Original Research Article

Investigation of the potential of energy recovery from poultry droppings in a semi-industrial farm in the Sangalkam

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 poultry farm sector to fulfill the growing demand for food. The activity produces organic waste and the management of which can pose problems in the farms. Poultry farming requires energy for the production processes. It is in this context this study aims to examine the energy potential of poultry waste depending where it came from (factory farm or domesticfarm). The methanogenic potential of these wastes was determined using the Biochemical Methane Potential (BMP) test on poultry droppings from factory farms or domestic farms and other wastes as controls, such as cow and horse dung. The tests showed that the poultry droppings from factory farms had higher gas content and methane (CH_4) than the controls. The link between biogas production and the chemical composition of the poultry droppings, was also demonstrated. These findings suggested that poultry droppings from factory farms can be used to produce biogas and/or energy. The latter can be reused for the needs of the farm itself.

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

1) INTRODUCTION

The global world population has grown rapidly resulting in an escalation of activities [1]. such as agriculture, fishing, poultry farming etc. Among these sectors, poultry farming, specifically, operates as a noteworthy sector involved in the production of essential raw material to meet the need of nutritional demand of the current society. The global poultry sector is currently the fastest growing sector consumption and trade than any other major agricultural sector [2]. 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 2021 [3], and egg production increased from 15 to 93 million tonnes[4]. Today, chicken production is a global industry with a projected meat protein intake of 17% by 2031 [5].

This increase in poultry production leads to a large-scale accumulation of waste, especially droppings and litter, which ones are major problem for the poultry industry. This poses a significant challenge for the poultry factory farm, raising concerns about environmentally and economically sustainable waste management solutions to address disposal and pollution issues [6]. Most of the litter produced by the poultry factory farm is currently directly applied in agricultural lands as a source of nutrients and soil amendment. However, environmental pollution can arise as a consequence of nutrient and contaminant leaching under certain climatic conditions that are not conducive to the efficient agronomic utilization of the nutrients contained in the manure [7]. Thus, the context of current study justify the choice of 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 involved are substantial and estimated at 41 tons of poultry waste per month [8] with different valorization outcomes (energetic, agronomic, calorific) [9].

As organic waste undergoes decomposition, it releases methane, a potent greenhouse gas with a global warming potential 25 times higher than carbon dioxide [10], [6]. Effectively managing organic waste, particularly from major sources such as poultry factory form, becomes crucial for actively mitigating methane emissions resulting from waste decomposition and/or the use of fossil energy in the industry. Indeed, fossil fuels are generallyconsidered the as foundation of oursociety'senergysupply, whichcontributessignificantly to the environment pollution [11]. Simultaneously addressing the energy needs of these industries, the anaerobic digestion process proves to be a highly efficient solution. This approach holds particular promise for recirculating farming systems and hatcheries within poultry farms, given their substantial energy requirements [12]. Methanization, a key process in the emerging field of organic waste management and recovery [6], exemplifies anaerobic digestion for producing biogas containing methane - a classic resource recovery process that integrates the processing and stabilization of particulate organic matter with the generation of a valuable end product [13].

The anaerobic decomposition of organic matter facilitated by microorganisms, leading to the production of 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 CH4 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 [4]. This product is rich in nitrogen and could be used to fertilize food crops, such as sorghum, in Senegal [14] [15].Methanization provides an efficient approach to pollution reduction, surpassing the effectiveness of conventional aerobic processes [6]. 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 [13]. The anaerobic processes also 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. So, the aim of this study was to characterize poultry droppings waste according to the nature of litter and to evaluate their Biochemical Methane Potential. For this purpose, a poultry factory farm in the peri-urban area of Sangalkham of Dakar area was chosen. Our study try to access the energy potential of poultry droppings within the broader context of poultry farming and environmental management.

2) **MATERIALS AND METHODS**

2.1) Sampling condition

The materials used are mainly poultrydroppings from factory farms in the peri-urban area of Dakar. The chickens were raised on the floor, resulting in the production of waste in the form of droppings, sometimes mixed with a particular type of crop residue or industrial by-product. 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 factory farms. All samples collected were subsequently crushed and coded.

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 from factory farms, 2 from domestic farms, 1 from cow dung, and 1 from horse dung. The 16 samples from factory farms adhered to specific standards and were designated with codes ranging from B1 to B16 based on their respective building numbers. The two samples obtained from non-industrial sources were labeled with the letter D followed by the type of letter (DMixr: poultry droppings + rice litter and DMixw: poultry droppings + wood litter).

2.2) Biochemical characterization of poultry dropping

The samples collected were systematically weighed (1kg) 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 analyzed by a quality-certified chemical analysis laboratory (LAMA lab, Dakar, [16]).

Other chemical analyses of poultry droppings included total solids (TS), fresh matter (FM), volatile solids (VS) and chemical oxygen demand (COD) [17]. Total solids (TS) were determined by incubating a sample at 104°C until the weight of the sample remains constant on leaving the oven. Volatile solids (VS) were measured by the loss after samples were burn at 550°C. COD was determined by a chemical method, and the calorific value was determined in a bomb calorimeter.

The pH of samples were determined in advance, and the values observed were closed to neutral pH (**Table 1**). For the pH of samples collected from the poultry droppings from factory farms values ranged from 5.87 and 7.29. For poultry from domestic farm (DMixr and DMixw) the values of pH were 7.24 and 7.29, respectively. The pH of Cow dung (DC) was 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 Building (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 [18], 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 (lCG).

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; AddinsoftInc, Long Island City, NY, USA).

3)RESULTSAND DISCUSSION

3.1) Chemical composition of chicken droppings

The **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%).

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 Building (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

The production of methane depends on the composition and availability of mineral elements, such as nitrogen, carbon, phosphorus and other trace elements. [19]. 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) (**Table 3**), 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) [20]. This pH close to neutrality is ideal for microorganisms which are very sensitive to the ionic balance of the environment [6] 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) [21], whose research on pig manure typically yielded TS percentages ranging from 4.97% to 7.8% [21]. 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) [22], where the TS content for poultry waste was recorded at 96.16% [22].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 3**). 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% [23], [24], 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 (**Table 2**). TS is crucial in determining the appropriate digestion method (dry or wet), while VS provides insights into the organic matter content [6], 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) [25] 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 [26].

If Nitrogen levels are too low compared to carbon**(Table 4)**, 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) (**Fig 2**), which deviates from the recommended optimum range of 25-30 [27]. Despite this, the trials achieve high quality biogas with CH_4 proportions above 50% for almost all samples.

Table 3: 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

Table 4: 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 Building (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

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 (**Fig 1**). 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 out of 14 droppings from factory farms produced methane with significantly higher 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 consisting of animal waste. 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 (**Fig1**) 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.

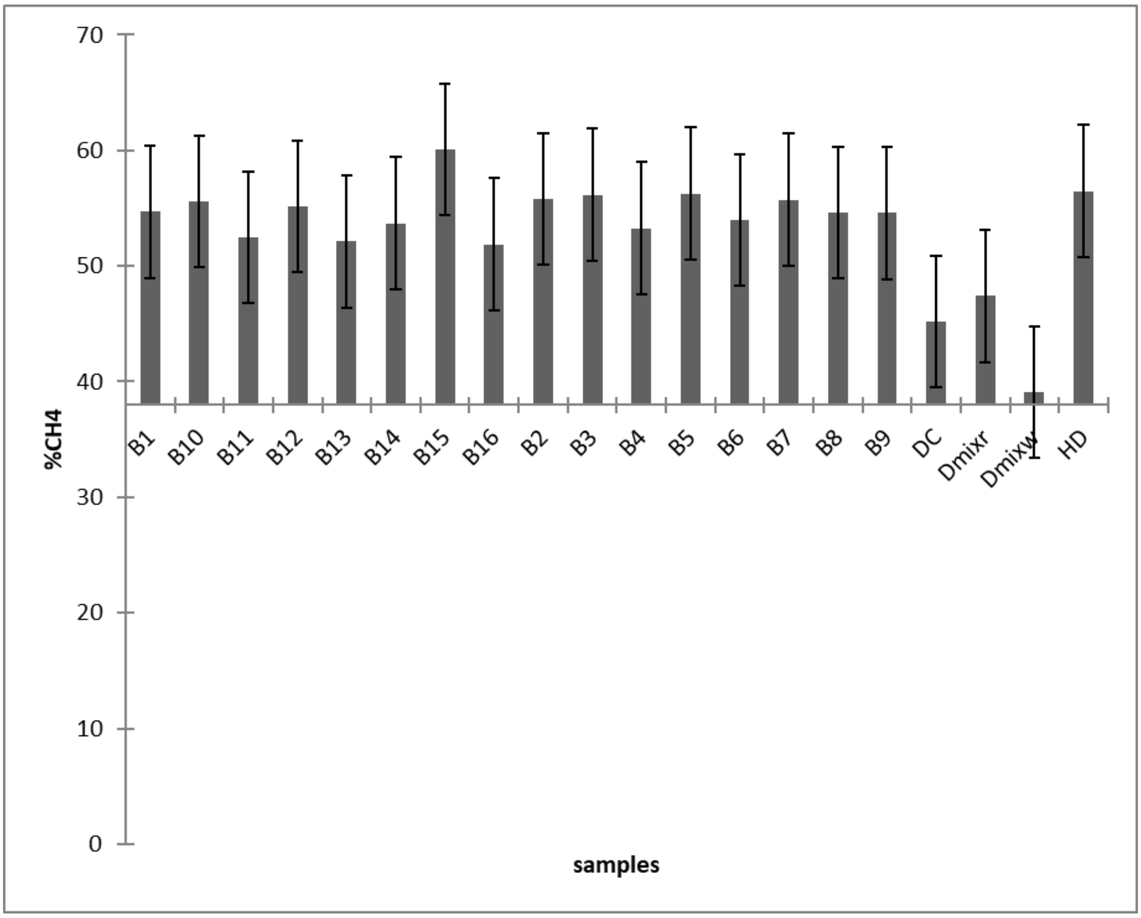

Fig 1: Proportion of methane (CH_4) in biogas produced from inoculated chicken faeces compared to references CD (cow dung) HD (horse dung)

The quality of biogas has a direct influence on the calorific value of the substrate [28] 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.Notably, biogas production diminishes after 30 days, which could correspond to the depletion of mineral elements in the substrate in the BMP test [4].The calorific value of the biogas is strongly correlated with the CH_4 content. Intriguingly, when comparing biogas produced from poultry dropping to that feces from cows, the former demonstrated a higher quality, getting close to 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) [23].

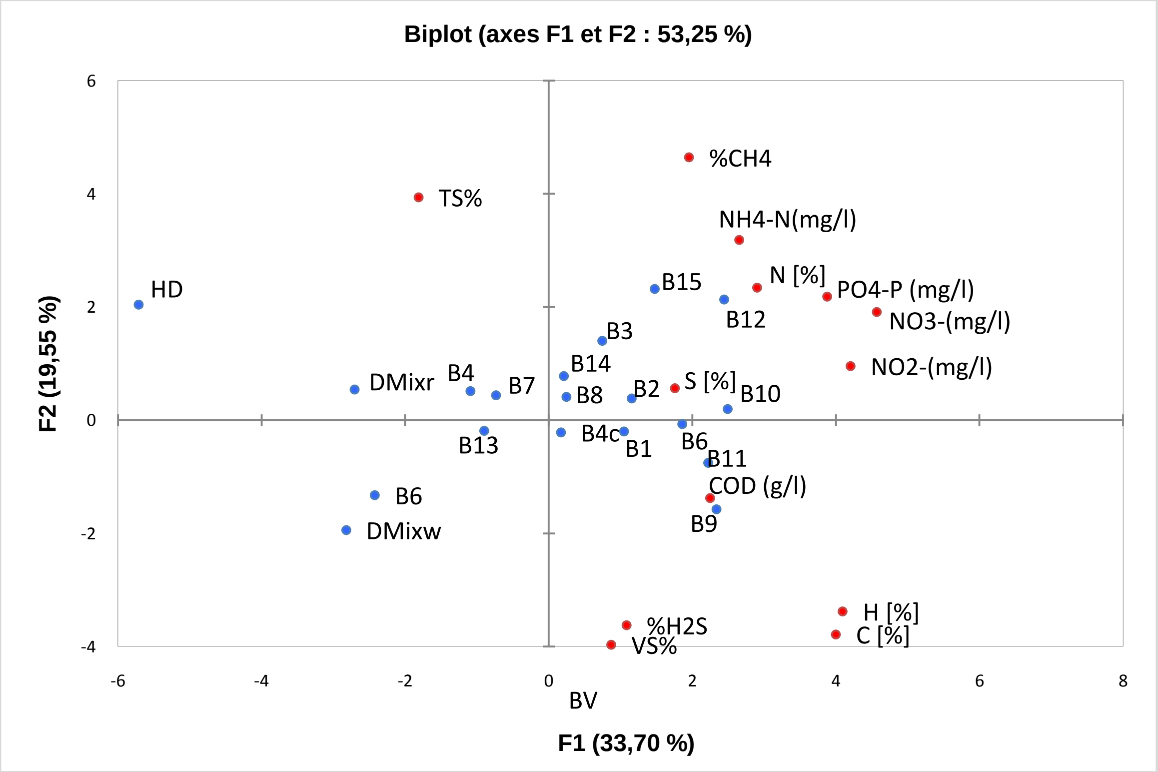

Fig2:Comparison by PCA of the chemicalelements essential for methanisationwith the quality of the biogas in the samples

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 are in agreement with the research conducted by Dupont in 2010 [29], which report values of methane percentages form cattle feces between 60 to 75%. Most of the sample samples have exhibit CH_4 percentages above 50% except for B11, B13 and B16. The results of methane values are consistent with the work of Imen et al, 2009[23], 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 (Horse Dung) 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 CH_4 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 fiber is not high. Secondly, the age of the individualchickens in thissample, whichis over 50 weeksold and shavings used as layers, canalsocontribute to the highermethane production, as olderpoultrymayproducedroppingwithdifferentcharacteristicsthatfavormethane 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 dropping collected from our study site compared with off-site manure, cow and horse dung.

4) CONCLUSION

This study shows that poultry droppings from factory farm have a high biogas production potential in the presence of external methanogenic microorganisms, compared to samples from non-factory farm (such as DMixw and DMixr) which may be linked to the high presence of plant fiber in these non-industrial samples.

These potential of industrials poultry droppings was higher than or equal to the one reported for cow dung consistent with the results of Riggio et al 2017 [30].These results could reduce electricity bills in poultry industries and meet energy demand in hatcheries for example to heat of bulding for of poultry growth moving towards integrated and multi-trophic farms. The anaerobic digestion of industrials poulty and the energety interest of the waste resulting from this process will reduce the impact of poulty farming on the environment, facilitating the economic development of this sector. Thus, we recommend extension towards open avicol frames to increase significantly energy productions, collection systems for open environment.

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