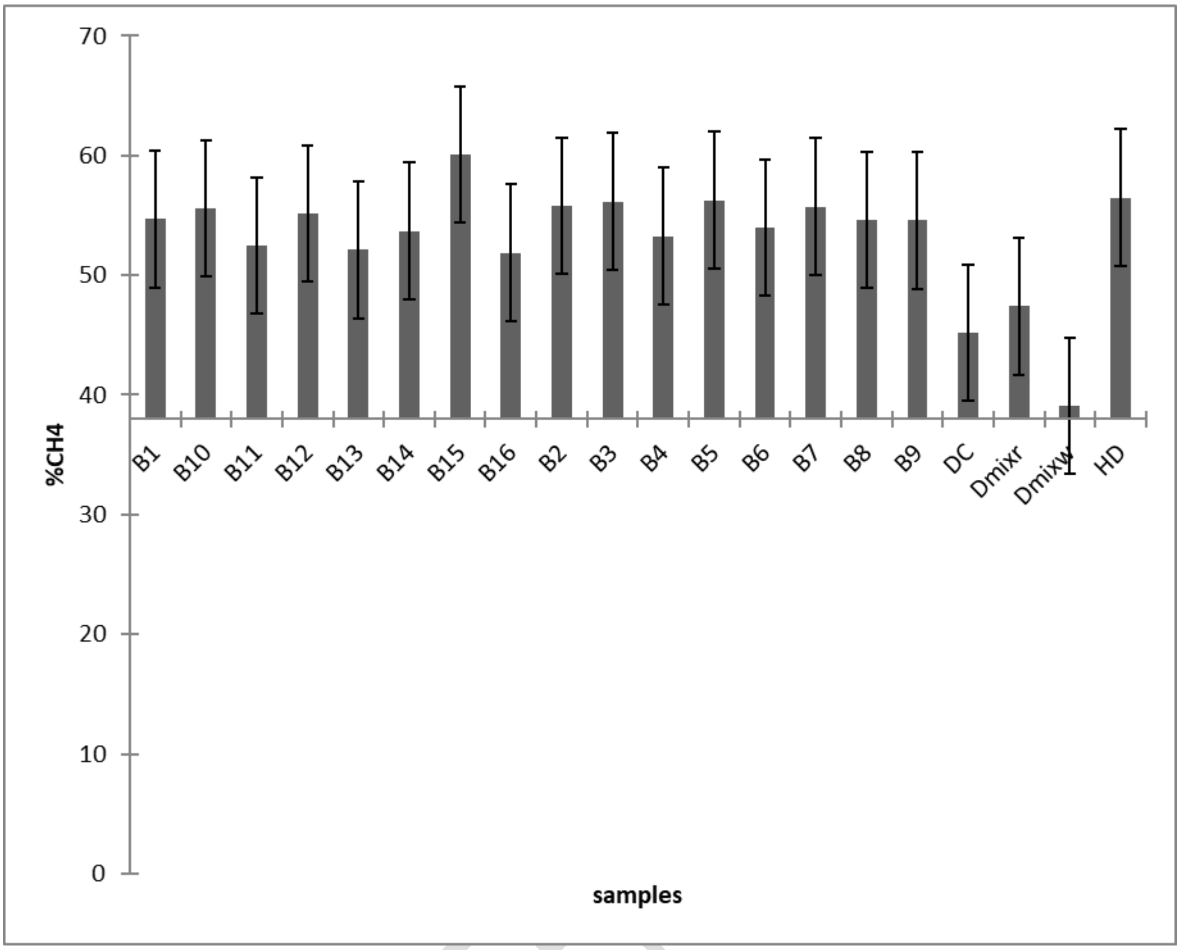

Fig 2: Proportion of methane (CH_4) in biogas produced from inoculated chicken faeces compared to references CD (cow dung and horse dung)

References

[1] Perspectives agricoles de l'OCDE et de la FAO 2010 OECD-FAO Agricultural Outlook 2010 - ISBN 978-92-64-083752 © OECD 2010.

[2] TomonoriIshigaki, Masato Yamada, MasanaoNagamori, Yusaku Ono and YuzoInoue ; « Estimation of méthane emissionfromwholewastelandfill site usingcorrelationbetweenflus and groundtemperature » ; Environ Geol (2005) 48 : 845–853DOI 10.1007/s00254-005-0008-0.

[3] Moletta R (2008) Methanisation de la biomasse. Techniques de l'Ingenieur, TraiteBioprocedes, BIO5100, 21pp. Available from URL https://www.techniques ingenieur.fr/base-documentaire/archives-th12/archives-bioprocedes-tiabi/archive-1/methanisation-de-la-biomasse-bio5100/.

[4] Moletta R (2011) Methanisation de la biomasse. Paris, 552 p. Available from URL https://www.techniques-ingenieur.fr/base-documentaire/procedes-chimie-bio-agro th2/bioprocedesdans-les-domaines-de-l-energie-et-de-l-environnement-42161210/methanisation-de-la-biomasse-bio5100.

[5] Lumsden, R. D., Lawis, J. A., &Papavizas, G. S. (1983). “Effect of organicamendments on Soilbone plant diseasesanbpathogeneantagonists”. Environmentallysoundagricultureeditor W.1.Eretz, PraegerPress, p51-70.

[6] Maiguizo-Diagne H, Nadieline CV, Ndiaye-Cisse MF, Ndiaye NA, Ndoye I, Fall S (2016) Effects of biofertilizers and biodigestates of poultry droppings and cow dung on the growth of maize (Zea mays) and sorghum (Sorghum sp). Africa. Science 12:45–54.

[7] A. Comparetti, P. Febo, C. Greco and S. Orlando; « Current state and future of biogas and digestate production » Bulgarian Journal of Agricultural Science, 19 (No 1) 2013, 1-14 Agricultural Academy.

[8] OCDE/FAO (2021), Perspectives agricoles de l’OCDE et de la FAO 2021-2030, Éditions OCDE, Paris, https://doi.org/10.1787/e32fb104-fr.

[9] FAO, 2023 ,Aviculture | Passerelle sur l’aviculture et les produits avicoles | Organisation des Nations Unies pour l'alimentation et l'agriculture (fao.org) (22/03/2023).

[10] OCDE/FAO (2022), « Statistiques agricoles des Perspectives agricoles de l’OCDE et de la FAO (base de données) », https://doi.org/10.1787/agr-data-fr.

[11] Ndiaye, N.A. (2014). Biochemical characterization and fertilizing power (biofertilizing) of some methanizable substrates from the Sangalkam area. Dakar: FST, Dep. of Chemistry, Master of chemistry and biochemistry of natural products.

[12] Maiguizo-Diagne H, Ndiaye NA, Ndour-Badiane Y, Masse D, Torrijos M, Sousbie P et al. (2018) The use of green macroalgae (Ulva lactuca and Codiumtomentosum) that have a high methanepotential, as a source of biogas in Senegal. Journal of Applied Biosciences 132: 13404–13412.

[13] Baird, R. and Bridgewater, L. (2017). Standard Methods for the Examination of Water and Wastewater. 23e edition Wshington, D.C., American Public Health Association.

[14] Gregoire, P., Fardeau, M., Guasco, S., Bouanane, A., Michotey, V., & Bonin, P. (2009). Les micro-organismes de l’extrême. La Presse thermale et climatique, 146, pp 49–61.

[15] Ferry, J. G. (1993). Methanogenesis-Ecology, Physiology, Biochemistry et Genetics (éd. Chapman et Hall, Vol. 536). New York-Londre: Chapman et Hall Microbiology Series.

[16] Quideau, P., Levasseur, P., Charpiot, A., Lendormi, T., & Guiziou, F. (2014). Combined effects of rapid discharge of manure and their anaerobic digestion. Innovations Agronomiques, 34, p 309–320.

[17] Tahri, A., Djaafri, M., Khelafi, M., Kalloum, S., & Salem, F. (2012). Improvement in the yield of biogas production by co-digestion of organic waste (slaughterhouse and poultry waste). Revue des Energies Renewables SIENR'12 Ghardaia, 375-380.

[18] Couacy-Hymann E. (1991). Les pathologies en milieu villageois. Ethiopie du 22-26: séminaire FAO, Debré Zeit.

[19] Boye C. (1990). Aviculture au Sénégal: caractéristiques, contraintes et perspectives de developpement (199-204). In Wagnengen: CTA. -Seminar proceedings on smallholder rural poultry production. 9-13 octobre.

[20] Rumbaugh, M., Clark, D., & Pendery, B. (1988). Determination of root mss ratios in alfalfa-grass mixture using near infrared reflectance spectroscopy. Journal of Range Management, 488-490.

[21] Tou I., Igoud S., Touzi A. (2001) Production de Biomethane a partir des Dejections Animales. Rev. Energ. Ren.: Production et Valorisation-Biomasse, 103–108. Available from URL https://www.cder.dz/download/bio_17.pdf

[22] Imen, S., Ismail, T., Sami, S., Fathi, A., Khaled, M., & Ahmed, G. (2009). Characterization and anaerobic batch reactor treatment of Jebel Chakir Landfill leachate. Desalination, 417–424.

[23] Dupont, N. (2010). Valorization of fermentation biogas: catalytic combustion. Lyon: Claude Bernard Lyon I University.