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BIOGAS PRODUCTION FROM AMARANTH BIOMASS

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Energy variety of amaranth (*Amaranthus* spp.) was grown in large-scale trials in order to verify the capability of its cultivation and use as a renewable energy source in a biogas plant. The possibility of biogas production using anaerobic co-fermentation of manure and amaranth silage was verified in the experimental horizontal fermentor of 5 m^3 volume, working at mesophilic conditions of 38–40 °C. The goal of the work was also to identify the optimum conditions for growth, harvesting and preservation of amaranth biomass, to optimize biogas production process, and to test the residual slurry from digestion process as a high quality organic fertilizer. The average yield of green amaranth biomass was 51.66 t.ha^{-1} with dry matter content of 37%. Based on the reached results it can be concluded that amaranth silage, solely or together with another organic materials of agricultural origin, is a suitable raw material for biogas production.

Keywords: amaranth, biogas, biomass, co-fermentation, renewable energy sources

The problems resulting from global climate changes and increase of world prices of fossil fuels are becoming a more urgent reason for the cultivation of alternative crops, e.g. cultivated varieties of amaranth (*Amaranthus* sp.). This approach could help to maintain long term environmental sustainability. Amaranth belongs to the genus *Amaranthus* and family *Amaranthaceae*, containing approximately 60–70 species, which are disseminated throughout the world and 40 of which are considered native to the America (Sravanthi et al., 2012). Nevertheless, only a limited number of them are cultivated, whereas many are considered to be weeds. Amaranth is an annual plant with more effective C4 type of photosynthesis and more intensive nitrogen metabolism compared with C3 type plants. The high productivity of biomass production – up to 100 t.ha^{-1} (Ofitserov, 2001) creates a great opportunity for its use as a perspective and important renewable energy source as a solid fuel – straw pellets, briquettes, with heating value of dry biomass up to 17 MJ.kg^{-1} (Víglaský et al, 2009), or a renewable energy source for biogas production – green biomass, silage (Mursec et al, 2009; Mast et al, 2012). Higher effectiveness of water and CO_2 utilization create a very good tolerance of amaranth to drought (Liu and Stützel, 2004). Among other advantages belongs a high reproduction rate (it is possible to grown seeds necessary for one hectare only on several dozens of plants). For the successful implementation of amaranth in individual climatic conditions it is necessary to select appropriate species and varieties, to identify key points in production technology, variant intensity of cultivation and the possibility of regionalization (Jamriška, 1996; Sitkey, 2012).

Material and methods

For the field trials, appropriate kinds of seeds were selected and their germination was verified. In the conditions of predominantly warm, dry maize production area, on the brown soil type, there was prepared an experimental field (0.9 hectare). The genotype *A. caudatus* variety Oscar Blanco (Peru) was cultivated in the location of Southwest Slovakia – in Kolíňany (180 m above sea level: 48° 20′ N, 18° 14′ E). The goal of the experimental research was to achieve the optimum yield of green biomass for the purpose of its fermentation in biogas plant (BP). Sowing was performed on May 10, 2011, using precise sowing machine Schmotzer 3 m (line distance of 0.5 m with an established plant stand of 160,000–220,000 plants per hectare, seeding rate of 1.7 kg.ha^{-1}). The field was fertilized before sowing using complex mineral fertilizer at the rate of N 30 kg.ha^{-1}, P 30 kg.ha^{-1}, K 30 kg.ha^{-1}. Weeds were controlled by pre-emergent application of herbicide Cosmic (2.5 L.ha^{-1}) and post-emergent application of Targa Super (1.2 L.ha^{-1}). In addition to chemical treatment, there was applied mechanical weeding by means of knife weeder 2 times in order to remove weeds during the vegetation period. Before harvesting, average samples were taken by hand (inflorescences, stalk, and leaves) for detecting dry matter content (%) and other quality parameters and after that these were chopped and dried. Dry matter content was detected by drying samples up to the constant weight at 105 °C. Harvesting of amaranth biomass was performed by Claas Jaguar 940 forage harvester. Amaranth was subsequently ensilaged to plastic barrels and used in BP Kolíňany. A part of amaranth biomass was also placed to silage bags and tested in the commercial biogas station in Malý Cetín.

Anaerobic digestion of amaranth silage was performed in the facility of the Slovak University of Agriculture in Nitra, locality Kolíňany. A scheme of the experimental biogas plant (BP) is shown in the Figure 1. The equipments consisted of a homogenization tank, co-mixture tank for substrate preparation, 5 m^3 pilot fermentor with biogas holder, and storage tank of the digested sludge.

The substrate preparation composed of the cattle manure diluted with pig manure in a ratio 20 : 80%, and 10–33 kg of amaranth silage was prepared in

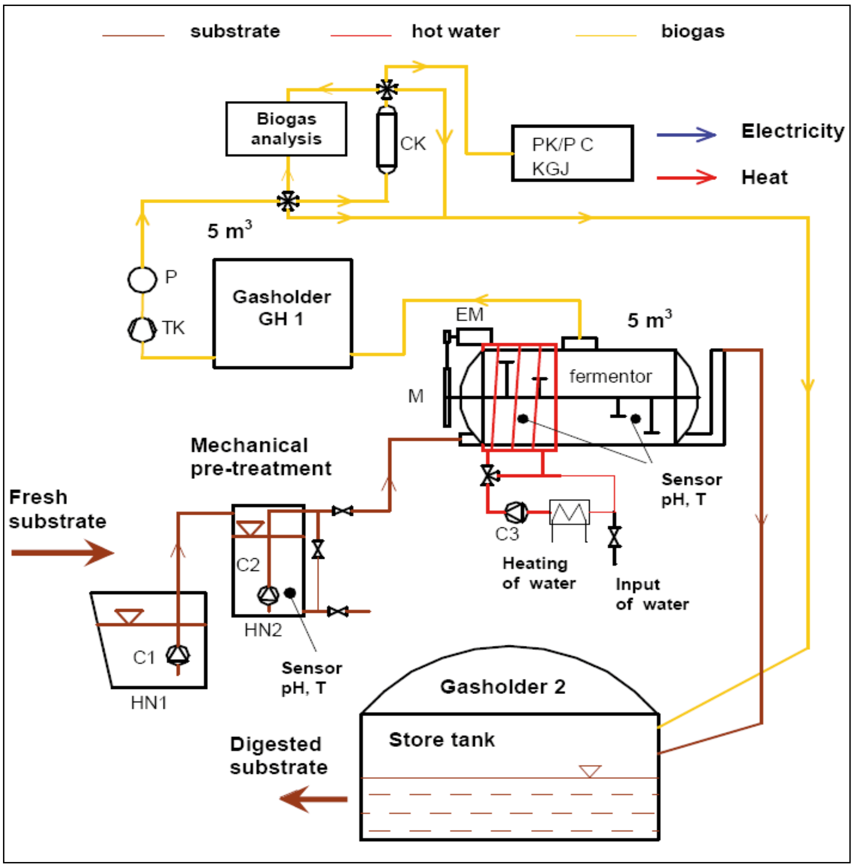

Figure 1 An operational chart of the experimental biogas plant
HN1 – homogenizing tank, volume 8 m^3, HN2 – polypropylene homogenizing tank, volume 2 m3, C1 – drowned pump, C2 – sludger, C3 – hot water pump, M – low-speed mixer, EM – electromotor, TK – turbocompressor, P – gasmeter, CK – cleaning column, PK – gas boiler

a homogenization tank. After a rough homogenization, the substrate was transported through a sludger (C1) to the equipment for the mechanical pre-treatment of the substrate. A main part of this unit is a sludger with a slicer – cutting mechanism (C2) serving to cut uniformly solid parts of the biological substrate material. The size of the sliced elements depends on duration of the substrate mechanical pre-treatment which can be exactly checked and justified by a digital timer. During trimming, the substrate is fully mixed up by a return flow. The content of the fermentor was mixed by means of a low-speed vane mixer set centrally in the fermentor's centre line. The required temperature of the fermentation was ensured by means of hot water circulating through a double jacket of the fermentor. The digested substrate off take was solved through a flow-off at the end of the fermentor. The produced biogas is led away through a collecting line to a flexible gas holder (GH1) of a volume 5 m^3. After the filling of the gasholder, the biogas is transported through a turbo-compressor (TK) to a cleaning biological column (CK) or to a greater elastic gas reservoir located above the storage tank. After the cleaning process, a part of the biogas is fired in a gas boiler (PK) or a cogeneration unit (KGJ).

The substrate was pre-processed in the homogenizing tank HN1 and the final homogenization was carried out in the tank HN2. Substrate preparation time was 30 minutes. After homogenization of coarse manure, 250 L of daily substrate dose was pumped into the experimental fermentor with the capacity of 5 m^3, to guarantee the residence time of 20 days. During the years 2010 and 2011, 4 cycles of experiments were performed.

Analysis of the raw biogas composition was done once a day by a gas analyzer Madur GA-21 Bio plus. The measured biogas components were: CH_4 (% vol), CO_2 (% vol) , O_2 (% vol), H_2S (ppm). Temperature and pH of the substrate were measured using bag measuring instrument WTW 340i. Biogas daily production VBP ($m^3.d^{-1}$) was measured by a traditional gasmeter and also on the basis of the number of the gasholder fillings per day (Gaduš et al., 2011).

The following substrate parameters were recorded in the fermentor: volatile fatty acids VFA ($kg.m^{-3}$) were measured by a titration through a distillation unit, NH_4^+ ($mg.L^{-1}$) in the substrate was measured by a photometer, pH level was measured by a pH probe, substrate temperature Ts (°C) was measured by a temperature sensor integrated in the pH probe.

An analysis of the feed-in and outgoing substrate was done 2 times a week. Following parameters were tested by a photometer: chemical oxygen demand COD ($mg.L^{-1}$), chemical oxygen demand of both the input substrate COD_f and outlet substrate COD_e, SO_4^- ($mg.L^{-1}$) in the input and outlet substrate, N_{total} ($mg.L^{-1}$) – total nitrogen content in the input substrate, the amount of the fresh substrate added daily into the fermentor Ms_d ($kg.d^{-1}$) was recorded and the reactor organic loading rate (OLR) was calculated. One of the main characteristics related to the composition of the input substrate is a value of chemical oxygen demand (COD), which is directly proportional to the total amount of organic compounds contained in the substrate, which could be theoretically converted to the biogas. From the COD value, the organic loading rate (OLR) was calculated as described previously (Gaduš et al., 2011).

Field trials: in Kolíňany location there

Results and discussion

was reached a representative stand of average height of 2.50 m. Harvest was performed on October 27, 2011. Average yield of fresh biomass was 51.66 $t.ha^{-1}$ containing up to 37% of dry weight, due to very dry weather conditions. These results are very promising, because the reached dry matter yield 19.11 $t.ha^{-1}$ is considerably higher in comparison with 6.98 $t.ha^{-1}$ as recently reported (Balodis et al, 2011). The achieved results also confirmed the positive effect of fertilization for both plant height and biomass yield.

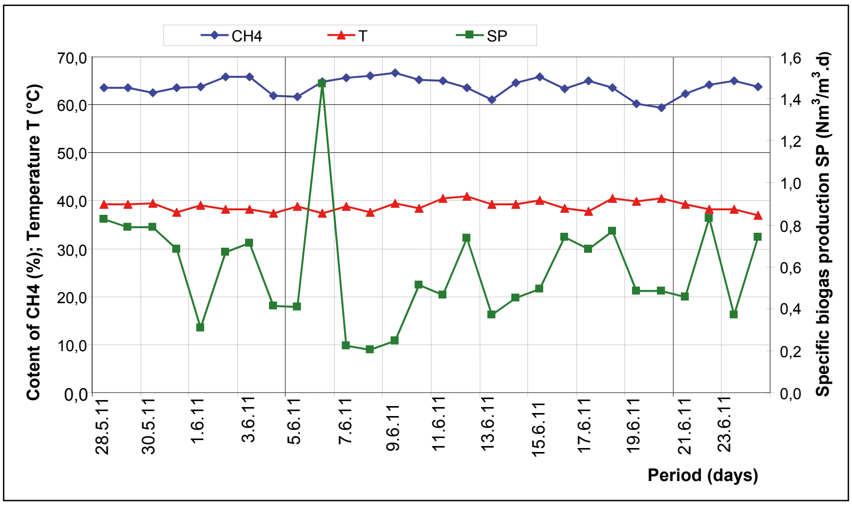

Figure 2 Time course of observed parameters during amaranth co-fermentation – 4th cycle

Despite the drought conditions, amaranth demonstrated its viability. The plants reached the height from 200 to 240 cm after 100 days from sowing, depending on their position in the field (availability of moisture).

Biogas trials: In the Fig. 2 there are illustrated the results of the cycle no. 4, where the amount of added amaranth silage to the basic substrate was 33 kg. It can be seen that the temperature in the fermentor was very stable and reached 38.9 °C in average. During the whole time, the content of methane was stabilized to the average value of 63.9%. Dry matter content in the substrate (5.58%) was higher, due to the daily addition of 33 kg of amaranth silage which ensured the achievement of the highest average specific biogas production (0.542 N $m^3.m^{-3}.d^{-1}$) compared to previous cycles.

From the average values of the observed parameters (Table 1), it can be seen that the input substrate (manure + amaranth silage) in fermentor exhibited a high value of the organic (biodegradable) total solids OTS of 74.11%. The samples from the homogenizing tank (prior to entering the fermentor) had an average chemical oxygen demand COD of 49.1 $g.L^{-1}$.

The results of the experiments are summarized in Table 2. In each cycle, co-fermentation of amaranth silage ensured the increase of biogas production and very stable and high levels of the methane content in biogas. In addition, a significant reduction in hydrogen sulfide was reached, which is an undesirable impurity in the biogas and must be eliminated before biogas burning. Using the dose of 33 kg of amaranth silage, nearly 3.39 times higher specific

Table 1 Average values of observed parameters – 4th cycle

Parameter	Unit	Samples	
		manure	fermentor
pH	–	5.90	7.33
Temperature	°C	20.00	38.9
Total suspended solids (TS)	%	4.90	5.58
Volatile suspended solids (VSS)	%	–	3.72
Organic total solids (OTS)	% TS	–	74.11
Chemical oxygen demand (COD)	mg/l	49,100	–
Total nitrogen (N_{tot})	mg/l	153	–
Ammonium ions (NH_4^+)	mg/l	–	1,040
Sulfate ions (SO_4^{2-})	mg/l	163	–
Iron (Fe)	mg/l	–	8.53

Table 2 Comparison of average parameters of biogas production using co-fermentation of manure and amaranth

Cycle	Substrate	CH_4	H_2S	CO_2	Biogas production	Specific biogas production	OLR
		vol. %	ppm	vol. %	$Nm^3.h^{-1}$	$Nm^3.m^{-3}.d^{-1}$	kg COD. $m^{-3}.d^{-1}$
1st	S + A1	60.6	718	39.3	0.091	0.436	1.781
2nd	S + A1	59.5	1000	40.9	0.080	0.385	1.460
3rd	S + A1	62.9	897	32.7	0.073	0.365	1.950
4th	S + A2	63.9	998	28.9	0.113	0.542	2.455
Ref	S	60.8	1343	31.2	0.032	0.160	0.720

PM – pig manure; CM – cattle manure; Substrate (S) – 250 liters of PM:MH 80:20 vol.% ; A1 – 10 kg of amaranth silage; A2 – 33 kg of amarant silage; Ref – reference substrate; OLR – organic loading rate biogas production was reached, with the average methane content of 63.9% compared to the reference substrate, which is a very important result confirming the suitability of amaranth application in the biogas plants.

During the experiments of amaranth co-fermentation, the defined requirements for COD removal (efficiency above 85%) were met at a substrate delay in the fermentor for more than 5 days and at OLR less than 10 kg $COD.m^{-3}.d^{-1}$. However, full conversion of the volatile fatty acids (VFA) to methane requires a delay of the substrate in the fermentor for more than 10 days (Mockaitis et al., 2006). The rest after fermentation, i.e. waste from digesters (digestate) was tested in field trials and confirmed as a good organic fertilizer (Pospišil and Režo, 2011). As a result of collaboration with agroindustry, amaranth biomass was successfully filled to silage bags and tested in commercial biogas station in Malý Cetín (the data will be published later).

Conclusions

During two years experiments the research and verification of amaranth cultivation in real large-scale field conditions were carried out, confirming the possibility of the production of 100 tons of fresh biomass per 1 ha with the minimum dry content of 20% (average yield ranged from 100 to 200 $t.ha^{-1}$, depending on fertilization). It was clearly shown that the amaranth cultivation for energy purposes should be done on non-weedy land, using original seeds, preferably from the Andean region. These plants need short-day light conditions for flowering, however, they rose to an excessive (gigantic) size in Slovak long-day light conditions, without forming the seeds. Based on the reached results, it can be concluded that amaranth silage can be used as a raw material for biogas station solely or together with another organic materials of agricultural origin. Our experience also confirmed the stable long-term storage parameters of amaranth silage. Biogas production from amaranth silage has also the advantage due to high and relatively stable harvests compared to most of the other crops, and in small demands for intensification factors (fertilizers and pesticides), resulting in low production costs. Success depends on the choice of appropriate species, varieties or hybrids, having a higher biomass yield.

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