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Conservation losses in the course of ensiling sugar beet for biogas production

In a joined research project of several companies a procedure for conservation of sugar beet was developed. Model experiments were carried out for this purpose. The conception of the procedure tested is the ensiling of whole sugar beets in large plastic bags, after the surface of the individual beets is treated with an antimycotic preservative. Chopping of the beets is done after the storage in the bags. In the course of these experiments, a method was developed and tested which enables the determination of the conservation losses expressed as losses of the methane forming potential. This method is also suitable to evaluate other procedures of sugar beet conservation and storage.

Keywords

Biogas, sugar beet, conservation losses, methane yield

Abstract

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The use of sugar beet as energy crop has attracted significant attention. The combination of high yield per hectare and good fermentability make this crop particularly suitable for biogas production. Practical experience has confirmed the high specific gas yield and, even more importantly, the rapid gas production. It has been known that sugar beet can only be stored for a limited period of time so that preservation is required in order to make the crop available throughout the year. The advantage of high yields can only be exploited fully if the gas forming potential can be vastly maintained from harvest to use in the fermenter. Different technologies are currently tested and evaluated regarding storage and preservation of sugar beet. However, the best possible concept to maintain the gas production potential best at justifiable costs has yet not been found.

Crop-specific issues in the evaluation

The evaluation of sugar beet as substrate for biogas production must discern between two traits: gas production potential per weight unit and degradation rate per time unit. If, under practical conditions, maize silage is mass-equivalent replaced by fresh sugar beet, then an increase is frequently observed in gas yield. However, this does not allow to drawing the conclusion that sugar beet possess a higher gas forming potential than has maize silage. This finding can rather be explained by the more rapid degradation of sugar beet than that of maize silage. Consequently, it would be misleading, and even wrong, to relate the higher gas yield per time unit to the specific gas production potential per mass unit of sugar beet, which, occasionally, has been done already.

If sugar beet is used as substrate an increase is frequently observed in methane concentration of the biogas. The reason for this finding is the alcohol content of the silage which has a significantly higher energy value than the sugar it was produced from. Also for this reason, losses in organic matter (OM) during fermentation are higher than energy losses. Consequently, loss in OM is not a suitable parameter to evaluate the efficiency of preservation with sugar beet. On the other hand, the gas forming potential based on OM of ensiled sugar beet is often markedly higher than that of fresh sugar beet and must therefore not be used for the calculation of total biogas production per hectare of fresh beet. If this is done then gas yield per hectare is overestimated. Thus, in the evaluation of fresh and ensiled sugar beet as substrate for biogas production specific issues need to be taken into consideration to estimate yield and preservation losses.

The present article addresses the question how to maintain the mass-specific gas forming potential of sugar beet during fermentation and storage. Methods have been proposed recently to determine the gas forming potential based on laboratory analyses [1]. In which way losses in gas forming potential should be measured is described here on the basis of results which were found within the scope of a joint project on the storage of sugar beet. These results have been published elsewhere without having shown in detail how losses were determined [2].

Materials and methods

The tested technological concept includes surface treatment of the washed individual sugar beets with an antimycotic chemical silage additive and subsequent storage in plastic tubes. To simulate the prevailing conditions in plastic tubes, sugar beets from the 2008 harvest were stored in plastic drums (215 litres volume). Drums were equipped with devices to restrict gas exchange and to collect effluent. The washed sugar beets were either stored unprocessed or crushed, and subsequently treated with the chemical silage additive or left untreated, respectively. In addition, one treatment was tested which simulated storage in clamps by allowing unrestricted air ingress into the drums for the entire storage period. Storage was done at ambient temperature. A total of 8 drums per treatment were used whereof 4 were opened after 4.5 months of storage in March 2009, and the remaining 4 drums per treatment were opened after 9 months of storage in August 2009. Regarding data on fermentation, only those are presented from August 2009 so that the effects can be evaluated at including higher storage temperatures in summer.

The following evaluation criteria were used: the methane forming potential (MFP) of fresh and ensiled sugar beet as well as the losses in MFP which occur during the entire period of fermentation and storage. Silage and effluent were analyzed for fermentation products (acids and alcohols) and DM corrected for the loss of those volatiles during drying [3]. Also the contents were determined of all required nutrients, crude ash (XA) and ADF_{org} (organic proportion of acid detergent fiber) in fresh and ensiled sugar beet. Concentrations of fermentation products and nutrients in silages and effluents were calculated based on corrected dry matter (DM_c). Results from routine laboratory analyses for XA and ADF_{org}, which are like normally based on DM, were finally multiplied with the coefficient of DM/DM_c. Methane forming potential was calculated by using the contents of fermentable organic matter (FOM) and alcohol [1].

The following equations were used for the calculation of FOM

in fresh sugar beet:

$$FOM\ [g/kg\ DM] = 991 - XA\ [g/kg\ DM] - 0.50\ ADF_{org}\ [g/kg\ DM] \quad (Cl.\ 1)$$

and in silages and effluents:

$$FOM\ [g/kg\ DM_c] = 991 - XA\ [g/kg\ DM_c] - 0.50\ ADF_{org}\ [g/kg\ DM_c] \quad (Cl.\ 2)$$

(In effluents, ADF_{org} was not determined, of course.)

Calculation of the MFP was performed by using the following equations:

Fresh sugar beets:

$$Methane\ [litres/kg\ DM] = 0.375\ FOM\ [g/kg\ DM] \quad (Cl.\ 3)$$

Silages and effluents:

$$Methane\ [litres/kg\ DM_c] = 0.375\ FOM\ [g/kg\ DM_c] + 0.32\ AL\ [g/kg\ DM_c] \quad (Cl.\ 4)$$

where AL is the total concentration of alcohols ($C_1...C_4$, including diols).

The potential losses in OM and MFP by effluent seepage (EL) were calculated as follows, where FSB is fresh sugar beet and FM is fresh matter:

$$EL_{OM}\ [\%] = 100\ \frac{effluent\ [kg] \cdot OM_{effluent}\ [g/kg\ FM]}{sugar\ beet\ [kg] \cdot OM_{FSB}\ [g/kg\ FM]} \quad (Cl.\ 5)$$

$$EL_{MFP}\ [\%] = 100\ \frac{effluent\ [kg] \cdot MFP_{effluent}\ [litres/kg\ FM]}{sugar\ beet\ [kg] \cdot MFP_{FSB}\ [litres/kg\ FM]} \quad (Cl.\ 6)$$

(Equations for calculating the fermentation losses see page 256.)

Results and discussion

The principle of preservation by ensiling comprises storage of the crop in anaerobic conditions and the formation of lactic acid. Sugar beet releases very high amounts of effluent under these conditions once the plant tissue has died off. This effluent, which is high in nutrients must be collected and utilized. The storage of sugar beet in plastic tubes offers the advantage of vastly avoiding exposure to air, but this technology can only be used if relatively small amounts of effluent are produced. In our experiments, chopped sugar beet released about 400 l effluent per tonne of fresh sugar beet, whereas whole beet produced significantly less effluent (maximum 140 l effluent per tonne of fresh sugar beet) [2]. Only these reduced effluent volumes can be safely retained in plastic tubes and, under the precondition of a careful management, fully utilized. Thus, only avoiding the processing of sugar beet make it possible to store this crop in plastic tubes.

Losses in OM and MFP, respectively, by fermentation and respiration (FL) were calculated by using the following equations:

$$FL_{OM}[\%] = 100 - 100 \frac{(\text{kg silage} \cdot OM_{silage}[\text{g/kg FM}]) + (\text{kg effluent} \cdot OM_{effluent}[\text{g/kg FM}])}{\text{kg fresh sugar beet} \cdot OM_{FSB}\ [\text{g/kg FM}]}$$

(Gl. 7)

$$FL_{MFP}[\%] = 100 - 100 \frac{(\text{kg silage} \cdot MFP_{silage}[\text{litres/kg FM}]) + (\text{kg effluent} \cdot MFP_{effluent}[\text{litres/kg FM}])}{\text{kg fresh sugar beet} \cdot MFP_{FSB}[\text{litres/kg FM}]}$$

(Gl. 8)

The high value of the released effluent - regarding OM and MFP - can be seen in **table 1.** In contrast to other plant biomass is the OM of sugar beet mainly composed of water-soluble components, namely sugar and its degradation products. Therefore, the drained effluent is practically as valuable as the beet silage retained in the silo.

Also in **table 1** it can be seen that the OM content of beet decreases during fermentation due to the production of fermentation gases. Simultaneously, the specific gas-forming potential per kg OM increases. This increase is caused by the formation of ethanol, which is the main fermentation product in beet silage. Based on fresh matter (FM), however, silage and effluent as well as fresh beets at harvest and those carefully stored until the end of winter in clamps or barns produce very similar amounts of methane.

Besides the desired reduction in effluent production there is a disadvantage of storing whole beets which is related to the unavoidable creation of voids between the unprocessed beets. This relatively high porosity not only causes the inclusion of high amounts of oxygen at filling but also some air ingress during storage as a consequence of unavoidable pressure equalisation between the inner bag and the outer atmosphere. This results in higher loss than found during the fermentation of chopped beet **(see figure 1).**

The chemical additive was used in order to alleviate these detrimental effects. The liquid additive contains active ingredients which are potent inhibitors of yeasts and moulds. Whole beets were treated with the additive by dipping so that a surface treatment was achieved. Chopped beets were treated by homogeneous spraying. Treatment reduced fermentation losses so that the negative effects of not chopping could be compensated for. Higher standard deviations in treatments with whole beets than those for chopped beets are typical for that material and unavoidable. Regardless of beet processing measures did the use of the silage additive result in similarly low losses in methane forming potential.

Another disadvantage of storing whole beets regarding the maintenance of MFP becomes obvious during removal of the material after opening of the bags. After opening, the gas mixture (containing carbon dioxide and nitrogen) contained in the voids of the bag flows off and is replaced by air. This enables the rapid development of yeasts and moulds and leads to heat formation and aerobic deterioration. In order to keep the related losses as low as possible, the bags must be emptied during summer within a few days. As confirmed by the tests on aerobic stability [2], the use of a chemical additive delays the onset of aerobic deterioration and heat generation, and thus allows a somewhat slower feed-out rate without additional losses.

Table 2 summarises the results of balancing experiments and, for comparison reasons, data on measured losses of fresh beets which had been stored under optimal conditions.

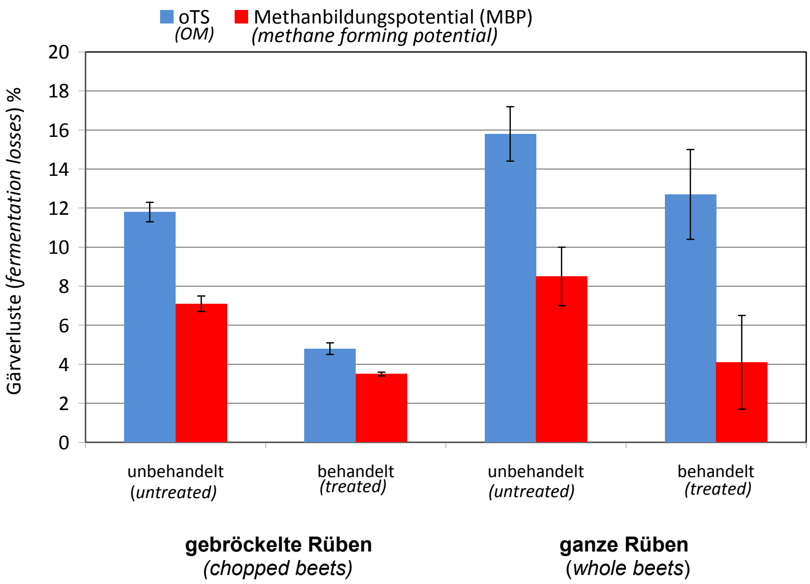
Losses in MFP of sugar beets stored in plastic bags are similar to those found during preserving storage under optimal conditions until the end oft the winter season. The described technological concept, however, makes it possible to store sugar beet for biogas production with low losses in MFP beyond this season. However, due to higher monetary input it seems likely that the concept will only be feasible for beets which are going to be used in the warmer season.

Table 1

Content of OM and methane forming potential of washed sugar beets as well as of silage and effluent obtained therefrom

Substrate	*OM content*	*Methane forming potential*	
	g/kg FM	*litres/kg OM*	m^3/t FM
Beets, fresh in November	**231** (226–236)	**361** (360–361)	**83** (82–85)
Beets, carefully stored till end of March	**221** (218–225)	**363** (361–364)	**80** (79–82)
Silage, in silo till August	**212** (198–231)	**383** (357–403)	**81** (77–86)
Effluent, undiluted	**199** (177–214)	**385** (374–410)	**77** (68–80)

Fig. 1



Fermentation losses during ensiling of chopped or whole sugar beets, both untreated versus treated with the silage additive KOFASIL®STABIL

Conclusions

Stockpiling of sugar beet beyond spring time requires a conservation method which is characterised by low losses. Ensiling of unchopped beets in plastic bags is considered well suitable for this purpose but effluent must be carefully managed by fully collecting it and subsequent utilization in the biogas fermenter.

Avoiding of chopping of the sugar beet significantly reduces effluent production and fulfills this requirement. However, this approach is related with higher losses due to respiration and fermentation as well as with an increased risk of aerobic deterioration of the ensiled beet during emptying of the plastic bags.

The higher fermentation losses and the increased risk of spoilage upon exposure to air can be reduced by surface-treatment of the whole beets with a chemical additive prior to filling the bags.

The use of the tested conservation method, which is described in this article, results in losses in methane-forming potential whose magnitude is as low as known from preserving storage of fresh sugar beets under optimal conditions until the spring season. Losses are found to be approximately 5 %. Other conservation methods which have recently been frequently discussed, need to show similar results.

Table 2

Losses during storage and conservation of whole sugar beets (n = 4)

	Losses [%]	
	Organic matter	*Methane forming potential*
Careful storage till end of March		
	5 (4–7)	**5** (3–7)
Ensiling in large plastic bags till middle of August		
I *untreated, effluent lost*		
	27 (26–29)	**21** (19–23)
II *untreated, effluent totally collected and exploited*		
	16 (14–17)	**9** (7–11)
III *treated with silage additive, effluent totally collected and exploited*		
	13 (10–17)	**4** (2–6)

Literature

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