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ORIGINAL RESEARCH

Potential for biogas production from the anaerobic digestion of chicken droppings in Morocco

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Abstract
Purpose The chicken droppings can have a negative impact on the environment and public health. In this work, we are interested in treating this waste by anaerobic digestion and we estimate the national potential of green energy produced by anaerobic digestion and map the areas that need digesters to improve national poultry farming.
Methods The anaerobic digestion of this waste is performed in three steps. In the first step, the chicken droppings are placed in a laboratory digester without pretreatment. In the second step, the droppings are placed in an industrial digester without pretreatment. In the third step, a methanogenic inoculum is incubated with the chicken droppings in a batch digester. The biogas production is measured by manometer, and the composition of this biogas is analyzed by gas chromatography.
Results The chicken droppings without pretreatment generated a small amount of biogas (11.24 and 20 m^3 for one ton of waste fresh) in the laboratory and in the prototype digester. After pretreatment (heating and grinding), this waste produced a large quantity of biogas, on the order 230,58 ml/gCOD, equivalent to 64.4 m^3 for one ton of fresh waste, with 60.2 % methane, 38.8 % carbon dioxide and 0 % hydrogen. This biogas production has a lower heating value of 385 kWh for one ton of chicken droppings. Based on these results, our country has high potential for green energy (200 GWh) by transforming the droppings of broilers by anaerobic digestion.
Conclusion In Morocco, the installation of biogas digesters in poultry units is an effective technique for this industry, because this waste is a potential energy source.

Keywords Chicken droppings · Anaerobic digestion · Green energy · Biogas · Pretreatment · Inoculums

Introduction

The generation of organic waste in Morocco continues to increase each year (Afilal et al. 2007). Moroccan poultry is one of the fastest growing industrial activities. Morocco is the first country classified for breeding broilers in northern Africa, with 195 million heads produced in 2013 (FAOSTAT 2015). This production represents 43.1 % of the livestock in the Maghrebian region, because chicken is the most consumed meat by Moroccan (52 % of all meat consumed in 2014) (Agriculture du Maghreb 2010; FAOSTAT 2015). The national poultry sector has undergone significant development; the poultry meat production increased from 510,000 tons in 2010 to 649,000 tons in 2013 to cover 100 % of the demand for poultry meat on the Moroccan market (Ministère de l'Agriculture 2012).

This important development of the Moroccan poultry activities resulted in a large production of organic residual waste. Morocco produces more than 519,000 tons of broiler droppings per year, of which more than 95 % is directly used as fertilizer for agriculture without pretreatment (Elasri and Afilal Elamin 2014). This organic waste can have a negative impact on the environment and public health, because the droppings contain high contents of nitrogen (4.48 %), total organic carbon (16.5 %) and pathogenic bacteria, mainly Staphylococci and

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Enterobacteriaceae (114.10^8 and 154.10^6 CFU/g) (Arifin et al. 2006; Elasri and Afilal Elamin 2014; Karwowska 2005; Plewa and Lonc 2011). These quantities of bacteria, carbon and nitrogen can be lost through lixiviation or runoff and can be found in groundwater and surface water, causing diseases or epidemics (Chen and Jiang 2014; Ganoulis 2012; Kostadinova 2013; Stefanova et al. 2012). Outdoor landfills produce greenhouse gases (emission factor is 0.023 kg $head^{-1}$ $year^{-1}$) (Jun et al. 2002; Kostadinova et al. 2014). Morocco is under strong energy constraints, as illustrated by an energy deficit that has worsened over time (approximately 83 % in 1980 and increased to 97 % in 2009) (Afilal et al. 2013).

In addition to these problems, with the progressive production of droppings of chickens and the energy deficit, it is necessary to develop technology that combines the management, valorization and production of green energy starting from these wastes to improve the energy balance of this livestock. Among the current technologies, methanization is gaining more importance in Morocco and around the world. Methanization is based on the degradation of various organic wastes in hermetically closed bioreactors (Niu et al. 2015). These wastes are partially converted by microorganisms to biogas (Budzianowski 2016).

In this work, we are interested in:

1. Treating this waste by anaerobic digestion and achieving the maximum production of biogas with a high percentage of methane for energy use.
2. Estimating the national potential of green energy produced by the anaerobic digestion of broiler droppings and maps the areas that require the installation of digesters to improve national poultry farming.

Materials and methods

Substrate

The substrate studied in this paper is the droppings of chickens taken from a poultry unit (Fig. 1a). Droppings were collected after cleaning the hen-houses of intensive breeding unit broiler located a few kilometres from the city of Oujda in Morocco (Fig. 1b). The sampling location is at the following coordinates (34°41′43.7″N° 50′35.0 1″W). The determination of the type of waste is difficult, because the classification of waste is highly variable (Buenrostro et al. 2001); it depends on the criteria chosen by the authors (Castelli et al. 2012). After a synthesis of these criteria, the broiler droppings are qualified as organic waste, putrescible, residual and rapidly biodegradable (Elasri and Afilal Elamin 2014).

Chemical analyses

In this article, we have identified several chemical characteristics for Moroccan chicken droppings, including, total solids (TS), fresh matter (FM), volatile solids (VS) and chemical oxygen demand (COD), but for the inoculum, we determined COD (Table 1).

Dry matter and volatile dry matter

The determination of total solids is performed according to the standard protocol, which consists of drying the wet sample at 105 °C to a constant weight (over 24 h) (APHA 1999).

$$TS = (M_1 \times 100)/M_0 \quad (1)$$

TS: Total solids (g TS/gFM).
MF: Fresh matter (g).
M_0: Initial weight of the sample before drying (g).
M_1: Final weight of the sample after drying (g).

The determination of volatile matter (or volatile solids) is also a gravimetric method based on the weight loss of the dry sample (the sample from determining TS) in a muffle furnace at 550 °C for 6 h (APHA 2005). The remaining material is considered mineral material (MM), and the material that disappeared is organic matter (OM).

$$VS = (M_1 - M_2) \times 100/M_1 \quad (2)$$

VS: volatile Matter (g VS/g TS).
M_1: Mass of dry substrate (g).
M_2: Mass of substrate calcined at 550 °C (g).

Chemical oxygen demand (COD)

This characteristic is determined using the chemical oxygen demand corresponding to the amount of oxygen required for complete oxidation of organic matter and a mineral in a sample. The COD gives the quality of the substrate before placing it into the digester. COD was determined for the inoculum and droppings. The inoculum used in this article is in the liquid state. We determined the COD of the inoculum by kit (Spectroquant Merck Cod cell test 114,555, measuring range 500–10,000 mg/L) (Perimenis et al. 2015).

The chicken droppings are in the solid state; therefore, they are analyzed using the Belgian standard, which comprises the oxidizing agent in excess and potassium dichromate ($K_2Cr_2O_7$). The reaction occurs in an acid medium (H_2SO4) upon heating at reflux in the presence of a catalyst (Ag_2SO_4) and a complexion agent of chloride ions ($HgSO_4$). In this paper, we titrated the residual potassium dichromate (back titration) with a solution of sulfate of iron and ammonium ($Fe(NH_4)_2(SO_4)_2$) called Mohr salt. We

Fig. 1 **a** Chicken droppings collected in a truck; **b** Hen-houses of intensive breeding

used ferroin as an indicator, because it changed colour from blue-green to red-brown (APHA 1999). The COD is expressed as grams of oxygen per gram of sample.

Test of the anaerobic digestion of droppings without pretreatment

This test is performed on two levels: at the laboratory scale, all digesters used in this test are 5 litre hermetically closed bottles with waste at 10 %, that is to say, 10 g of dropping in 100 ml of tap water. We followed the production of biogas for 40 days (Afilal et al. 2014).

On the industrial scale, we filled a 1000 litre capacity prototype (a horizontal digester) with 260 kg of droppings dissolved in 640 litres (8 % TS), and we followed the biogas production for 40 days. We adjusted the temperature of the digester to 35 °C. The biogas product is measured every day by a flow meter. In the two tests, the waste does not undergo any pretreatment.

Test of the anaerobic digestion of droppings with pretreatment and addition of inoculum

Origin and activation of inoculum

The inoculum used in this article is an anaerobic sludge collected at the treatment plant Chastre/Mont-Saint-Guibert, Belgium. This inoculum was maintained at 35 °C under anaerobic conditions. The inoculum is preserved in a 20 L reactor sealed with a silicone plug. The activation of the inoculum is performed with the sludge collected from the same sewage plant. The addition of activation substrate to the inoculums was in the ratio of 3 g COD/7 g COD, i.e., 30 % of the total chemical oxygen demand (COD) of the digester of inoculum (20 L) (Perimenis et al. 2015). In practice, 1.8 L of the sludge (substrate of activation) was added to digester (119 COD) of inoculum. Then, we put the digester in a room at 35 °C for 10 days. Before testing the digestibility, all organic matter must be exhausted, and the bacteria must be activated.

Test of biodigestibility

The droppings of chickens underwent two pretreatment steps: heating at 105 °C for 24 h, this thermal pretreatment also leads to pathogen removal, improves dewatering performance and reduces viscosity of the digestate, with subsequent enhancement of digestate handling (Ariunbaatar et al. 2014; Bougrier et al. 2007) and the second pretreatment is a very fine grinding with a mill (IKA A11 Basic) (Carlsson et al. 2012). The incubation obeys the 1/5 ratio for testing potential methanogenics, i.e., each digester has to contain a quantity of droppings (1.5 g COD) in the inoculum (7.5 g COD), so that the inoculum is not limited, but the organic matter accompanying the inoculum does not contribute to the production of biogas with respect to the substrate to be tested (Van Aarle et al. 2015). We performed six digestions: three controls (inoculum only)

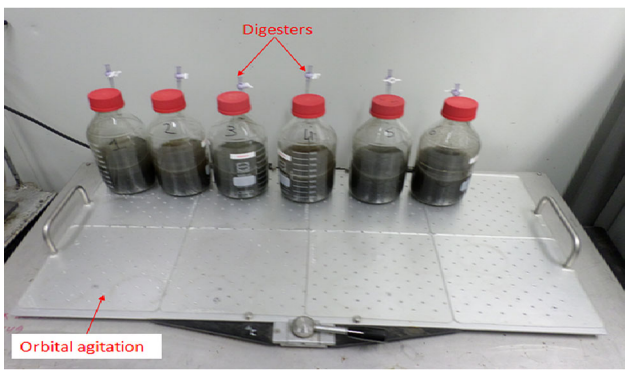

Fig. 2 Six digesters under continuous orbital agitation (120 rpm)

and three tests (inoculum with droppings) (Fig. 2). The initial pH for the six digesters is 7.1 ± 0.41 for the three tests and 6.8 ± 0.2 for the inoculums; these values show that the pH is favorable and it is in areas of optimization of anaerobic digestion (Chen et al. 2008); therefore, the pH of the batch does not require an adjustment. The filling of the six reactors is performed on a balance. The gas spaces of the six reactors are subjected to nitrogen flushing to remove the oxygen present in the reactor and to stabilize the anaerobic conditions. We closed all reactors. The six reactors were incubated in a warm room at 35 ± 1 °C under continuous orbital agitation (120 rpm) (Chun et al. 2015; Vindis et al. 2009). The anaerobic digestion continues for 40 days in batch mode.

Measurement and analysis of biogas production

The daily biogas production can be measured using a digital manometer with a three-way valve at the top of the connector. This manometer measures the pressure in each reactor. This pressure is measured manually by connecting the manometer previously calibrated to the two-way valve of the reactor (Fig. 3a).

The measured pressure value is used to calculate the volume of biogas produced under the standard conditions using the following equation (Estevez et al. 2012):

$$\Delta V_2 = \frac{\Delta P_1 \times V_1 \times T_2}{T_1 \times P_2} \quad (3)$$

where ΔV_2 = Volume of biogas produced between two measurements and corrected to the standard conditions (ml).

ΔP_1 = Pressure difference between two measurements in the reactor (Pa).

V_1 = Volume of gas headspace of the reactor (ml).

T_1 = Temperature in the reactor (308.15 K).

T_2 = Standard condition of temperature (273.15 K).

P_2 = Atmospheric pressure at standard conditions (101,325 Pa).

The quantity of biogas generated by the substrate is obtained by subtracting the amount of biogas produced in the control reactor, i.e., inoculum alone.

As soon as the measurement of biogas production is complete, we proceed in collecting and analyzing the composition of biogas. The biogas collected by the polycarbonate syringe of 50 ml (Terumo Luer lock), it was

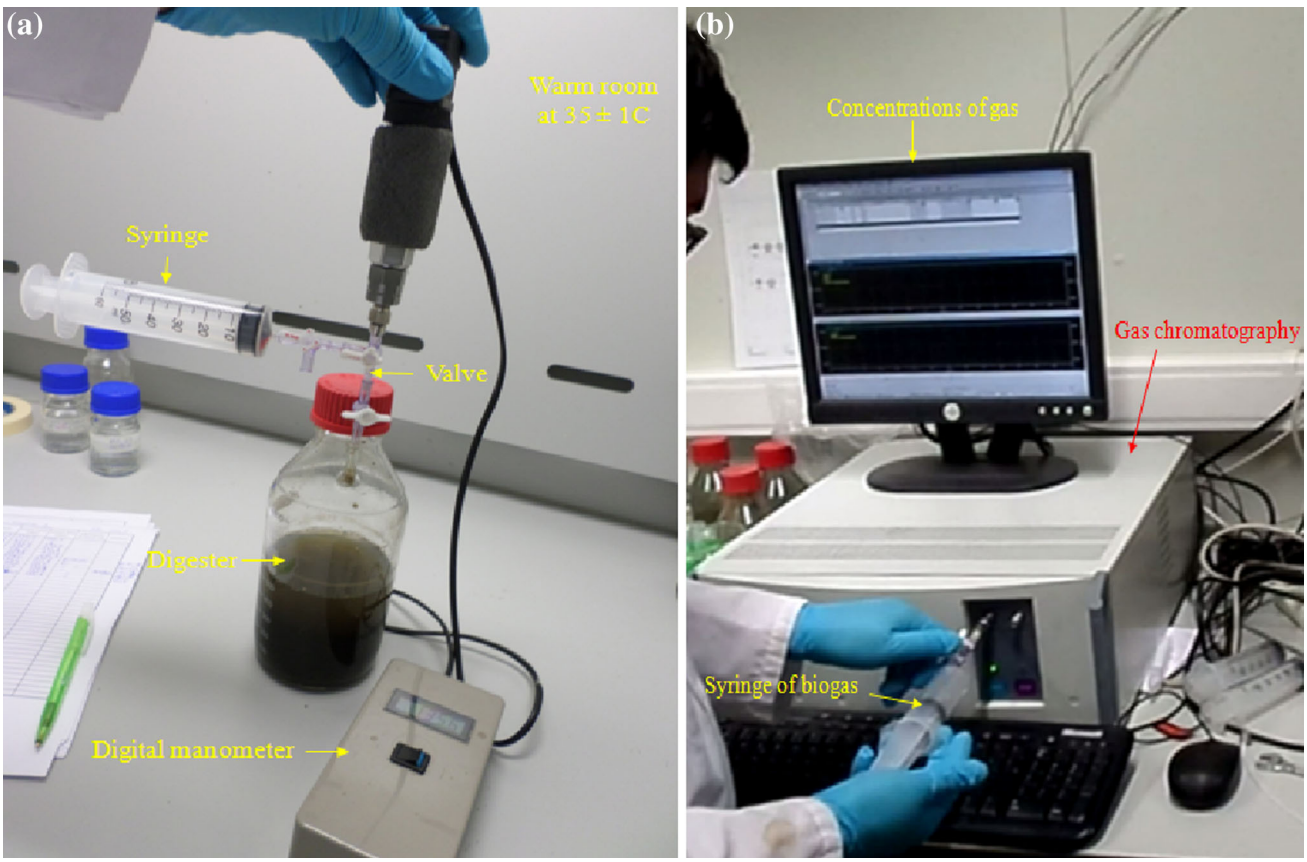

Fig. 3 Measurement and analysis of biogas production. **a** Measurement of pressure. **b** Analysis of composition of biogas produced

immediately injected into the gas chromatography (GC) (Saady and Massé 2016) (Fig. 3b).

The gas chromatography used in this work is the type (Compact GC-TCD); it determines automatically three types of gases (CO_2, CH_4 and H_2) in biogas production. The Compact GC-TCD is composed of two separate channels operating in parallel and each provided with a 25 µl injection loop and an independent TCD detector. These channels are called the "Front Channel" and "Back Channel". The injection of a gas is done using a polypropylene syringe fitted with a valve; the gas enters an injection circuit via the injector (sample in) and passes through the two injections loops and spring (sample out).

Results and discussion

The characterization of the substrate before anaerobic digestion

The chemical characteristics are shown in Table 2. One gram of COD is equal to 1 g of VS; therefore, the organic matter present in the droppings is all biodegradable (Hamilton 2012). These three chemical characteristics of the chicken droppings show that the droppings contain a large organic biodegradable fraction, which leads to the production of large quantities of biogas. This result is confirmed by the production of a large quantity of biogas (230.58 ml/g COD).

Table 1 Nomenclature

CFU	Colony-forming unit
CH_4	Methane
CO_2	Carbon dioxide
COD	Chemical oxygen demand
FM	Fresh matter
GC	Gas chromatography
H_2	Hydrogen
N	North
TCD	Thermal conductivity detector
TS	Total solids
VS	Volatile solids
W	West

Table 2 Composition of chicken droppings

Chemical characteristics	Quantity	Unit
COD	1.01 ± 0.01	g/g VS
TS	32 ± 4	g/100 g FM
VS	28 ± 0.2	g/100 g FM

Test of the anaerobic digestion of droppings without pretreatment

The first test produced a small amount of biogas (11.24 ± 1.2 m^3/T MF) compared to other studies that considered an optimal amount within the range 61–112 m^3/T MF (Afilal et al. 2014; Brodeur et al. 2008) (Table 3). At the industrial scale, the prototype produces a large amount of biogas (20 m^3/T MF) compared to that obtained at the laboratory scale for several reasons: the use of an optimal concentration (8 % TS) (Budiyono et al. 2010; Salam et al. 2015; Zennaki-Bensouda et al. 1996); the significant volume of the digester (1000 L) can contain a large quantity of waste (250 kg) and thus have a high probability of having methanogen bacteria in each batch (Nopharatana et al. 2007); the design of the prototype allows for rapidly reaching anaerobic conditions by effective sealing and reduced gas headspace; and, finally, the addition of an inoculum increased the speed of the process (González-Fernández and García-Encina 2009).

Test of the anaerobic digestion of droppings pretreated with inoculum

Analysis of the quantity and composition of biogas production

We follow the production of biogas in the six digesters (three controls and three tests) for 1195 h (equivalent to 49 days). The anaerobic digestion of chicken droppings begins in the early hours of incubation (not time latency) and generates a high quantity of biogas of 230.58 ± 4.36 ml/g COD substrate during the 49 days of incubation. One gram of COD is equal to 1 g of VS, and consequently, this the quantity of biogas is equivalent to 64.4 ± 4.36 m^3/TMF, i.e., one ton of the pretreated droppings produced 64.4 m^3 of biogas. Comparing these results with the previous results shows that this quantity is very high (7.66, 11.24 m^3/t FM and other researchers that 112 m^3/t FM) (Afilal et al. 2014; CRAAQ 2008; Fischer 2007). This significant quantity of biogas is the result of several conditions: an efficient inoculum capable of converting the organic matter present in the studied waste, the use of a closed room at 35 °C (Yadvika et al. 2004), continuous agitation during 1194 h of incubation, and the pretreatment of the droppings increased surface area provides better contact between substrate and anaerobic bacteria (Carrère et al. 2010; Val del Río et al. 2011). The droppings contain less efficient methanogenic bacteria flora compared to the inoculum used in this article. Therefore, we need to avoid the anaerobic digestion of this waste by its own bacteria.

We analyzed the composition of biogas produced during the incubation (1195 h, equivalent to 49 days) by gas

Table 3 Comparison of the biogas potential of three tests

	Potential of biogas (m^3/T FM)
Waste without pretreatment in laboratory	11.24 ± 1.2
Waste without pretreatment in prototype	20 ± 1.5
Waste with two pretreatments and inoculum	64.4 ± 4.36

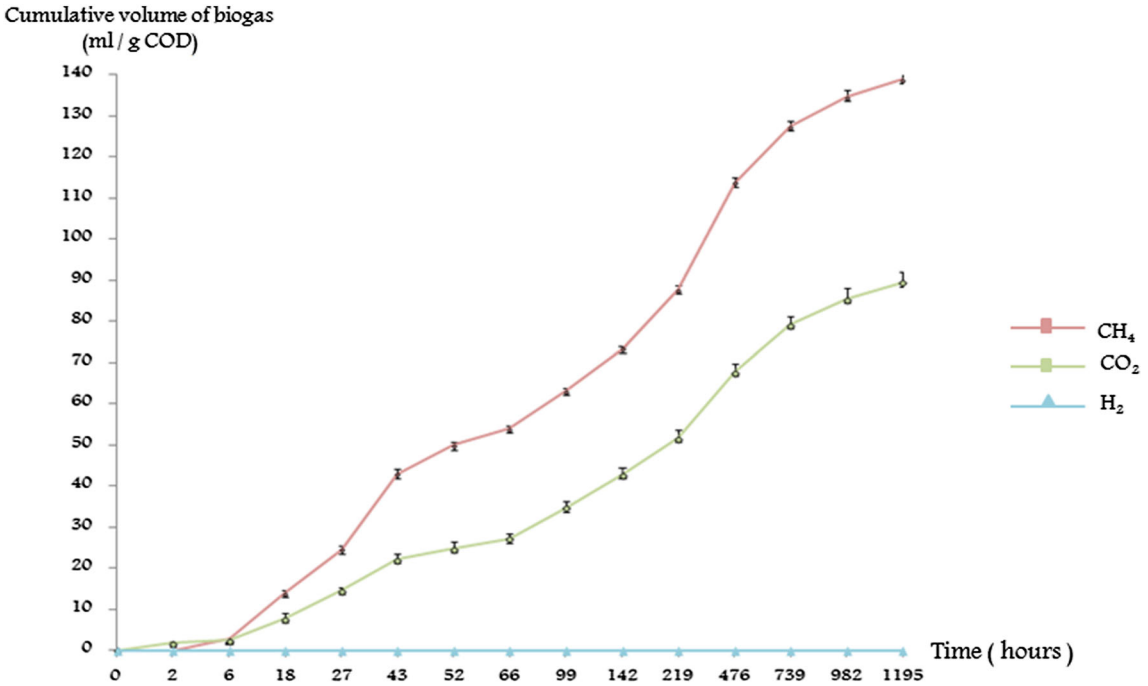

Fig. 4 Kinetics of gases produced by chicken droppings

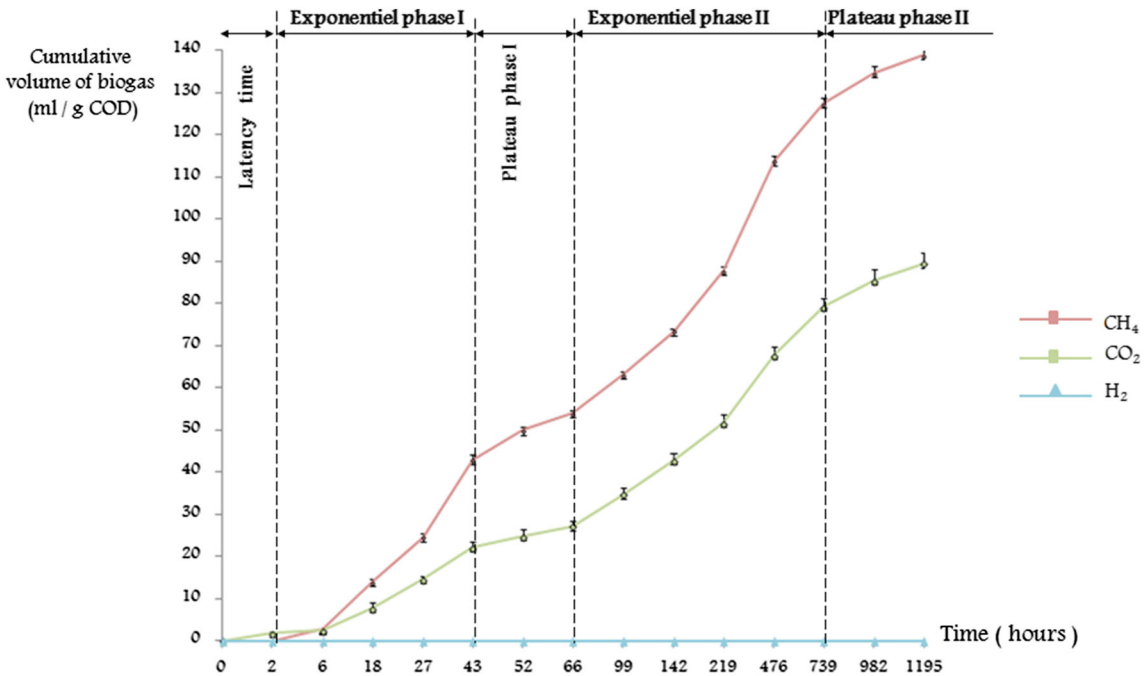

Fig. 5 Different phases of methane production by the Belgian inoculum

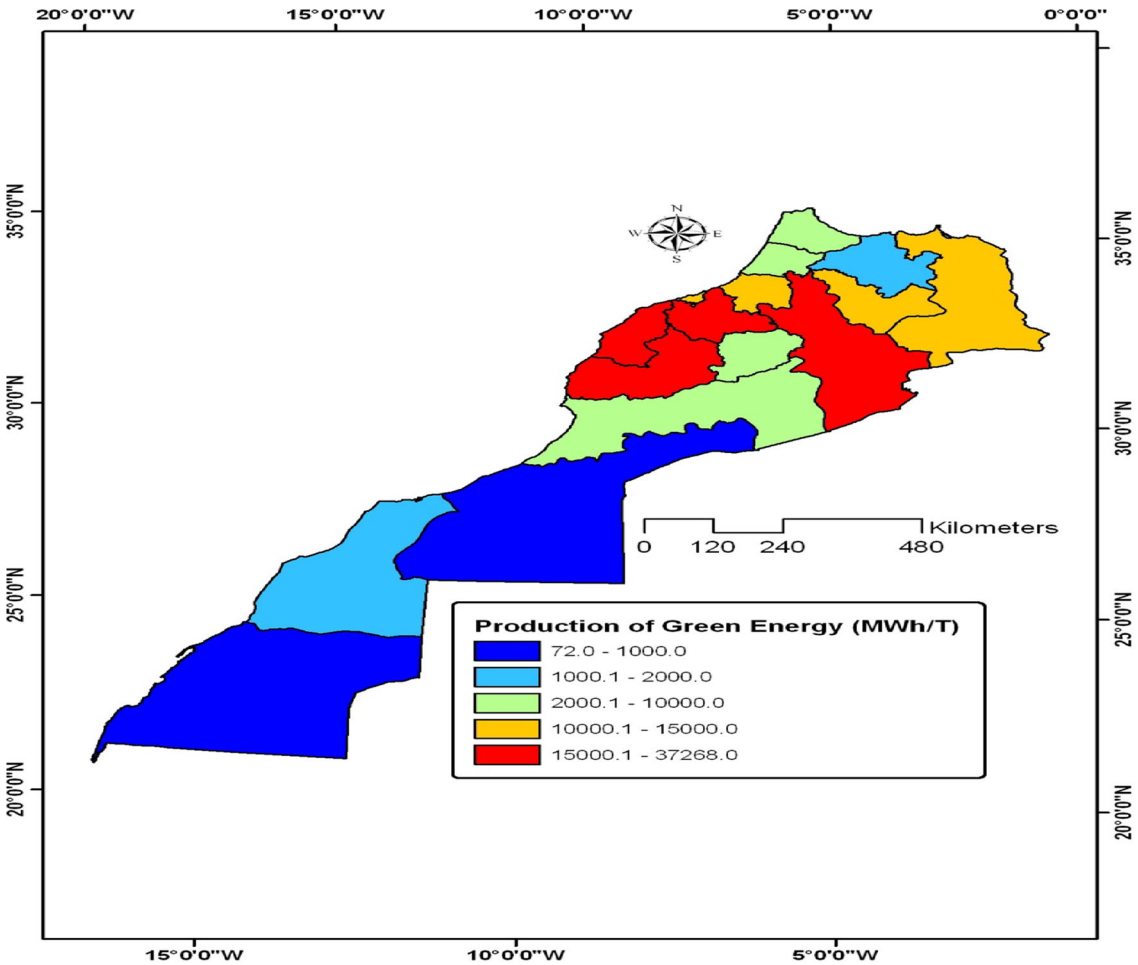

Fig. 6 Map of distribution of green energy produced by the anaerobic digestion of chicken droppings in Morocco

chromatography and obtained the kinetics of the constituent gases (Fig. 4). The biogas produced has only two gases: methane (CH_4) and carbon dioxide (CO_2). Hydrogen is absent during the incubation, indicating that it is not stored in the headspace of the digester.

From an industrial and economic point of view, the anaerobic digestion of droppings from chickens in a digester allows for storing all of the biogas that is produced. The anaerobic digestion of droppings from chickens produced biogas with a minimum of 60.2 % ±2.33 methane and 38.8 % ±2.71 carbon dioxide. Therefore, the biogas presents a lower heating value of 5.98 ± 2.33 kWh/m^3.

Kinetics of methane production

The kinetics of the production of methane shows a biphasic exponential pace, with a single latency time for methane. According to the speed of methane production, this curve can be cut into five phases (Fig. 5):

- The latency phase is 2 h, resulting from the use of an organic complex chemical composition, which needs the intervention of bacteria in the first three stages of anaerobic digestion (hydrolysis, acidogenesis and acetogenesis) to degrade and convert the substrates available for the methanogenic stage (acetate, CO_2 and H_2). This time (2 h) is very short in other works, which have very high latency time of up to a few days (Afilal et al. 2014; Budiyono et al. 2010). Therefore, this short latency time showed that the inoculum used in this study includes a range of bacteria for hydrolysis, with high-performance acidogenesis and acetogenesis, which rapidly degrades droppings and makes the substrates available for the production of methane. Thus, this short period may be utilized by methanogenic bacteria that are acclimatizing to environmental conditions and new substrates (Nopharatana et al. 2007).
- After the latency time, the production of methane gradually began as exponential phase I. After 2 h of

incubation, the production of methane is accelerated with a high speed of 1.04 ml/g COD.h. This phase corresponds to the availability of simple and biodegradable substrates for methane transformation. This result shows that methanogens in the inoculum require little time for their appearance (less than 2 h), which is less than the standard of 3–7 h. Therefore, this inoculum has interesting properties.

- Plateau phase I, which require a 23 h incubation, corresponds to the low production of methane with a speed on the order of 0.48 ml/g COD.h. During this phase, there is a decrease of easily biodegradable organic material present in the chicken droppings (Alfa et al. 2014).
- Exponential phase II lasts 673 h with the low production of methane of 73.27 ml/g COD with low production speed of 0.10 ml/g COD.h. Methane produced during this phase transformation is from the organic fraction of the complex, which is difficult to microbially degrade and takes more time to degrade, producing a small quantity over a long time period.
- The plateau phase (II). During this phase, there is negligible production of methane with negligible speed of 0.02 ml/g COD.h due to the absence of substrate for digestion. Therefore, this phase represents the exhaustion of all biodegradable material present in the droppings.

The kinetics of methane production shows an acclimatization phase and very short bearing phase, but the exponential phases have fast speeds. Consequently, the conversion of organic waste material to methane is very fast when using this Belgian inoculum.

Estimation of deposit of green energy

Based on these results, we can to map the potential of green energy produced by the anaerobic digestion of chicken droppings in every region of Morocco and localize the regions that need to install digesters. This production (64.4 m^3/TMF with 5.98 kWh/m^3) is multiplied by the amount of waste produced in each region (Kumaran et al. 2016). Morocco has a high potential for green energy (200 GWh) from transforming the droppings of broilers by anaerobic digestion (Fig. 6).

The region Chaouia-Ouardigha has the highest potential green energy production of 37,268 MWh. Four regions (Chaouia-Ouardigha, Tensift-Al Haouz Marrakech, Meknes-Tafilalet and Doukkala-Abda) represent 55 % of the whole national potential. The installation of biogas units for chicken droppings should be focused on western Morocco. In Fig. 2, the areas in red and orange are the principal regions of energy production by methanization. These regions are the target regions for installation of methanization units for chicken waste.

Conclusion

The anaerobic digestion of Moroccan chicken waste by inoculum sludge from the waste water treatment plant Chaste/Mont-Saint-Guibert in Belgium generates a high quantity of biogas of 230.58 ml/g COD substrate. The quantity produced is composed of 60.2 % methane, 38.8 % carbon dioxide and 0 % hydrogen; therefore, it presents a lower heating value of 5.9 kWh/m^3.

Based on this work, the daily development of the Moroccan poultry keeps getting better. This development is accompanied by the progressive production of broiler chicken droppings, which can cause several types of pollution. This waste is an energy source that renews every day. The treatment of this waste by anaerobic digestion has shown that these substrates can produce a large amount of biogas (64.4 m^3/TMF), which can be converted to green energy (385 kWh/t FM). The methanization of wastes requires pretreatment by heat, grinding and the addition of an inoculum before introducing the waste into a digester.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests. We do not have any financial competing interests, because we have no financial support. We want to release this work to the whole world.

Author's contribution Elasri Ouahid made substantial contributions to the conception, design, analysis and interpretation of data; he has been involved in drafting the manuscript and revising it critically for important intellectual content. Finally, he has given final approval of the version to be published. (AB, MT, ES and FG). Afilal Mohamed Elamin has been involved in drafting the manuscript and revising it critically for important intellectual content (FG).

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