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Biogas Production from Date Palm Leaves

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ABSTRACT

This work aims to study the possibility of benefiting from date palm leaves as an alternative energy source and the production of organic fertilizers by using batch-type anaerobic digesters at a thermophilic temperature (about 50°C). Four different mixtures of date palm leave and cattle feces were compared in terms of the amount of produced biogas and the chemical composition of the fermentation effluent slurry. The different mixtures were 100% cattle feces, 10% cattle feces with 90% palm leaves, 20% cattle feces with 80% palm leaves and 50 % cattle feces with 50% palm leaves). The contents of methane and carbon dioxide of the biogas produced daily were recorded. *Salmonella* and total fecal *coliforms* were counted in the influent and effluent. The results showed that palm leaves can be used to produce biogas by anaerobic fermentation after mixing it with cattle feces. It was possible to obtain the highest yield of biogas when mixing palm leaves with cattle feces at a ratio of 50:50%. The effluent slurries of different mixtures of palm leaves with cattle feces can be used as an excellent organic fertilizer because it contains phytonutrients and organic matter.

Keywords: Date palm leaves, anaerobic digestion, cattle feces, biogas production, organic fertilizer.

INTRODUCTION

One of the main agricultural products in the Middle East and North Africa region is the date palm (*Phoenix dactylifera L.*). Due to the abundance of date palm trees in the Arabic region (100 million), which produce about 3,316,500 tons of secondary products annually, including midribs, leaves, spadix stems, and fronds, date palm secondary products are of great interest to the region (Taha, *et al*., 2006).

Due to its potential to increase rural income generation and improve nutrition security, date palm cultivation is becoming increasingly important in Egypt. The number of palm trees in Egypt increased from 6 million palm trees in 1980 to 12 million palm trees in 2020. Although about 1.4 million tons of dates are produced, only 1.5% of the total dates produced in Egypt are exported, which is often from half-dry varieties. Egypt ranks first among the five largest dates producing countries in the world, with productivity reaching about 16,90959 tons in 2020, including semi-dry varieties such as Sewi and Medjool, which are suitable for export (FAO, 2021).

El-Hadidi (1994) reported that the advantages of using biogas as a source of energy can be seen in the environmental benefits of the utilization of animal and agricultural wastes, conservation of natural resources, pollution control, and exploitation of new resources of energy. Also, Sayed-Ahmed and Huzayyin, (1986) reported that biogas technology is an important technical innovation, which not only solves the problem for farmers and rural inhabitants but also saves vast amounts of traditional fuel for other fields of technology. Thus, it can play a significant role in simulating both industrial and agricultural production.

El-Mashad (2003) mentioned that the process of anaerobic fermentation of organic waste is a process that is carried out by anaerobic bacteria that digest and break down organic matter with no oxygen present, and this process occurs by nature within the digestive system of ruminants as well as in the soil. Anaerobic fermentation technology has been used in the treatment of industrial waste and waste sewage, as well as for the treatment of agricultural waste.

Dried leaves are one of the by-products of date palm trees. A mature date palm tree has between 30 and 140 leaves with spines on the petioles. Date palms produce 10 to 30 new leaves each year, and each year the same number of leaves are removed after drying (Barreveld, 1993). In the past, this dried organ was used to make crates, ropes, baskets, shading, and other handicrafts. Animals do not consume it (Chao and Krueger, 2007). Apart from a few more recent uses, like in panel boards and soil amendments, palm date waste is now most frequently burned.

This sizeable amount of biomass can be used to produce bioenergy such as biogas through anaerobic digestion technology. One of the promising methods for producing biogas is anaerobic digestion (Bain *et al*., 2003). Furthermore, biogas, which is primarily made of methane and carbon dioxide, is a cheap and clean energy source (Agoudjil *et al*., 2011). Additionally, biogas has a high calorific value and can be used for a variety of tasks, including cooking, lighting, fueling vehicles, generating electricity, and other energy requirements (Chen *et al*., 2010).

To stabilize bio-solid waste, such as agricultural, municipal, and industrial waste, anaerobic digestion has been and is still one of the most popular methods used. The widespread adoption of this technology is a result of its many potential benefits, which include the production of energy from methane, a reduction of 30–50% in the volume of waste requiring final disposal, and a rate of pathogen destruction, particularly in the thermophilic process. After being properly treated, the stabilized biomass can also be used as a great soil conditioner (Converti *et al*.,1999). The types and relative contents of various raw materials, as well as the various

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conditions and fermenting phases, all affect the composition of biogas. The quality of biogas made from organic waste materials is not constant but changes throughout digestion (Abdel-Hadi, 2008). Several studies have been reported about the co-digestion of lignocellulosic waste materials and agro-wastes for biogas production.

Yiridoe *et al*. (2009) stated that anaerobic digestion (AD) is an effective and successful way to treat organic waste. In addition to being a method for producing biogas, which is a clean energy source, there are numerous other advantages, such as the production of organic manure, a decrease in the pathogenic and toxic effects, a decrease in odors and greenhouse gas emissions, and a decrease in weed germination. Microorganisms convert solid organic matter into methane and CO_2 gases during the anaerobic digestion process. A wide range of microbial associations that live in symbiotic relationships is involved in the intricate process.

Anaerobic digestion can be divided into four stages, each of which has a different active bacterial group: (a) Polymer hydrolysis, or the hydrolysis of lignocelluloses into simple sugars; (b) Acidogenesis, or the process by which sugars are transformed into acetate and non-acetate fatty acids; (c) acetogenesis, or the process by which non-acetate fatty acids are changed into acetate; and (d) Methanogenesis, the process by which acetate is changed into methane (IWA, 2002). The polymer hydrolysis is regarded as the first rate-limiting step in AD processes (Appels *et al*. 2008; Yadvika *et al*. 2004), Therefore, pretreatment of lignocellulosic materials is crucial to improving the ability of microbes to digest it.

Biogas plants create biogas slurry, a byproduct of anaerobic digestion, which also yields biogas (combustible methane gas), which is used for cooking, lighting, and operating engines. Crops may be fertilized with bio-slurry alone or in combination with other organic materials and synthetic fertilizers. Bio-slurry is a digested source of animal waste and it will contain more nitrogen if urine (from animals) is added, which will speed up the compost-making process. This increases the slurry's carbon/nitrogen (C/N) ratio, allowing plants and soil biota to access nutrients more easily (Kumar *et al*., 2015).

The biogas slurry contains about (93% water and 7% dry matter), of which 2.5% is inorganic matter and 4.5% is organic. Additionally, the digested biogas slurry contains phosphorus, potassium, zinc, iron, manganese, and copper, many of which have been depleted from the soil as a result of intensive farming practices. The development of healthy, fertile soil for crop production is another application for bio-slurry. In comparison to composted manure, bio-slurry contains more nutrients and micronutrients that are readily available to plants (Ishikawa *et al*., 2006). The use of biogas slurry is providing a sustainable way for agriculture, the environment, and farming communities (Alam, 2006).

Based on the significant amount of palm leaf waste produced annually in Egypt, the main goal of this research is to investigate the viability of utilizing "date palm leaves" mixed with cattle feces as a source of alternative energy and organic fertilizer.

MATERIALS AND METHODS

This work was conducted at the lab. of biogas at the Agric. Eng. Department, Faculty of Agriculture, Mansoura university.

Materials

The leaves of date palm used in this study resulted from the processes of tapping and trimming for date palm trees at the faculty farm, while the cattle feces were freshly collected from the animal farm, faculty of Agriculture Mansoura University.

Laboratory Digesters:

Four bench-scale fermenters operated in the batch mode were set up as given in Table (1). A 5-liter conical flask was used as a digester for laboratory experiments. The digester opening was sealed with a rubber stopper and carefully wrapped with para-film to prevent leakage of the resulting gas. The rubber stopper contains a small hole with a diameter of 4 mm through which a glass tube passes, one end is inside the digester, and the other end is connected to a rubber tube to transfer the resulting gas to the gas collection sacs as shown in figure (1).

Table 1. Composition of the various experimental mixtures.

Mixture	Palm leaves, %	Cattle feces, %
1	0	100
2	10	90
3	20	80
4	50	50

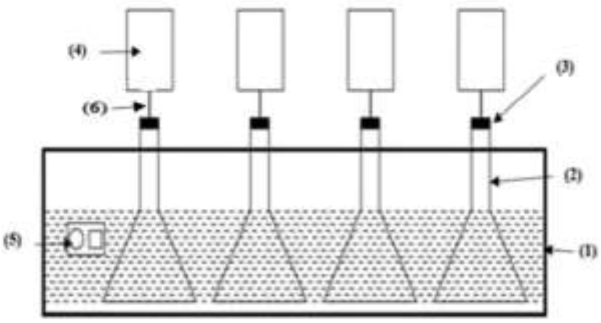

Figure 1. Digesters used in laboratory experiments
(1) Water bath (2) Digester (3) Rubber stopper (4) Gas sac (5) Thermostat (6) Rubber tube

To control the temperature of the digestion process, digesters were placed in a water bath and the temperature of the water was controlled by a thermostat. To carry out the process of stirring the mixture to ensure that the anaerobic bacteria mix well with the mixture, manual stirring or shaking of the digesters is carried out four times a day.

Four different mixtures of palm leaves and cattle feces were tested to evaluate the anaerobic digestion process, as shown in figure (2).

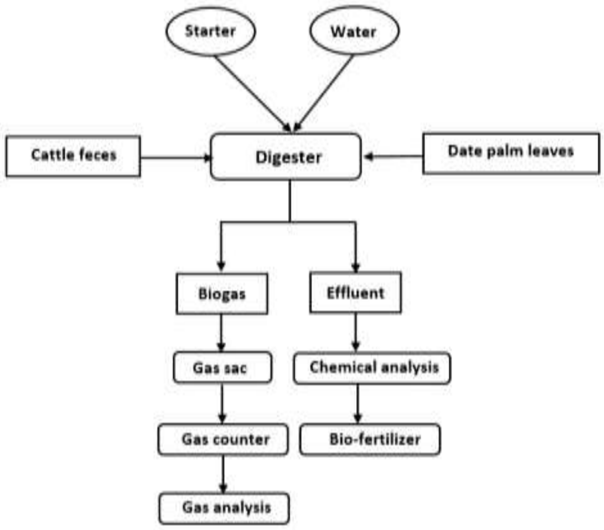

Figure 2.Schematic diagram of the laboratory biogas system.

A mixture of milled palm leaves and cattle feces was diluted using distilled water to reach a 12% total solids concentration. To determine how much water needs to be added to the mixture in order to change the ratio of solids, the equation proposed by Lo *et al*., (1981) was used as follows:

$$Y = X\left[\frac{(TS_{man} - TS_{dig})}{TS_{dig}}\right] \qquad (1)$$

Where:

Y: The required amount of water (Liter).
X: Mass of raw material, (kg).
TS_{man} & TS_{dig}: The percentage of solids for raw and fermentation material (%)

According to APHA, (1998), the total solid percentage (TS) of influent and effluent was determined using the oven method at 105°C for 24 hours. Chemical analysis of the components of the mixture was carried out before and after the treatment according to AOAC (2000), as well as the pH of the mixture was measured before and after the treatment procedure using the pH meter model (JENWAY 3505). The number of fecal and total coliforms was counted based on the method mentioned by Feng *et al*., (2001). Also, *Salmonella* was isolated using the method of Andrews and Hammack, (2001).

During the experiments, the produces gas is collected in the gas sacs, and the daily gas production is measured by using a Ritter gas meter according to CET, (1997) under room temperature and the atmospheric pressure. Then, it was transformed using the following equation into standard conditions (273 °K and 1.013 bar), as found by Gosch *et al*., (1977):

$$V_{tr} = \frac{V_f\,[273.15\,(P_1 - P_2 - P_3)]}{1013\,T} \qquad (2)$$

Where:

T: the temperature of wet gas (°K)
V_{tr}: the dry gas volume under standard conditions (Litre).
V_f: wet gas volume at pressure P and temperature T (Litre).
P_1 and P_2: the pressure of air and wet gas at temperature T (millibar).
P_3: vapor pressure at T (millibar).

During the experiment period, the components of the produced gas (CH_4 and CO_2) were analyzed every 7 days, and the percentage of methane (%) in the produced gas was determined using a gas composition analyzer GA 2000.

RESULTS AND DISCUSSIONS

The results of anaerobic digestion of different mixtures of palm leaves and cattle feces are shown in figures (3 and 4) and Table (2). The highest values of biogas production were reached during the twenty-sixth, thirty-one, thirty-fifth, and thirty-eighth day of fermentation time for mixtures 1, 2, 3, and 4, respectively, as shown in figure (3). For mixtures 1, 2, 3, and 4, the total cumulative amount of produced biogas was 16.73, 17.74, 20.88, and 24.94 liters, respectively. This means that the amount of gas produced from mixture 4 was higher by 49.1%, 40.6%, and 19.4% than the amount of gas produced from mixtures 1, 2, and 3, respectively, and this may be due to the difference in the components of the mixtures.

The results also revealed that "the hydraulic retention times" (HRT) for the "anaerobic digestion" of mixtures 1, 2, 3, and 4 were 38, 47, 55, and 63 days, respectively. Accordingly, for mixtures 1, 2, 3, and 4, the mean values of the rates of producing biogas during this study were 0.440, 0.377, 0.380, and 0.396 liters, respectively.

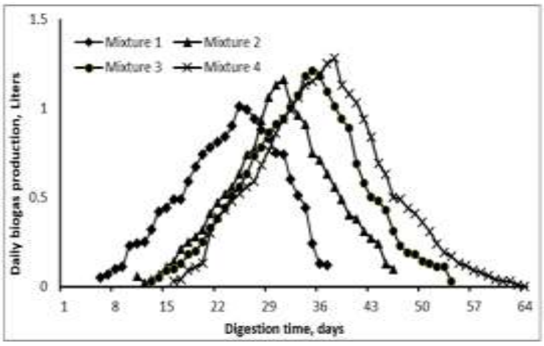

Figure 3. Daily production of biogas produced from different mixtures.

As shown in Figure (4), the methane content in the produced biogas ranged from 28 to 66% for the first mixture, 15-65% for the second mixture, 10-69% for the third mixture, and 25-70% for the fourth mixture. This shows that during the first week of digestion, only carbon dioxide gas is produced instead of methane, and after the consumption of oxygen inside the fermenter, anaerobic conditions are reached and the production of flammable gas begins. These results are consistent with the results obtained by Sayed-Ahmed and Huzayyin, (1986).

Table (2) shows the results of the chemical analysis of the components of the influent and effluent slurries of the different mixtures used in laboratory experiments. The effluent slurry of the various mixtures can be utilized as excellent organic fertilizer, as can be seen from the table, where it can be seen that the first mixture's effluent slurry contains the highest percentages of nitrogen (2.62%) and potassium (0.093 mg/kg), while the fourth mixture's effluent slurry has the highest concentration of phosphorous (0.016 mg/kg). Additionally, the ratio of carbon to nitrogen in the effluent slurry of the various mixtures is suitable and ideal for the mineralization of organic materials. This indicates that the effluent slurry from the four used mixtures can be utilized as superior organic fertilizer, particularly on sandy lands. These results are in agreement with the results obtained by EL-Shimi and Badawi, (1993), who stated that the effluent slurry obtained from bio-fermentation contains a high concentration of organic matter and plant nutrients, and its use as an organic fertilizer led to an increase in the yield of corn, wheat, beans, carrots and spinach by about 35.7 and 12.5 and 6.6, 14.4 and 20.6% respectively compared to the use of chemical fertilizers.

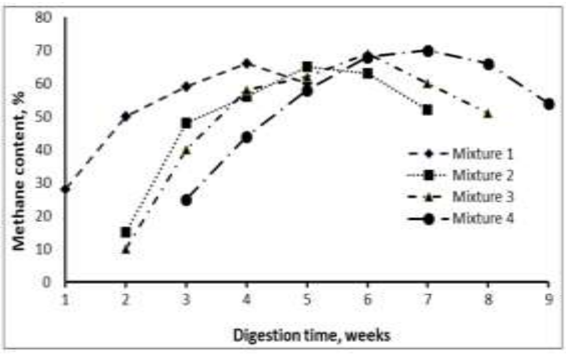

Figure 4. Daily methane production for various mixtures.

Table 2. Chemical analysis of different mixtures and the effluent slurry.

Constituent	Mix. 1		Mix. 2		Mix. 3		Mix. 4	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
Dry Matter, %	5.20	4.66	14.22	12.61	14.95	13.0	13.10	11.60
N, %	2.51	2.62	1.35	1.50	1.28	1.49	1.21	1.36
C, %	21.20	23.50	26.68	33.10	27.10	38.70	29.30	39.40
C / N Ratio	8 : 1	9 : 1	19 : 1	22 : 1	21 : 1	26 : 1	24 : 1	29 : 1
K, mg/kg	0.061	0.093	0.061	0.073	0.052	0.071	0.040	0.080
P, mg/kg	0.008	0.012	0.011	0.013	0.012	0.015	0.012	0.016

Salmonella, total, and fecal *coliform* levels in influent and effluent of different mixtures are shown in Table (3). It demonstrated that none of the effluent slurries for the four different mixtures contained any total or fecal coliform or Salmonella. The reason for this can be attributed to the fact that the gas resulting from fermentation, in addition to the high temperature, leads to kill of any pathogenic or non-pathogenic bacteria in the waste. There is evidence that various mixtures' effluents have the potential to be excellent organic fertilizers for soils.

Table 3. Fecal and total *Coliforms* and *Salmonella* in various mixtures

	Mix. 1		Mix. 2		Mix. 3		Mix. 3	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
Total Coliforms*	$4.7x10^5$	Nil	$2.1x10^5$	Nil	$1.2x10^5$	Nil	$1.1x10^6$	Nil
Fecal Coliforms*	$8.9x10^3$	Nil	$1.3x10^5$	Nil	$4.2x10^3$	Nil	$1.5x10^4$	Nil
Salmonella	+	-	+	-	+	-	+	-

*** Estimated by the most probable number (MPN)- (+) Presence, (-) Absence**

CONCULSION

Date palm leaves can be used to produce biogas by anaerobic fermentation after mixing with cattle feces. It was possible to obtain the highest yield of biogas when mixing palm leaves with cattle feces at a ratio of 50:50%. The effluent slurries of different mixtures of palm leaves with cattle feces can be used as an excellent organic fertilizer because it contains phytonutrients and organic matter.

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انتاج الغاز الحيوي من أوراق نخيل البلح

سامي إبراهيم الفار

كلية الزراعة – قسم الهندسة الزراعية – جامعة المنصورة - مصر

الملخص

يهدف هذا العمل إلى دراسة إمكانية الاستفادة من أوراق نخيل البلح كمصدر بديل للطاقة وإنتاج الأسمدة العضوية باستخدام هاضمات لاهوائية من النوع الدفعي عند درجة حرارة محبة للحرارة (حوالي 50 درجة مئوية). تم إجراء مقارنة بين كمية الغاز الحيوي الناتج والتركيب الكيميائي للمخلفات السائلة كسماد عضوي لأربعة مخاليط مختلفة بين براز الماشية وأوراق النخيل (100٪ براز مواشي و10٪ براز مواشي مع 90٪ أوراق نخيل و20٪ ماشية براز 80٪ أوراق نخيل و50٪ براز مواشي و50٪ أوراق نخيل). كما تم تسجيل محتويات الميثان وثاني أكسيد الكربون للغاز الحيوي المنتج يوميًا. تم حساب السالمونيلا والبكتيريا القولونية البرازية الكلية في المخلوط الداخل للمخمر والمخلفات الناتجة من المخمر. أظهرت النتائج أن أوراق النخيل يمكن استخدامها لإنتاج الغاز الحيوي عن طريق التخمير اللاهوائي بعد الخلط ببراز الماشية. كان من الممكن الحصول على أعلى إنتاج للغاز الحيوي عند خلط أوراق النخيل مع براز الماشية بنسبة 50: 50٪. يمكن استخدام المخلف الناتج من التخمر اللاهوائي لمخلوط أوراق النخيل مع براز الماشية كسماد عضوي ممتاز لاحتوائه على المغذيات النباتية والمواد العضوية الهامة للتربة.

الكلمات الدالة: أوراق نخيل البلح – التخمر اللاهوائي – براز الماشية – انتاج الغاز الحيوي – السماد العضوي.