doi: 10.17221/36/2017-PSE

Technological value of raw materials from sugar beet growing area fertilized with digestate from sugar beet pulp biogas plant

Andrzej BARYGA*, Bożenna POŁEĆ, Ewelina MAŁCZAK

Sugar Department, Wacław Dąbrowski Institute of Agricultural and Food Biotechnology, Leszno, Poland

**Corresponding author: baryga@poczta.onet*

ABSTRACT

Baryga A., Połeć B., Małczak E. (2017): Technological value of raw materials from sugar beet growing area fertilized with digestate from sugar beet pulp biogas plant. Plant Soil Environ., 63: 207–212.

The purpose of the work was to study the suitability of residue obtained during the methane fermentation process of sugar beet pulp for agricultural use in sugar beet plantations. Studies were performed with the sugar beet pulp fermentation residue and sugar beets (*Beta vulgaris* cv. Fighter) harvested from experimental plots. It was found that the by-product of sugar beet pulp digestion may be utilized in agriculture taking into account its chemical and microbiological standards. The nutrients in digestion residue were as assimilable for sugar beet plants as the nutrients in mineral fertilizers. The evaluation of technological parameters of sugar beet harvested from experimental plots based on standard technological criteria showed that irrespective of fertilization treatment, the raw material obtained met most of the requirements and can be used as a stock material for sugar production.

Keywords: biogas residue; sugar beet fertilization; technological value of sugar beet; anaerobic digestion; utilization in agriculture

Sugar beet pulp, which is a waste from sugar beet processing, has traditionally been used as full value animal fodder for cattle. The excess number of beet pulp and evolution of the agricultural system in Poland forces sugar plants to find another method for the utilization of this by-product. Using sugar beet pulp to produce biogas by anaerobic digestion appeared to be a very beneficial method of processing it. Plant material fermentation is common in many countries (Hutnan et al. 2001, Brooks et al. 2008, Khanna et al. 2008, Seppälä et al. 2008, Murphy and Power 2009, Połeć et al. 2011, Ziemiński and Kowalska-Wentel 2015). However, it should be noted that, additionally to biogas, during anaerobic digestion, waste products are generated, so there is the necessity to seek possibilities of its efficient management. Fermentation residue (digestate) contains a lot of nitrogen, potassium plus other macro- and microelements (Lošák et al. 2016). Many authors reported economic and environmentally safe methods of post-digestion effluent management and indicated the agricultural use of digestates as an optimal way of utilizing it (Cirne et al. 2007, Gunnarson et al. 2011, Chen et al. 2012, Berruto et al. 2013, Bachmann et al. 2014). The use of beet pulp fermentation residue as a fertilizer in sugar-beet growing area requires verification of technological suitability of the raw material for sugar beet processing.

MATERIAL AND METHODS

The studies were performed on the sugar beet pulp fermentation residue and sugar beets harvested from experimental plots (*Beta vulgaris*

doi: 10.17221/36/2017-PSE

cv. Fighter) in growing seasons 2013–2015. Six experimental plots with the surface of 18.75 m^2 each were established. Nitrogen rate of 120 kg N/ha was applied. Three plots were fertilized with mineral fertilizer and three plots were fertilized using the outflow from the fermenter (a mixture of liquid and sludge). As a mineral fertilizer, a granular compound of trade name Lubofos pod buraki was applied. Beet samples (10 per plot) were collected at the end of October and were subjected to chemical quality studies, covering: determination of the content of: sugar (sucrose), dry mass, parenchyma, ash, invert sugar, non-sugars, α-amino acid nitrogen, urea nitrogen, sodium and potassium.

Based on raw material chemical quality parameters, there were 11 indicators specifying the sugar beet technological value calculated: expected purity of thick juice (Cz_{sg}) calculated with formula: 99.36 – 0.1427(Na + K + α – N); indicator of purity of the beets: Ck% × 100/Ss%; expected amount of sugar in molasses (Ck_m): 0.349 (Na + K); alkalinity factor taking invert into account (WAI): Na + K/α – N + I; ash indicator: Ck/Pp sol (soluble); α-amino acid nitrogen indicator: Ck/α – N; urea nitrogen indicator: Ck/N urea; reducing substances content: Ck/Inv; non-sugar indicator: Ck/Nc sol; potassium alkalinity indicator: K/α – N; ash alkalinity indicator: Pp sol./α – N.

Where: Na, K, α – N – content of soluble sodium, potassium and α-amino acid nitrogen in beets in $mmol_+$/100 g of sucrose; Ck, S.s, Pp sol, urea N, Nc rozp, Inv – content of sugar, dry matter, conductive ash, urea nitrogen, soluble non-sugars ash, invert in beets in %: I – content of invert in beets in $mmol_+$/100 g of beets. All results were subjected to statistical analysis (two-factor analysis of variance – growing season and fertilization method, Fisher's test of homogeneous groups at P = 0.05, Statistica ver. 12.0, StatSoft Polska, Krakow, Poland).

The following parameters were determined: pH by the potentiometric method; dry matter, organic dry matter and pulp by the balance method; reducing compounds, calcium, magnesium, ammonia nitrogen, urea nitrogen by the titration method; α-amino acid nitrogen by the spectrophotometrics; Cd, Ni, Cr, Hg, Cu and Zn content by flame atomic absorption spectroscopy (FAAS), mercury by the atomic absorption spectroscopy (AAS) with amalgamation, sucrose by the polarimetric method, ash by the conductometric method, Na and K content by the AAS atomic spectrophotometry, the presence of *Salmonella* sp. according to PN-Z-19000-1:2001, the number of living eggs of *Ascaris* sp., *Trichuris* sp., *Toxocara* sp. according to PB-04 edition 3, dated on 9/4/2010.

RESULTS AND DISCUSSION

In the light of the European law regulations, post-digestion by-products from the biogas plants can be applied in agriculture as soil amendments, providing that they meet certain requirements. Number of *Salmonella* sp. and intestinal parasites, as well as heavy metals content in digestion residues are shown in Table 1 and they comply with all requirements. No presence of pathogenic bacteria and intestinal parasites in the fermentation by-product confirmed the sanitizing aspect

Table 1. The quality of sugar beet pulp fermentation residue

Parameter	Unit	Growing season			Permissible parameters for agricultural use
		2013	2014	2015	
Cadmium	(mg/kg of dry matter)	2.7	2.2	5.2	≤ 20
Lead		17.1	42.4	22.1	≤ 750
Nickel		5.5	8.8	5.5	≤ 300
Chromium		29.6	< 25.0	26.3	≤ 500
Mercury		0.543	0.357	0.426	≤ 16
Copper		108	88	115	≤ 1000
Zinc		446	295	470	≤ 2500
Salmonella sp.	(in 100 g of sludge)	–	–	–	–
The number of living eggs of *Atrichuris* sp., *Trichuris* sp., *Toxocara* sp.	(unit/kg of dry matter)	–	–	–	–

doi: 10.17221/36/2017-PSE

Table 2. Main characteristics of mineral fertilizer and sugar beet pulp fermentation residue

Parameter	Unit	Lubofos pod buraki	Digestate
Dry matter	(%)	100	1.1
Total N	(g/kg of dry matter)	35	171.9
$N\text{-}NH_4^+$		35	85.5
Phosphorus		44.0	13.7
Potassium		174.3	11.5
Calcium		42.9	115.0
Magnesium		13.2	7.9
Sulphur	–	68.0	–
Organic matter	(% dry matter)	–	46.1

of anaerobic digestion (Luste and Luostarinen 2010, Massé et al. 2011).

Nkoa (2014) reported that there are some European requirements for organic fertilizers with respect to N, P, K (e.g. in France, total N, K_2O and P_2O_5 must be greater than 3% in fresh weight; in Germany, nutrient contents on a dry matter basis must be greater than 0.5% (N), 0.3% P and 0.5% K_2O). The main characteristics of mineral fertilizer and sugar beet pulp fermentation residue are shown in Table 2.

The technological value of sugar beet is defined by a set of biological, chemical and physical properties of beet roots, which directly influence the technological process, kind and amount of losses of sucrose and the yield of white sugar. Various assessment methods of the quality of sugar beet have been used by different researchers (Radivojević et al. 2008, Nges et al. 2012, Artyszak et al. 2014, Strochalska et al. 2014). The indicators for assessment of technological value of sugar beets used in this experiment were developed in the Institute of Sugar Industry in Poland and they enable the correctness of a technological process to be predicted and the mistakes resulting from the changes in the quality of the raw material to be significantly reduced (Butwiłowicz et al. 1990). Table 3 presents the results of statistical analysis of these indicators depending on the fertilization method (factor A) and growing season (factor B). Particular indicators were compared with optimal values for sugar beet processing.

According to the data presented in Table 3, no significant differences (average A from 3 years) were found between technological value of beets fertilized with minerals and fermentation residue in the range of 6 out of 11 technological value indicators. Those indicators are: purity of beets, α-amino acid nitrogen, reducing substances, non-sugars, potassium and ash alkalinity. Differences were statistically confirmed in 5 out of 11 indicators: ash, urea nitrogen, expected purity of thick juice, expected amount of sugar in molasses and alkalinity taking invert into account. However, it could be said that the replacement of mineral fertilization with sugar beets pulp methane fermentation residue ensured obtaining raw material that met all demands as raw material for sugar production. In case of biogas residue fertilization, 9 beet quality indicators beneficial for the sugar processing technology were obtained: high expected purity of thick juice (96.3%), indicator of beets purity (76.89%), ash indicator (56.11), α-amino acid nitrogen (6871), urea nitrogen (2050), reducing substances (271.6), (5.21), potassium alkalinity (46.6) and ash alkalinity (124.1). There were 2 indicators non-beneficial for sugar processing technology: expected amount of sugar in molasses (2.649 for mineral fertilization and 2.353 in case of biogas residue) and non-alkalinity including invert sugar indicator (3.63 after mineral fertilization and 3.47 in case of biogas residue). However, it should be emphasised that these factors were unfavourable in case of both methods of fertilization. The optimal value of sugar amount in molasses should not exceed 2 and indicator for non-sugars should be higher than 10. The lower value of the non-sugars index may be indicative of the fact that the raw material is immature, however according to Filipović et al. (2011) non-sugar content may depend on the genotype of sugar beet, as well as plant density in the field. The authors report that the technological value of beet roots is not only influenced by their fertilization but also by the beet seed, location, sowing date, density, agricultural practices, the incidence and weed control, protection from pests and diseases; course of the weather conditions during the growing season (precipitation, temperature, sunlight).

The influence of the growing season (average B) was also confirmed in our studies. The differences were indicated in case of all technological value indicators irrespective of fertilization method. Data presented in Table 4 confirmed that sugar beet growing seasons in the years 2013–2015 were significantly different in terms of temperature, the amount of rainfall and the number of sunny days.

Moreover the studies showed that the 3-year average sugar content (%) in sugar beet roots

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Table 3. The influence of fertilization method and growing season on the raw material technological value (2013–2015)

Fertilization method (A)	Growing season (B)			On average (A)	Indicators beneficial for technology
	2013	2014	2015		
Cz_{sg} indicator – expected purity of thick juice					
Mineral	97.3[d]	89.9[a]	99.3[c]	95.5[a]	> 92
Through the outflow from the fermenter	97.9[e]	91.6[b]	99.3[c]	96.3[b]	
On average (B)	97.6[b]	90.8[a]	99.3[c]		
Beets 'purity' indicator					
Mineral	81.00[b]	77.33[ab]	75.00[a]	77.78	> 70
Through the outflow from the fermenter	77.00[ab]	77.33[ab]	76.33[ab]	76.89	
On average (B)	79.00	77.33	75.67		
Ck_m indicator – expected amount of sugar in molasses					
Mineral	1.300[b]	4.200[e]	2.446[c]	2.649[b]	< 2
Through the outflow from the fermenter	0.967[a]	3.567[d]	2.526[c]	2.353[a]	
On average (B)	1.133[a]	3.883[c]	2.486[b]		
WAI indicator – alkalinity factor taking invert into account					
Mineral	3.03[ab]	10.37[e]	6.67[cd]	6.69[b]	>1.8
Through the outflow from the fermenter	2.23[a]	8.80[de]	4.60[bc]	5.21[a]	
On average (B)	2.63[a]	9.58[c]	5.63[b]		
Ash indicator					
Mineral	60.33[cd]	42.67[a]	56.00[c]	53.00[a]	> 40
Through the outflow from the fermenter	63.33[d]	49.33[b]	55.67[c]	56.11[b]	
On average (B)	61.83[c]	46.00[a]	55.83[b]		
α-amino acid nitrogen indicator					
Mineral	2341[a]	2096[a]	16 967[b]	7135	> 800
Through the outflow from the fermenter	3050[a]	2163[a]	15 400[b]	6871	
On average (B)	2129[a]	2696[a]	16 183[b]		
Urea nitrogen indicator					
Mineral	1.544[a]	1233[a]	1964[c]	1580[a]	> 750
Through the outflow from the fermenter	1.426[a]	1581[ab]	3143[e]	2050[c]	
On average (B)	1.485[a]	1407[a]	2553[b]		
Reducing substances indicator					
Mineral	260.7[ab]	229.7[ab]	585.3[c]	358.6	> 100
Through the outflow from the fermenter	176.7[a]	237.0[ab]	401.0[bc]	271.6	
On average (B)	218.7[a]	233.3[a]	493.2[b]		
Non-sugars indicator					
Mineral	4.33[b]	3.57[ab]	3.00[a]	3.63	> 10
Through the outflow from the fermenter	3.67[ab]	3.47[ab]	3.27[a]	3.47	
On average (B)	4.00[b]	3.52[ab]	3.13[a]		
Potassium alkalinity indicator					
Mineral	15.0[a]	24.0[a]	98.3[b]	45.8	> 8
Through the outflow from the fermenter	17.0[a]	19.3[a]	103.3[b]	46.6	
On average (B)	16.0[a]	21.7[a]	100.8[b]		
Ash alkalinity indicator					
Mineral	38.3[a]	49.7[a]	303.3[b]	130.4	> 15
Through the outflow from the fermenter	48.0[a]	44.3[a]	280.0[b]	124.1	
On average (B)	43.2[a]	47.0[a]	291.7[b]		

Means in a column with different letters were significantly different ($P \leq 0.05$). The same letters for homogenous groups indicate that the mean values do not differ significantly. Cz_{sg} – expected purity of thick juice; Ck_m – expected amount of sugar in molasses; WAI – alkalinity factor taking invert into account

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Table 4. Weather conditions in the sugar beet growing seasons (IV–X) in the years 2013–2015

Month	Monthly average air temperature (°C)			Monthly average amount of rainfall (mm)			Monthly average number of sunny days		
	2013	2014	2015	2013	2014	2015	2013	2014	2015
IV	8.0	10.3	8.3	29.6	38.6	26.3	155.5	181.25	195.0
V	14.7	13.6	12.8	89.9	95.5	54.2	207.7	217.8	221.2
VI	17.6	16.0	16.4	109.4	55.0	39.0	223.0	244.0	240.2
VII	19.3	21.1	19.4	55.3	80.7	70.0	301.3	285.6	272.8
VIII	18.7	17.7	21.9	43.0	70.4	11.3	268.3	213.3	314.6
IX	12.2	14.9	14.8	82.1	47.9	46.8	130.2	190.1	169.2
X	10.2	10.0	7.5	15.4	29.7	32.3	121.8	137.2	130.8
Average during the growing season	14.4	14.8	14.4	60.7	59.7	40.0	201.1	209.9	220

reached 17.6 in case of biogas residue fertilization and 17.3 with mineral fertilization. Total yield of crops (t per ha) amounted to 42 for mineral fertilizer and 43 for biogas residue. White sugar yield at the level of 7.27 t per ha was obtained for mineral fertilizing, while in the case of biogas residue fertilization it was 7.57. The differences were not statistically confirmed.

Reports on the utilization of sugar beet pulp fermentation residue as a fertilizer for the cultivation of sugar beet, as well as for the cultivation of other crops, were not found in the scientific literature. Only Nges et al. (2012) reported the use of corn and sugar beet silage fermentation residue as a substrate for fertilizer. However, a recent study conducted by the Department of Sugar Industry has already confirmed the possibility of the use of sugar beet pulp fermentation residues in maize (*Zea mays*) (Baryga et al. 2015). The work on the use of pulp fermentation in the cultivation of willow is currently underway.

The results of the studies presented indicate the possibility of limitation of the mineral fertilizer application in the sugar beet growing area. According to Nkoa (2014) numerous studies across the world have shown that anaerobic digestates were at last as effective as mineral fertilizers. In case of sugar beet (*Beta vulgaris* L.), digestates derived from cattle manure gave similar results to chemical fertilizers. Lošák et al. (2011) reported that digestion is associated with large losses of organic C and digestates are poor in labile organic substances so the soil must be supplied from other sources in order to ensure soil fertility – by application of compost, farmyard manure or green manure. Similarly, in Spain, anaerobic digestates must be complemented with mineral fertilizers (Nkoa 2014).

There is a wide range of anaerobic digestates, whose composition and aspect depends upon the type of biomass inputs used (the most frequently used-manures from stables, crop residues, wastes from food industry, municipal wastes, and dedicated energy crops) and the configuration of the digester (Möller and Müller 2012), as well as the crops requirements. Nkoa (2014) reported that liquid digestates derived from dairy feedstock would be more suitable for crops that require relatively high amounts of P and K (leguminous plants) while the liquid digestates derived from broiler litter would be more suitable for cereal crops, vegetables and grasses, which are crops with high N demand.

In conclusion, the study showed that the content of heavy metals and pathogenic microorganisms as well as parasites in the sugar beet pulp fermentation residue is in accordance with the requirements that permit its application as a fertilizer in agriculture. The assessment of technological value of sugar beets harvested from experimental plots has shown that sugar beets, in most cases, met the technological criteria, regardless of the fertilizing method and may be used as a raw material for sugar production. The conducted experiments indicate that the mineral fertilization could be substituted with the use of sugar beet pulp fermentation residue in the sugar beets cultivation.

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Received on January 18, 2017
Accepted on May 8, 2017
Published online on May 17, 2017