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Evaluation of physicochemical, microbiological, and energetic characteristics of four agricultural wastes for use in the production of green energy in Moroccan farms

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Abstract

Background: Animal husbandry is one of the agricultural activities that generates economic benefits for agriculture. We detected significant development of these activities in Morocco. Currently, it is stuck between the increase of organic waste polluting the farm environment and the energy needed to ensure the activities. Faced with this challenge, we determined all physical, chemical, and microbiological characteristics for livestock wastes most spread in Morocco. We evaluated also their ability to be used as bioresources for the anaerobic digestion and incineration ways for energy production to agricultural units.

Methods: We worked on four organic wastes (cow dung, horse manure, broiler droppings, and the excrement of laboratory mouse). The physical, chemical, and microbiological characteristics: moisture, total solids, volatile solids, organic carbon, nitrogen, ions and heavy metals, staphylococci, coliforms, yeasts and fungi and total aerobic mesophilic bacteria are determined by standard methods. The determination of lower heating value is performed with calorimetric bomb. The biogas production is determined by four batch types of digesters. All digesters are incubated at 35 ± 1 °C for 40 days. The volumes of biogas produced are corrected under standard pressure and temperature conditions.

Results: We noticed that the four agricultural wastes have a lower heating value closer to each other. When comparing the physicochemical composition of our wastes with that of Tanner's theoretical waste, we have found that the valorization of these organic wastes by incineration is without energy and economic benefits. The microbiological content reflects the presence of a reservoir of pathogenic bacteria. On the other hand, the biogas potential shows that cow waste produces the largest amount of biogas. The co-digestion is necessary for horse manure, chicken manure, and excrement of laboratory mouse in order to increase their biogas potential. The mineral composition shows the possibility of using digestate of these wastes as an organic amendment to plants.

Conclusions: The comparison of the physicochemical and microbiological characteristics of the four organic wastes in Morocco reflects some important points. Firstly, there is an urgency to intervene to treat and valorize these wastes before putting them in the open air. Secondly, the incineration of this waste is inadequate from an energy point of

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view. In the third position, these wastes present a great ability to be used as feed substrates of farm digesters. Finally, the biogas potential and the mineral composition of these wastes demonstrates the ability to use them as biore-sources capable of producing green energy and an organic amendment to Moroccan farms.

Keywords: Biogas, Organic waste, Livestock, Green energy, Anaerobic digestion

Background

In Morocco, agriculture is a very important socio-economic sector, generating approximately 15 to 20% of the national gross domestic product [1]. This sector remains the first job provider in the country par excellence of more than 42% of the Moroccan population living in this sector [2]. Agricultural activities include animal husbandry, which is one of the pillars of national agriculture and contributes 25–30% of agricultural turnover [3]. In 2015, Morocco took first place on the podium of animal breeding countries (chickens, cattle, and buffaloes) in the Maghreb region, with a production of approximately 195 million head of chickens, 3 million head produced of cattle and buffaloes and second place in sheep and goat farming (25 million head) [4].

This important development of Moroccan farming activities is wedged between two constraints. The first is environmental: more meat products and more milk and eggs produce organic waste, of which more than 95% is thrown into the environment or used as a source of direct amendment for agriculture without prior pretreatment [5]. This waste contains pathogenic bacterial, carbonic, and nitrogenous loads that can harm groundwater and surface water. Landfilling is the open-air causes the production of greenhouse gases (13% of these gases are of origin breeding) and aerial microbial pollution [6–8]. The second constraint is energetic. Morocco is subject to a strong energy constraint illustrated by an energy deficit that has worsened over time, reaching 97% in 2009 [9]. As additionally, these breeding activities require thermal and electrical energy to meet these needs. Faced with these two constraints, this vital economic function of Moroccans will become difficult, and the price of meat, milk, and eggs will increase.

It is necessary to develop a technology that combines management, treatment, energy recovery, and the production of green energy from this livestock waste. Chandrappa and Das (2012) have shown that determining the physical properties of organic waste is necessary for good management [10]. Some researchers have demonstrated the presence of a close relationship between physical properties and microorganisms of organic waste [11–14]. Tsai and Liu [15] showed that thermochemical characterization of manure is relevant to its energy conversion and environmental implications. Other researchers have shown that chemical properties are essential in

the management and treatment of organic waste since it affects rheology, viscosity, fluid dynamics, clogging, and sedimentation [16, 17]. Therefore, it is necessary to determine the physicochemical and microbiological properties of livestock waste in order to choose a suitable treatment technique.

Some researchers confirm that chicken droppings are the most nitrogen-laden animal waste compared to other organic livestock waste [18, 19]. Skóra et al. [20] counted 3.2×10^9 CFU/g of total aerobic mesophilic bacteria (FMAT), 1.2×10^6 UFC/g fungi, and yeasts in chicken manure. This quantity of microorganisms produced in animal manure varies according to different parameters [21]. Jensen and Sommer [16] stated that the total solid (TS) of animal manure is between 30 and 70%. This dry matter variation is probably caused by the water that enters the waste. Lorimor et al. [22] showed that the nutritional values are linked to the concentrations of solids present in the organic waste.

Currently, thanks to technological progress and scientific development, there are different technologies for processing manure production. Azim et al. [23] have tried to treat this agricultural waste by composting. Makan (2015) have used animal manure to compost of trimmings and offcuts from casings and fat/mucosa, from cleaning and scraping the internal surfaces of the intestines which produced by agro-industrial company [24]. In Japan, the incineration of the chicken manure has been applied to produce the ash which contains a high concentration of phosphorus [25]. The incineration of animal manure is an effective reducing of the volume and concentrating of fertilizer nutrients [26]. Oshita et al. [27] confirmed that this incineration method is a potential source of greenhouse gas emissions (N_2O and CH_4). However, Irshad et al. [28] stated that research into the extractability of nutrient elements from fresh manures of different livestock have been insufficiently reported. Among current technologies, anaerobic digestion is gaining more importance in Morocco and around the world [29]. Anaerobic digestion is based on the degradation of various organic wastes in hermetically closed bioreactors, where they are partially transformed by microorganisms into biogas, which is essentially methane [30, 31]. The latter goes to a cogeneration engine to produce thermal or electrical energy [32].

From an agronomic point of view, anaerobic digestion transforms organic waste by producing biogas, and

digestate, which is a mineral reservoir [33]. Therefore, the anaerobic digestion leads to the production of significant amounts of ions and heavy metals that are indispensable and beneficial to plant development [34]. Some researchers have confirmed the possibility of using digestate as an organic amendment to plants after aerobic treatment to produce compost [35, 36]. Some studies have shown that the application of anaerobic digestate onto soils can have positive effects on their physical properties, such as reduction of bulk density, increase in saturated hydraulic conductivity, and enhancement of moisture retention capacity [37].

In this work, we have determined and compared all the physical, chemical, and microbiological characteristics of the four organic livestock wastes most applied in Morocco, i.e., cow dung, horse dung, broiler droppings, and excrement of laboratory mouses, to build a national database. Thus, we evaluated the ability of these wastes to use them as bioresources for biogas production and incineration technology. Finally, we have identified and compared their biogas potential to estimate their use as green energy sources on crop farms and livestock farms.

Methods

Determination of microbiological characteristics

All the manipulations of the microbiological characterization were carried out in a sterile flow host. Starting with the preparation of a stock solution of organic waste, using a balance, 1 g of the sample was weighed and then dissolved in 100 ml of sterile peptone water. Using a micropipette, cascade dilutions were made in test tubes of 10 ml of distilled water from the prepared stock solution. Then, 1 ml of each dilution was removed and spread on nutrient media:

- Chapman medium allows counting of the staphylococci at 37 °C for 48 h.
- Deoxycholate citrate lactose agar (DCL) allows counting of the total coliforms at 37 °C for 24 h.
- Potato dextrose agar (PDA) allows counting of the yeasts and fungi at 30 °C for 24 h.
- Plate count agar (PCA) allows counting of total aerobic mesophilic bacteria (TAMF) at 37 °C for 48 h.

The enumeration of anaerobic bacteria was calculated using the following equation [38]:

$$N = \Sigma \text{ colonies} / V(X_1 + 0.1X_2) D, \quad (1)$$

where N is the number of colony-forming units (CFU) per gram, Σ colonies are the sum of colonies in boxes that can be interpreted, V is the volume of solution deposited in the box (1 ml), X_1 is the number of boxes considered at the first dilution retained, X_2 is the number of boxes considered at the second dilution retained, and D is the

factor of the first retaining dilution. All manipulations of physicochemical and microbiological characterizations are replicated three times.

Physical and chemical characteristics

Moisture

Moisture (M) represents the water content in organic waste, and it is determined by a difference in weight of the sample before and after drying. The sample is dried at a temperature of 105 °C to a constant weight (usually after 24 h in the oven) [39].

Total solids and volatile solids

In this work, we analyzed the two most important physicochemical characteristics of anaerobic digestion: total solids (TS) was performed according to the standard protocol which consists of drying the fresh matter (FM) at 105 °C to a constant weight and volatile solids (VS) which is a gravimetric method based on the mass loss of the dry sample; sample from the determination of TS; in a muffle furnace at 550 °C for 6 h [40].

Total organic carbon and biochemical oxygen demand

The assessment of total organic carbon (TOC) in the organic waste is carried out from the previous determination of the volatile solids provided to use the common carbon proportion factor. According to Giroux and Audesse [41], factor 2.0 is more appropriate than the factor 1.724. Biochemical oxygen demand (COD) is determined by Hanna Instruments HI 83224 01 Compteur.

Total nitrogen

The technique used to determine total nitrogen (TN) is the Kjeldahl method [42]. This method is carried out in three steps: digestion of the sample, during which the protein nitrogen of the organic waste is transformed into ammonia nitrogen by oxidation of the organic matter in concentrated sulfuric acid at high temperature in the presence of a catalyst (CuSO_4), and a salt (K_2SO_4); ammonia distillation, during which the ammonia is then distilled by water vapor, and trapped in a boric acid solution to form borate ammonium salts; and ammonia titration, during which the ammonium borate salts are titrated directly with a standard solution of hydrochloric acid (HCl), and a colored indicator. We make a blank by combining all the reagents, except the sample, to subtract the ammonia contained in the sample.

Dosage of ions and heavy metals

Analyses and assays for determining the levels of ions and heavy metals in these four organic wastes were

conducted at the National Center of Scientific and Technical Research in Rabat. The samples are filtered on membranes with a porosity of 0.45 μm and then hot mineralized with aqua regia (3 volumes of HCl per 1 volume of HNO_3) in order to avoid interactions of the organic matrix. The metal ion concentrations were determined using an atomic absorption spectrophotometer furnace (VARIAN Spectra 800) with a system for the correction of the absorption of organic matter (Zeeman). The detection limit is of the order of 0.1 $\mu\text{g L}^{-1}$ [43].

Determination of the lower heating value

The determination of the lower heating value (LHV) of the four organic wastes are performed on samples dried at 105 $^{\circ}\text{C}$ and then ground and sent to the cement plant in the Oujda region, previously named Holcim.

Determination of biogas potential

We have built four types of digesters, and each digester has a type of organic waste (without the addition of inoculum). Each test is performed in a batch-type digester with a concentration of 8% MS [44]. We chose this concentration because it is considered an optimal concentration [45]. The filling of the digesters is carried out on a balance in order to allow a mass balance in grams directly in the reactors, supposing a density of the inoculum of one [46]. Each test is replicated twice. All digesters are incubated in a water bath at 35 ± 1 $^{\circ}\text{C}$ for 40 days. Every day, we monitor the production of biogas by moving an acidic and saline solution in an overturned burette connected to the digester [47]. The volumes of biogas produced are corrected under standard pressure and temperature conditions.

Results and discussion

Comparison of the bacterial load

Anaerobic digestion consists of biological degradation of organic waste under anaerobic conditions by different types of microorganisms [30, 48]. This important role of microorganisms has enabled De Vrieze et al. [49] to

consider anaerobic digestion as the first microbial technology that allows energy recovery from organic waste. The microbiological analysis of the four organic wastes shows that they are a reservoir of bacteria, mainly pathogenic bacteria. We found that cow dung, and chicken droppings are the most heavily loaded with aerobic bacteria, yeasts and fungi, while horse dung is the most organic waste loaded with pathogenic bacteria (*Staphylococci*, fecal and total coliforms) (Table 1). Laboratory waste shows a low bacterial load compared to that of the other wastes studied.

Some researchers, such as Nodar et al. [50] confirm that the type and number of microorganisms in manure can vary with the animal species, age of animals, type of bedding used, storage method (liquid or solid) and the storage period. The microorganisms in organic waste have a major role to ensure increasing the kinetics of the reactions of this process, as well as they have also a role in the secretion of the hydrolytic enzyme for biodegradation [51, 52]. The presence of a significant quantity of appropriate microorganisms such as ours, allows increasing the rate of degradation, to improve the production of biogas, to shorten the starting time, and to make the digestion process more stable [53].

Comparison of organic matter

We noted that laboratory waste has the largest amount of dry matter (95%), followed by horse waste (83.2%), then chicken droppings (82.9%) and cow dung (77.33%) (Fig. 1). This the result is due to the presence of litter (sawdust and straw) in these first three wastes, because, it serves as the bed rest in the breeding units of animals, and it is combined with waste at the time of shipment of cages and boxes; on the other hand, cow dung has no litter below. The solid content in manure affect the following parameters: (a) rheology and viscosity of the contents of the digester, fluid dynamics, clogging, and solid sedimentation which can directly influence the overall rates of mass transfer in the digesters [17, 54], (b) According to Lorimor et al. [22], the nutritional values are linked to the concentrations of solids present in organic waste, in general, the higher concentration of solid volatile matter

Table 1 Comparison of the bacterial load between the four wastes studied

	TAMF (CFU/g)	Yeasts and fungi (CFU/g)	<i>Staphylococci</i> (CFU/g)	Total coliforms (UFC/g)	Fecal coliforms (UFC/g)
Cow dung	25·10 ⁹	11·10 ⁹	14·10 ⁶	28·10 ³	24·10 ²
Broiler droppings	11·10 ⁹	12·10 ⁸	74·10 ⁵	59·10 ⁶	72·10 ⁴
Horse manure	92·10 ⁸	85·10 ⁵	18·10 ⁶	68·10 ⁸	32·10 ⁶
Excrement of laboratory mouse	93·10 ⁶	67·10 ⁴	18·10 ⁴	< 30	< 30

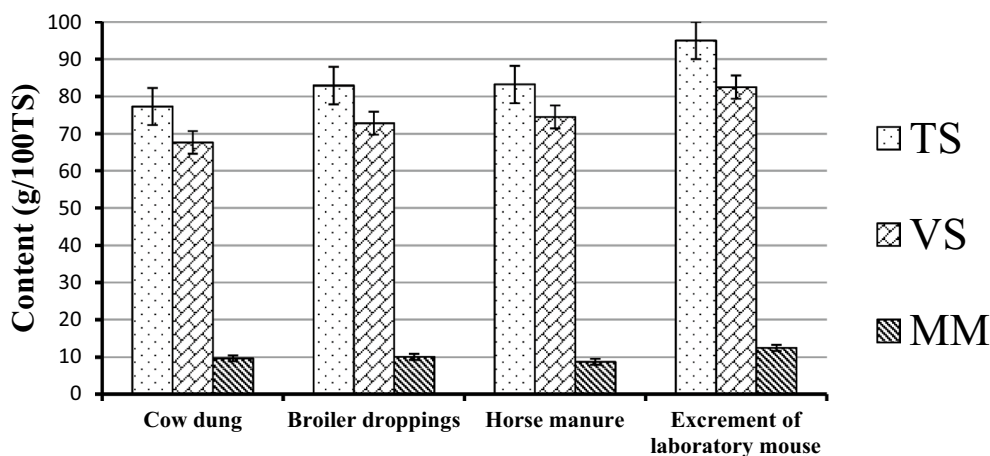


Fig. 1 Comparison of TS, MO, and MM content in the four organic wastes studied

product higher the concentration of nutrients, (c) This organic fraction is also one of the keys factors that influence the performance, cost, and stability of digesters, so the biogas production [55]. Therefore, cow dung is the least affected by these parameters.

We report the presence of a close relationship between moisture and organic matter in the organic waste [44]. Glancey and Hoffman [56] showed that moisture is correlated linearly to TS and VS for manure waste. So, water in manure has several roles of biogas production: (a) it is required for metabolic processes [11]; (b) water provides the essential medium for transporting nutrients and allows microorganisms to move [14]; (c) water can displace air from porous spaces, resulting in anaerobic regions in the material which improves anaerobic digestion [57]. Therefore, since cow dung has a high water content compared to the other waste studied, confirmed the obtaining of significant production of biogas.

Comparison of nitrogen, carbon, and C/N ratio

The amount of carbon available of the substrate determines the maximum amount of methane and carbon dioxide that can be formed by anaerobic digestion [58]. We also know that carbon is essential for bacterial growth [59]. The four wastes studied have significant carbon content which fluctuates between 33 and 41% (Fig. 2). So, this carbon fraction will be essential for two functions: it will be converted into CH_4 and CO_2 which are the basic constituents of the biogas produced and it accelerates the proliferation of the bacterial arsenal of the anaerobic digestion inoculum.

The chicken waste has the highest content of nitrogen compared to other waste (Fig. 2). The nitrogen plays two important roles in biogas production: the first role, it is necessary for the formation of new biomass,

because the microorganisms in digester need nitrogen for the production of new cell mass [60]. In the second role, nitrogen contributes to the stabilization of the pH value in the reactor [61]. In addition to that, on storage conditions, a large percentage of this organic nitrogen of manure is converted to ammonia within a year [62]. Ammonia exists in two forms: gas state (NH_3) that can be lost to the atmosphere for greenhouse gas production or in an ionized state NH_4^+ , which is water-soluble, this last state can be transformed by microorganisms to nitrate (nitrification process) [63, 64]. Ammonia is considered the major problem in the anaerobic digestion of organic waste. Chen et al. [65] declared that a wide range of inhibiting concentrations have been postulated that cause up to a 50% reduction in biogas generation in the range of 1.4 g/l to 14 g/l. So, we can have inhibitions by nitrogen in the chicken waste digestion case.

Determining of the C/N ratio is essential for optimal biogas production [66]. We found that the cow dung has the highest carbon-to-nitrogen ratio (C/N) compared with that of other waste because this waste contains the lowest amount of nitrogen in the presence of a large quantity of carbon (Fig. 2). Followed by the laboratory waste with an order ratio of 18.4, this waste contains the highest amount of carbon. Horse waste ranks third place with a ratio of 16.6. On the other hand, chicken droppings have the lowest C/N ratio because it contains the highest nitrogen content compared to that of the other wastes studied.

Therefore, cow waste has the most favorable ratio of anaerobic digestion, and thus, it does not require a co-digestion or inoculum to trigger the process. It must be in the range of 25 to 30 [67]. On the other hand, the three wastes require co-digestion by other organic substrates in order to achieve an optimal C/N ratio, which

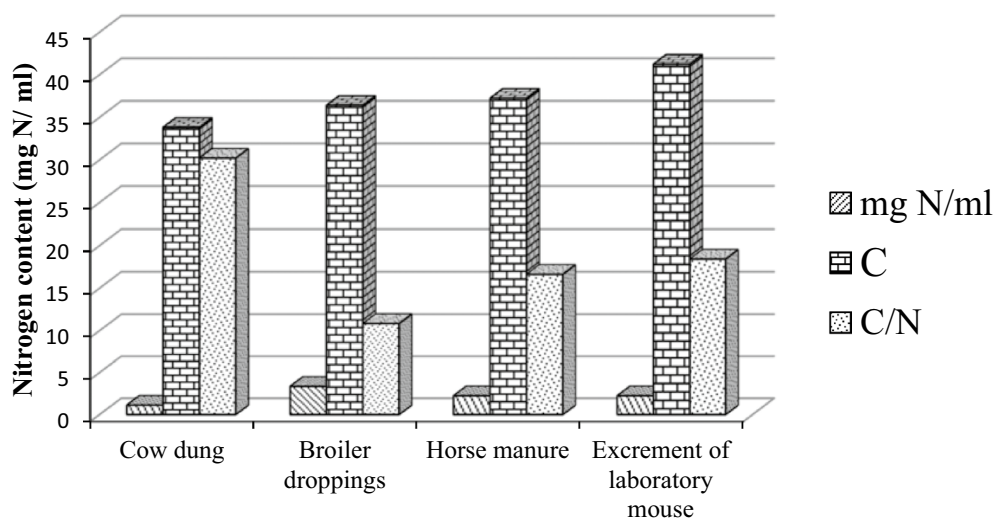


Fig. 2 Comparison of the nitrogen, carbon content and C/N ratio of organic wastes studied

is likely to improve the production of biogas. Some researchers, such as Wang et al. [55, 68] suggest that the co-digestion of animal manure has a better digestion performance (stable pH, and low concentrations of total ammonia) for adjusted the low C/N ratios. Thus, the three wastes (horse dung, laboratory waste, and chicken droppings) require organic co-digestion substrates that have a successive order of the carbon content of 30, 26, and 64.

Comparison of the lower heating values

When comparing the LHV of these organic wastes, we noticed that they have LHVs closer to each other with a slight deviation (63 kcal kg^{-1}) between them (Fig. 3). Therefore, the energy recovery by the incineration of this waste is almost similar. This amount of energy produced by incineration is due to the presence of cellulose in these organic wastes [69]. When comparing the chemical composition of our wastes with that of Tanner's theoretical waste (ashes below 60%, moisture below 50%, and organic matter above 25%) (Table 2), we found that our waste is theoretically possible for combustion without the use of an auxiliary fuel [70].

However, using Tanner's ternary diagram, which is based on the three constitutive parameters (amount of organic matter, ashes, and moisture) of organic waste to evaluate its use in incinerators [71]. We exported the three parameters of our four organic wastes on this diagram, and we noticed that they are located within the limits of the Tanner triangle, which indicates a suitable fuel for combustion [72] (Fig. 4). Additionally, the high moisture content of this waste leads to a need for energy to be supplied to release water by evaporation

[73]. Therefore, the valuation of these four organic wastes by incineration remains inadvisable without energy and economic profits.

Comparison of the potential of biogas

After 30 days of incubation, we found that cow waste produces the greatest amount of biogas ($260 \text{ mL g}^{-1}\text{VS}$) compared to other organic waste studied (Table 3). Horse waste followed with $230 \text{ mL g}^{-1}\text{VS}$. Laboratory breeding waste ranks third with $190 \text{ mL g}^{-1}\text{VS}$. In the last place is the chicken waste with the lowest production of biogas ($140 \text{ mL g}^{-1}\text{VS}$). This ranking is an exact correlation with the ranking of the C/N ratio. Cow waste has the highest C/N ratio, so it has the highest biogas production. Additionally, horse and laboratory wastes have a low C/N ratio, and hence, these energy productions are low. On the other hand, chicken droppings have a very low C/N ratio, from which the lowest biogas production was measured. Sattler (2011) stated that when the C/N ratio is too low such as our waste, the ammonia concentrations can become high enough to be toxic to microorganisms [74]. Therefore, the organic waste has a higher C/N ratio and is close to the 20–30 range, the biogas production is optimal [60]. On the one hand, Zeshan et al. [75] propose an adjustment of the carbon/nitrogen ratio to increase this production of biogas in order to valorize these organic wastes by anaerobic digestion. However, Siles et al. [76] have shown that adjusting the C/N ratio, particularly in large-scale centralized digesters, is one of the major problems since the overall net energy derived from this system is predominantly balanced with the costs of collecting, transporting and separating waste.

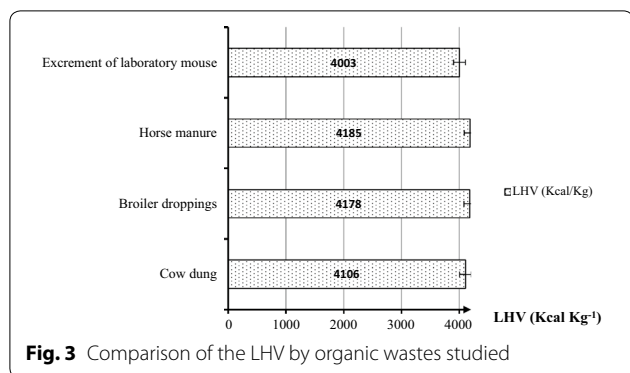


Fig. 3 Comparison of the LHV by organic wastes studied

Biogas production depends principally on the content and chemical nature of biodegradable matter [77]. Cow waste has the highest COD (960 mg O₂ L⁻¹) compared to that of other wastes studied (Table 3). This high biochemical parameter of cow waste reflects the presence of high content of readily biodegradable organic matter in the first two phases of anaerobic digestion. So, this waste has the highest biogas production. However, this is not the case for chicken droppings and laboratory waste with a high order COD (740 mg O₂ L⁻¹), whereas the production of biogas is the lowest. Therefore, there was a lack of correlations between COD and the amount of biogas produced. This result can be interpreted as follows: the presence of a significant COD reflects a significant hydrolyzable quality of these two wastes in the first phase of hydrolysis by aerobic bacteria. At the end of the hydrolysis, we will obtain intermediate metabolites (such as NH₄⁺ and H₂S), which produce inhibitions in the process [65, 78, 79]. Therefore, the determination of COD prior to anaerobic digestion is not always an important parameter for assessing the hydrolyzable quality of waste.

On the other hand, the mineral composition of organic waste is essential for the growth of microorganisms as it forms an important component of many enzymes involved in the metabolic pathways of anaerobic digestion [80]. When comparing the mineral composition of these wastes with the levels of inhibition into digesters,

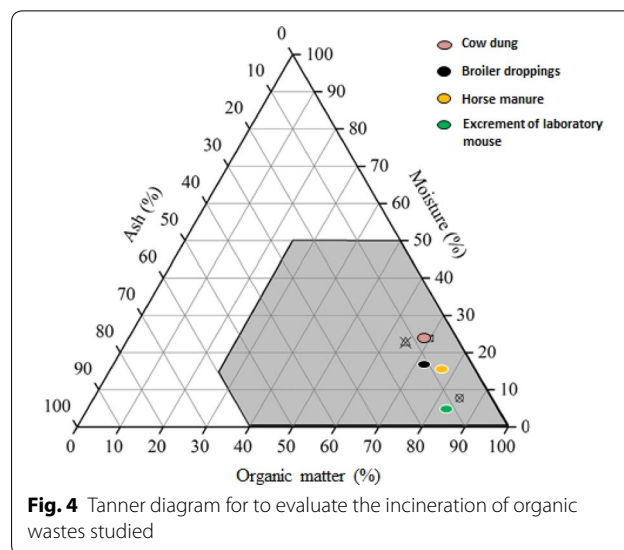


Fig. 4 Tanner diagram for to evaluate the incineration of organic wastes studied

Table 3 Comparison of biogas potential and COD of these organic wastes

Organic wastes	Biogas potential (mL/g VS)
Cow dung	260
Broiler droppings	160
Horse manure	250
Excrement of laboratory mouse	190

we noticed that the four organic wastes, without exception, do not have inhibitory content in their composition. Certain specific metals such as cobalt and nickel serve as cofactors in the enzymes involved in the formation of methane during anaerobic digestion [81]. Some elements such as molybdenum and selenium increase methane production when added to a digester [82]. In particular, Mo concentrations in the range of 3 to 12 mg kg⁻¹ TS and Se of 10 mg kg⁻¹TS increased methane production by up to 30–40% [83]. Thus, a mixture of metals increased

Table 2 Comparison of the four physicochemical parameters of these organic wastes with Tanner’s theoretical waste

	Cow dung	Broiler droppings	Horse manure	Excrement of laboratory mouse	Waste of tanner mouse
TS (%)	77.33	82.9	83.2	95	–
OM (%)	67.65	72.82	74.5	82.5	> 25
MM (%)	9.68	10.08	8.7	12.5	< 60%
H (%)	22.67	17.1	12.5	5	< 50
COD (mg O ₂ /L)	960	740	520	740	–

methane production up to a 45 to 65% range for inoculations with low trace metal concentrations [84]. Therefore, these wastes are recommended for anaerobic digestion and present no danger of mineral inhibition in digesters. The comparison of our biogas potentials obtained with those proposed by other researchers shows that they are weak. These results are normal because the wastes studied did not undergo any treatment or inoculation.

Comparison of the mineral composition

At the end of the anaerobic digestion process, it leaves two parts: the liquid phase of digestate is usually rich in plant-available nutrients which represent the mineral fraction [85]. Additionally, the digestate's solid phase also offers more nitrogen will be plant available by microbial decomposition and mineralization in soil. We noticed that these four organic wastes are rich in ions and heavy metals (Table 4). Thus, their contents are diversified from one waste to another: cow dung is rich in calcium (63 mg kg^{-1}); horse dung in nickel (73 mg kg^{-1}); and droppings and laboratory waste are rich in zinc (196 and 127 mg kg^{-1}). Teglia et al. [86] declare the presence of considerable variability in the biochemical properties of digestate, reflecting the diversity of the biomass in digesters. Some researchers have shown the high variability within the digestate group of organic materials with respect to their physical and biochemical properties which are a function of the initial biomass inputs [87]. So, in many instances the digestate equaled mineral fertilizers [37].

Conclusion

The comparison of the physicochemical and microbiological characteristics of the four organic wastes in Morocco (cow dung, horse dung, chicken droppings, and excrement of laboratory mice) reflects four important points:

1. There is an urgency to intervene to treat and valorize this waste before putting it in the open air.
2. The incineration of this waste is inadequate from an energy point of view.
3. The wastes present a great ability to be used as feed substrates of digesters.
4. The anaerobic digestion of this waste produces a reservoir of mineral elements.

The determination of the biogas potential and the mineral composition of these wastes demonstrates the ability to use them as bioenergetic substrates capable of producing green energy in the form of biogas that will be converted into heat and electricity on agricultural farms and buildings breeding in Morocco. Thus, the co-digestion of this waste is necessary for horse manure, chicken manure droppings, and the excrement of laboratory mice in order to increase their biogas potential. This last technique will be our topic of research in the coming days.

Table 4 Comparison of the mineral comparison of these organic wastes studied

Mineral element	Cow dung (mg/kg)	Broiler droppings (mg/kg)	Horse manure (mg/kg)	Excrement of laboratory mouse (mg/kg)	Inhibitory content of anaerobic digestion (mg/l)
Ca	59.73–63.31	29.82–30.4	21.79–22.61	20.42–20.73	8000 ^a
Fe	2.94–3.31	0.057–0.99	6.36–6.37	0.56–0.61	5650 ^a
K	11.81–12.28	32.85–34.96	13.72–13.84	12.75–13.54	400 ^b
Na	3.80–3.98	3.20–3.25	2.12–2.16	2.69–2.78	200 ^b
Co	0.251–0.256	0.072–0.072	1.435–1.561	–	100 ^b
Cr	4.178–4.353	7.967–8.296	23.259–32.370	6.44–8.48	300 ^b
Cu	24.559–24.612	69.453–70.909	16.354–17.444	25.24–26.48	250 ^b
Mo	4.008–4.018	5.768–7.533	3.021–5.022	2.43–2.43	–
Ni	6.613–29.931	9.166–14.993	17.237–73.856	6.64–7.08	300 ^b
Pb	1.364–2.009	2.318–2.370	5.293–5.588	0.51–0.64	340 ^b
Se	0.335–0.335	0.632–1.231	0.227–0.271	0.07–0.53	1.8 ^a
W	–	3.114–3.114	–	2.57–2.57	–
Zn	62.451–62.677	191.767–196.358	61.210–67.588	122.90–127.14	400 ^b

^a [80], ^b [65]

Abbreviations

COD: Chemical oxygen demand; CFU: Colony-forming units; M: Moisture; C/N: Carbon-to-nitrogen ratio; LHV: Lower heating values; HCl: Hydrochloric acid; MM: Mineral matter; OM: Organic matter; TAMF: Total aerobic mesophilic bacteria; TS: Total solids; TOC: Total organic carbon; TN: Total nitrogen; VS: Volatile solids; FM: Fresh matter.

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Authors' contributions

OEA and MEA designed the experiments; OEA, MEA and HL performed the experiments; OEA, MEA, HL, and LE wrote this manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

All data generated and analyzed during this study are included in this manuscript.

Ethics approval and consent to participate

Not applicable.

Consent for publication

All authors have approved to submit this work to Chemical and Biological Technologies in Agriculture. They declare that there is no conflict of interest in relation to the submission of the article.

Competing interests

The authors declare that they have no competing interests.

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