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Valorization of mango waste by biomethane production in Burkina Faso

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ABSTRACT
Mango waste is a source of bioenergy through anaerobic digestion. Although abundant in Burkina Faso, this material is not valorized through the process, due to technical problems. This study aims to determine the physicochemical parameters, to find efficient starter inoculums and to determine optimal organic loading conditions for mango waste transformation into biogas. Samples of mango waste were collected from mango transformation plant and fruit markets in different localities of Burkina Faso (Bobo Dioulasso, Orodara and Ouagadougou) were used as substrate. The physicochemical parameters were determined using standard methods (AFNOR, APHA) and the biogas produced was analyzed by gas chromatography. From the physicochemical analysis, Total solids, Volatile solids, Ash, Total carbon and pH were 8.04%; 99.7 ± 0.1%; 0.27 ± 0.02%; 57.83 ± 0.5%, and 5.87, respectively. Pig manure slurry was found to be efficient inoculum from mango waste anaerobic digestion and the optimal organic loading was 10% with 74 % of methane produced.

Keywords: Mango waste, anaerobic digestion, inoculum, biogas, methane.

1. INTRODUCTION
In Burkina Faso, as in other Sahelian countries, fruit production is dominated by mango. The production of fresh mangoes is estimated at around 200000 tons per year [1]. However, factors such as: (i) lack of control over harvesting, packaging and storage standards, (ii) poor transport conditions (iii) lack of cold chain (iv) poor road infrastructure, and (v) inadequacy of processing infrastructures, inflict enormous losses which handicap this sector. The resulting annual losses are estimated at about 1/3 to 1/2 of mango production [2, 3, 4]. These annual losses, in addition to the residues from mango processing and drying units, occasionally cause serious health and environmental problems [5, 6]. However, mango waste is a biological source of fermentable substances for the production of biogas, which can be used as fuel [6-10]. To this end, we propose to investigate for biomethanization parameters of mango waste to serve as a source of energy, in order to strengthen the dynamics of renewable energy production and to participate to a sustainable management of environmental pollution in developing countries, especially in Burkina Faso.

2. MATERIALS AND METHODS
2.1 Feedstock
The raw material used for the study was mango waste collected from two mango transformation plants in Burkina Faso (GEBANA AFRICA in Bobo Dioulasso and DAFANI SA in Orodara) and two mango markets in Ouagadougou (*"Sankaryaar" and "Katre Yaar"*) (Figures 1 and 2). After pulp and seed separation, a portion of the remaining mango waste was grounded by electric blender, passed through 2 mm mesh sieve, diluted with distillated water (1:1), and stored at 4°C until used.

Figure 1: Mango waste sampling sites in Burkina Faso.

Figure 2: Piles of mango waste at transformation plants: GEBANA AFRICA in Bobo Dioulasso (**A**) and DAFANI SA in Orodara (**B**)

2.2 Inoculums

Three inoculums were used for mango waste anaerobic digestion with regard to methane production: pig manure sludge (PMS) and cow dung sludge (CDS) collected from two digesters of the National Biodigester Program (NBP) at Nioko II and Loumbila (peripheral districts of Ouagadougou city), respectively and wastewater (WW) obtained from the slaughterhouse of Ouagadougou. The inoculum samples were anaerobicaly collected into serum bottles, carried to laboratory according to Trine and Jens [11] and then, stabilized during seven (7) days without adding a substrate to avoid biogas production during storage. After stabilization, they were stored at 4 °C until use.

2.3 Experimental Procedure

Batch studies were carried out in reactors of 120 ml capacity (120 ml glass bottles). The effective volume of the reactors was maintained at 50 ml. Experiments were carried out at room temperature (28-32°C). Separately, each reactor was initially filled with 36 ml of inoculum (wastewater, pig manure sludge or cow manure sludge) and diluted to 50 ml working volume with a buffer solution to avoid pH downing. Reactors were charged separately with a quantity of mango waste substrate containing 6%, 8%, 10%, 12%, 14% and 16% (m/v) of volatile solid (VS), respectively. Biogas production was measured by water displacement method at three days intervals. The volume of water displaced from the bottle was equivalent to the volume of gas generated. The reactors were mixed manually by shaking once a day.

2.4 Analytical methods

Mango waste samples were analyzed for total solids, volatile solids, ash mater, pH and total organic carbon, using standard methods [12, 13]. The pH was measured using a digital pH meter (WTW pH340). Reactors were periodically analyzed for gas production and composition for 32 days.

The methane content of the biogas was determined by taking 500 µl of the reactor headspace gas at three (3) days intervals and analyzed for CH_4 using a thermal conductivity gas chromatograph Girdel series 30 catharometer, equipped with porapak Q 80/100 and Q 100/120 columns assembled in parallel and connected to a thermal conductivity detector (TCD) and a potentiometric recorder (SERVOTRACE type sefram Paris 1 mV). The injector temperature was set at 90°C, column at 60°C and the detector at 100°C; N_2 was used as carrier gas. Methane standard (90% purity) supplied by Burkina Industrial Gas, allowed to establish the following regression equation from that the production of CH_4 during the experiments was deduced: Volume CH4 (µL) = 0.1094 X – 5.0911 (r^2= 0,9958), with X the area of methane peak.

2.5 Statistical analysis

The data collected were subjected to analysis of variance (ANOVA) using XLSTAT-Pro 7.5.2 software. Means were compared through Fisher test to determine significant differences among variables at α = 0.05.

3. RESULTS AND DISCUSSION

3.1 Physicochemical parameters of inoculums and mango waste

The results of the physicochemical analysis of inoculums and mango waste are shown in Table 1. The pH values of the inoculums were 6.92 ± 0.15, 6.51 ± 0.01 and 7.4 ± 0.14 for wastewater (WW), cow dung sludge (CDS) and pig manure sludge (PMS), respectively. These pH values are comparable to those of Dhanalakshmi and Ramanujam [14] who reported that pH of effluent in a digester oscillates between 6.15 and 7.26.

The dry matter content (Total Solid) of cow dung sludge (3.98 ± 0.12%) and that of pig dung sludge are within the range 1.5-45.7% reported by other authors [15, 16]. The dry matter content varies in a reverse proportion to the moisture (96.02 ± 0.3, 93.49 ± 0.09 and 99.5 ± 0.4% for pig manure sludge, cow dung sludge and wastewater, respectively). The PMS and CDS total volatile contents correspond to the range of volatile matter (38.6 - 75.4%) reported by Moller and Stinner [17] and Voca and Krica [18].

Table 1: Physicochemical characteristics of inoculums and mango waste.

	Inoculum			Substrate
Parameter	PMS	CDS	WW	MW
pH	7.4 ± 0.14	6.51 ± 0.01	6.92 ± 0.15	4.32 ± 0.08
Moisture	96.02 ± 0.3	93.49 ± 0.09	99.5 ± 0.4	91.96 ± 0.5
Total Solid	3.98 ± 0.12	6.9 ± 0.1	0.48 ± 0.13	8.04 ± 0.03
Volatile solid	98.86 ± 0.3	97.9 ± 0.01	99.82 ± 0.01	99.7 ± 0.1
Ash	1.14 ± 0.02	2.1 ± 0.33	0.17 ± 0.03	0.27 ± 0.02
Total carbon	57.34 ± 0.1	56.43 ± 0.4	57.94 ± 0.03	57.83 ± 0.5

PMS= pig manure sludge; **CDS**= cow dung sludge; **WW**= Wastewater; **MW**= mango waste

The pH recorded for mango waste (4.32) is comparable to the results of Hossain and Haque [19] who found pH values between 4 and 6 for different varieties of mangoes, and with those of Alexandro and Sergio [20] and Madhukara and Nand [21] who reported pH values of 4.21 and 4.80, respectively. The low pH value is explained by the presence of organic acids.

The moisture content of the mango waste (91.96 ± 0.5) is consistent with the result of Gunaseelan [22] who reported that the moisture content of fruits and vegetables is above 80%. The high moisture content shows a high water content in the mango waste. Inversely to the moisture content, we obtained a low dry matter content (8.04 ± 0.02). In agreement with this result, Askar and El-Tamani [23] showed that increasing of dry matter content results in a decrease of water content and vice versa.

The high volatile solid rate (99.7 ± 0.1%) is consistent with the results of Gunaseelan [22] which showed that the total volatile solids content of fruit and vegetables is greater than 95%. In view of the physicochemical parameters (Table 1), mango residues don't present any problem capable of blocking or inhibiting the anaerobic digestion of this substrate, according to the literature data.

3.2 Evolution of pH in relation to inoculum type and mango waste substrate load during anaerobic digestion process

The evolution of pH as a function of inoculum type and anaerobic digestion time was carried out at mango waste total volatile charges of: 6%, 8%, 10% for wastewater inoculum, 6%, 8%, 10%, 12% for cow dung sludge inoculum, and 6%, 8%, 10%, 12%, 14%, 16% for pig dung sludge inoculum. The results obtained during the monitoring of pH evolution are shown in figure 3.

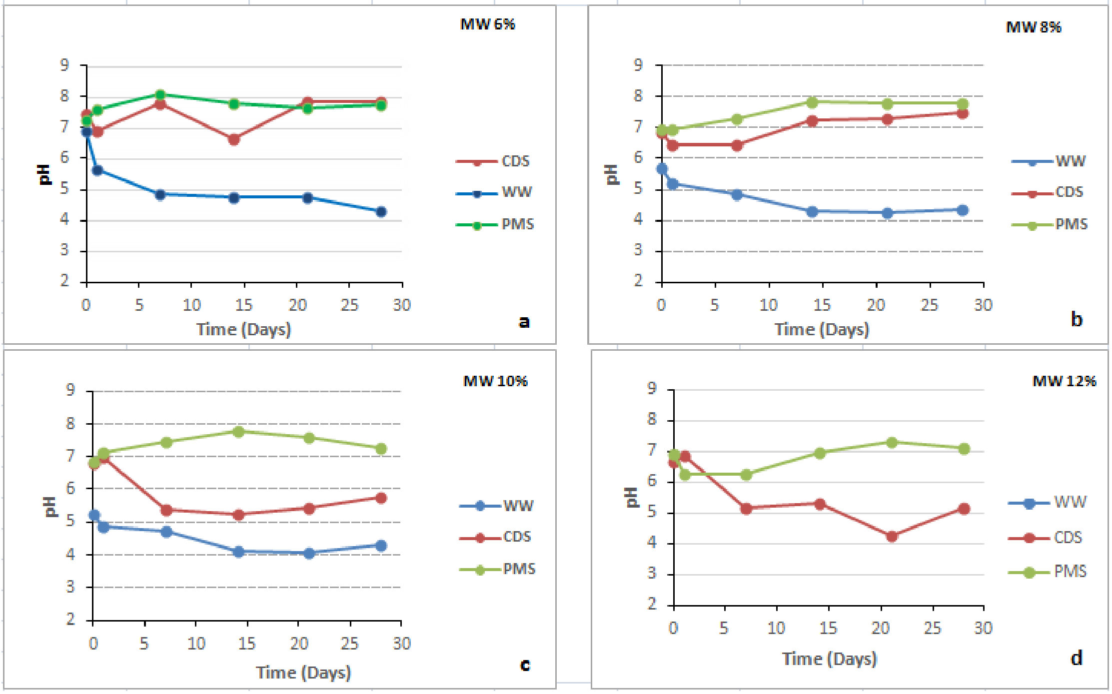

Figure 3: Evolution of pH in relation to inoculum added (waste water, cow dung sludge or pig manure sludge) and organic substrate load (6, 8, 10, 12, 14%, respectively) during mango waste anaerobic digestion process (means of 3 replicates). **WW**= Wastewater; **CDS**= Cow dung sludge; **PMS** = Pig manure sludge; MW = Mango waste.

During the anaerobic digestion process using slaughter house wastewater (WW) as inoculum, acid pH (< 7) was observed for all the organic loads (6, 8 or 10%) with average values of 4.84 ± 0.45, 4.58 ± 0.38 and 4.42 ± 0.33, respectively (Figures 3a-b-c).

In digesters inoculated with CDS and loaded at 6% organic substrate, the pH dropped slightly from 7.20 to 6.88 in the first 24 hours (Figure 3a) then, fluctuated around an average pH 7 and stabilized near pH 8 until the end of anaerobic digestion. In the same digesters inoculated with PMS, the pH oscillates around 7.83 ± 0.18 on average during the anaerobic digestion process (Figure 3a). At 8 % substrate load, the pH in the digesters inoculated with CDS dropped to around 6.57 from the first day to the eighth (8th) day then, increased gradually and stabilized around 7.6 until the thirtieth (30th) day (Figure 3c). For the same substrate load (8% MW) with PMS as inoculum, the pH increased gradually from 6,8 to 7,8 in the during the 15th day incubation period then, stabilized around this value to the end of the anaerobic digestion (figure 3b). In the 10% and 12% substrate load with CDS as inoculum, a noticeable drop of pH was observed from the first days (Figures 3c-d)). The pH stabilized around an average of 6.13 from the first hours of biodigestion until the last day in the 10% substrate load (Figure 3c), while in the 12% one, the pH dropped from 6.64 on the first day to 4.89 at the end of the anaerobic digestion (Figure 3d). However, in digesters inoculated with pig manure sludge (PMS), the pH was close to neutral during the whole period of the anaerobic digestion process at all the substrate loads tested (6%, 8%, 10% or 12%) (Figures 3a-b-c-d). The pH values recorded in these digesters were 7.83 ± 0.18; 7.41 ± 0.6, 7.47 ± 0.34 and 6.74 ± 0.45.

From the analysis of the results, it appeared that the wastewater (WW) inoculum collected was not favorable to the biomethanization of mango waste. This result is well justified by the acid pH values found in all the digesters inoculated with this inoculum at 6, 8 and 10% substrate loads: 4.84, 4.58 and 4.42, respectively. The decrease in pH below 5.0 is fatal for methanization organisms and even values close to 6.0 often cause a halt in the process [24].

3.3 Determination of optimal organic load and efficient inoculum for mango waste biomethanization.

The results from the optimal organic load and efficient inoculum determination for mango waste biomethanization are shown in Table 2. From the data, mango waste at 10% load appears the optimum organic load when using PMS as inoculum. At this load, we obtained the highest biogas production (203.37 ml) with the highest methane content (129.55 ml: 64%). Moreover, for all the substrate loads (6, 8, 10, 12, 14 or 16%), we observed a good progress of the methanization process with this inoculum. The results of biogas production corroborated with the normal evolution of pH noted during the anaerobic digestion process. The pH values observed during the process (between 6.74 and 7.83) are consistent with the optimal pH range (6.8 - 7.4) reported by Barlaz [25] and the one (6 – 8) according to El-Fadel and Findikakis [26]. These different results confirm the effectiveness of PMS and the bacterial consortium that exists in this inoculum.

Table 2: Productions of methane and methane in relation to inoculum type and substrate load during the anaerobic digestion of mango waste (means of 3 replicates).

Inoculum	Mango waste load (%)	Biogas (ml)	CH4 (ml)
	0	53.6**a**	11.64**a**
	6	140.07**bc**	87.55**bc**
	8	156**bc**	92.90 **cd**
PMS	10	203.37**d**	129.55**d**
	12	164.14**bc**	98.83**bc**
	14	150.39**bc**	95.57**bc**
	16	195.08**c**	101.88**c**
	0	39.37**a**	6.02**a**
	6	145.07**d**	91.07**e**
CDS	8	122.79**c**	58.05**d**
	10	64.64**b**	24.08**c**
	12	68.39**b**	20.30**b**
	0	32.7**a**	3.23**a**
WW	6	41.28**b**	4.19**b**
	8	36.42**b**	6.85**b**
	10	57.8**c**	9.04**b**

Within a column, values with a same letter are not significantly different according to Fischer test at α risk= 0.05. **PMS**= pig manure sludge; **CDS**= cow dung sludge; **WW**= Wastewater.

The decrease in biogas production from 10 to 12% organic load observed with CDS inoculum in our study (Table 2), may be a consequence of a too high concentration of organic matter causing pH drop. This pattern was also observed by Kirtane and Suryawanshi [8] who showed that the pH in digester drops when the feedstock load increases. With organic loads of 0.25 and 3.5 Kg/VS these authors found pH values of 7.4 and 6.3, respectively. At low pH, there is a high production of Volatile Fatty Acids (VFAs) [27-28] which is synonymous of middle acidification. This acidification could be explained by the increase of the organic load of the digester and may lead to a rapid production and accumulation of VFAs. These VFAs have to be consumed by acetogenic and methanogenic bacteria in order not to reach critical pH values. Vavilin and Rytov [29] by a process called acidogen/methanogen balance, showed that methanogenesis requires a balance between formation and consumption of acids produced. However, the low development of acetogenic and methanogenic bacteria is likely to completely block the process of biodegradation by an increasing acidity of the medium. This sequence may lead to an acidification level at which no bacteria can develop [30-31]

In the digesters inoculated with slaughterhouse wastewater (WW), biogas production was very low and the CH_4 fraction as well, for all the substrate loads (6, 8 or 10%) (Table 2). This result confirmed that the wastewater tested as inoculum in this study did not favor biodegradation of mango waste, because the pH values fluctuated below the margin allowed by the bacterial consortium of the anaerobic digestion, as reported [24]. The low production of biogas and methane content testify to the abnormal progress of anaerobic digestion in this case. The wastewater sludge may contain substances such as solvents, detergents, chlorine, soda, lime and other toxic chemicals that can block the development of the chain of bacteria during anaerobic digestion [32]. The overload of organic matter may also slow down the hydrolysis phase which constitutes the crucible stage of methanization. At the beginning of the process, a total acidification of the mixture happens, causing the pH drop and consequently the death of certain bacteria [31].

Globally, the study results (Table 2) show that not only the inoculum supply is crucial in optimizing the production of biogas but also the organic substrate load rate is very important. These results are supported by those of Traoré and Nikiema [33] who detected no methane production in the absence of inoculum during vegetable waste anaerobic digestion process. Moreover, Murto and Björnsson [34] examined methane production rate and methane yield as a process indicator and demonstrated that the rate of methane production depends not only on the process status but also on the load of the reactor. They concluded that methane yield could reflect a process imbalance. During mango residues anaerobic digestion process, Kirtane and Suryawanshi [35] observed an increase in biogas production and methane content at organic loads of 0.25 and 3.5 kg/SV, producing 5.9 and 15.4 l of biogas with 53.8 and 77% CH_4 content, respectively. That proves the importance role of organic load in the optimization of anaerobic digestion process.

The favorable pH evolution in the anaerobic digestion process (6.74 ± 0.45 to 7.83 ± 0.18) observed with PMS inoculum indicates that this sludge may contain a consortium of efficient bacteria adapted to the biomethanization of mango waste than that of the CDS or WW inoculums. Overall, the results of the study highlight the crucial role of inoculum in the methanization process of mango waste.

3.4 Influence of incubation time on anaerobic digestion of mango waste

Biogas and methane productions over mango waste anaerobic digestion process are presented in Figure 4.

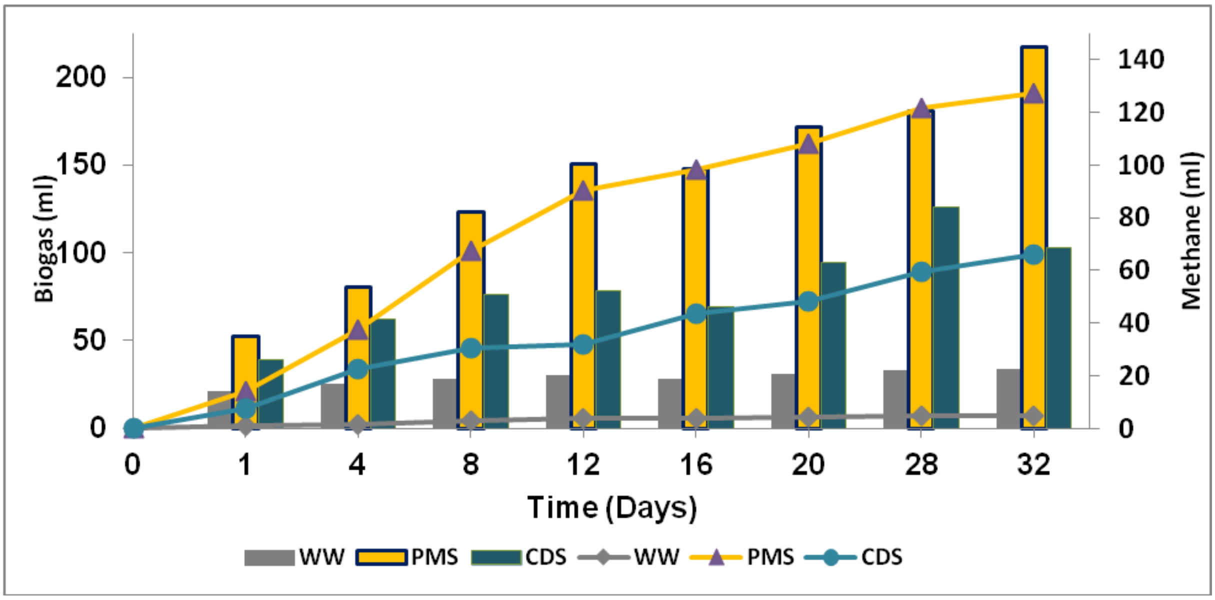

Figure 4: Methane and biogas productions during mango waste anaerobic digestion process (means of 3 replicates).

From the results, it appears that the anaerobic digestion time significantly influences the biogas production and its methane load. Previous studies showed that the production of biogas from fruit is maximum the first 10 days [14]. Contrary to biogaz production, chromatographic analysis reveals low levels of methane during the first days of methanization, then, this rate gradually evolves until reaching the maximum load. The same pattern was observed by Igoud and Tou [36] who reported an increase in CH_4 from 58.30% to 65.35% between the 18th and the 31th day of the anaerobic digestion of bovine excreta. This is due to the fact that in anaerobic digestion in batch mode, the substrate is widely available the first days but is exhausted as the microbial flora increases. Afilal and Belkhadir [37] demonstrated that the greater the availability of organic matter, the faster the production of biogas. However, the low level of methane in the first days is explained by the prolonged time of the anaerobic digestion process staking through a succession of four different phases (hydrolytic, acidogenic, acetogenic and methanogenic phases). Besides, it should be noted that the bacterial groups involved in anaerobic digestion are growing slowly. The acetogenic bacteria have a doubling time of about 1 to 7.5 days [38, 39], while the generation time of the methanogenic bacteria is 3 days [40].

4. CONCLUSION

Based on the results obtained from pH study, biogas production and methane content, we mention that pig manure sludge (PMS) and in a lesser extent, cow dung sludge (CDS) can serve as starter for mango residues methanization. Wastewater (WW) can be used as an inoculum according to the literature; however, the wastewater subjected to this study could not be used as starter for the anaerobic digestion of mango waste. From the study, we can conclude that mango waste can serve as a renewable energy source in Burkina Faso in addition to pig and cow dungs the main wastes valorized through biogas production throughout the country by the Burkina National Program of Biogas.

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