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Effect of coarse grain on foam formation in biogas plants

Grain accounts for around 2 % of the renewable raw materials used in biogas production. This grain is used in the form of coarse grain here. However, the fermentation of ground grain often leads to excessive foam formation in biogas reactors, and this has a negative impact on the economic viability of plant operation. The effect of the processing of the grain on foam formation in the biogas process has been investigated here in the case of six sample grain species and soya. The finer the grain was ground the higher was the intensity of foam formation. Wheat, rye and triticale caused the strongest foaming in digestates.

Keywords
Biogas, foam, grain, coarse grain

Abstract
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According to data from the Fachagentur Nachwachsende Rohstoffe e.V. (Agency for Renewable Resources), renewable resources accounted for 49 % of the substrates used in biogas plants in 2011. Grain accounted for 2 % of the substrate mix – in comparison, sugar beet only accounted for 1 % in 2011 [1]. However, the use of coarse grain in the process of anaerobic fermentation is often associated with significant foam formation. A similar phenomenon has already been described in the area of veterinary medicine, where coarse grain can cause bloating in the paunches of ruminants [2; 3]. The ground grain contains fine particles that are responsible for the formation and stabilisation of foam in the rumen. The surface area of the substrate is enlarged with every stage of size-reduction. As a result, the substrate particles can host more dense populations of microorganisms and the microbes reproduce more quickly. A clear relationship exists between the size of the particles in the coarse grain and foam formation in the paunch: the finer the particles, the more critical is the foam formation [2]. This observation is also of great significance for the operators of biogas plants, as coarse grain is often used as a means of quickly improving the biogas yield. Practical experience shows that the use of grain is often associated with foam formation in fermenters [4], but plant operators often do not identify this as the cause of foaming. Only a complete analysis of the operating parameters can verify that the use of coarse grain is the cause of the foaming.

Up until now, no scientific investigations have been carried out on foam formation in biogas plants caused by the use of grain. The aim of the work presented here was to investigate the influence of the milling of grain on foam formation in the process of anaerobic fermentation in more detail.

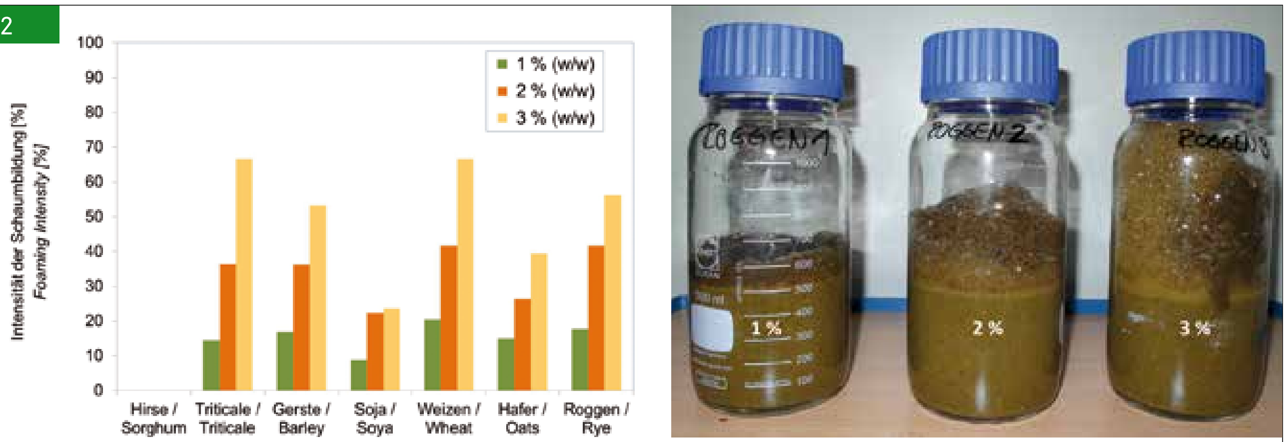
Materials and methods

The ability of six grain species – rye, triticale, winter barley, wheat, millet and oats – to cause foam formation in the anaerobic fermentation process was investigated. Soya, which is often used in investigations, was also included. The cereal grains were ground in a cutting mill with milling coarsenesses

Fig. 1

Fine to rough ground triticale and triticale grain (Photo: L. Moeller)

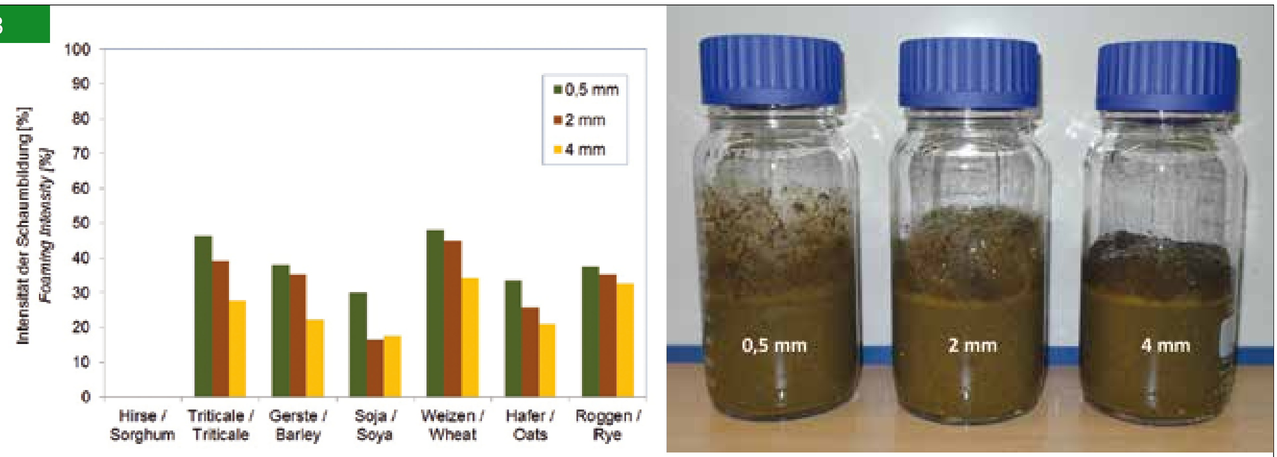
Fig. 2



A B

Foaming intensity in digestate from a biogas plant using renewables after addition of 1, 2 and 3 % (w/w) coarse grain and soya (2 mm), respectively, after 22 hours test duration (A); Experiment with rye groats as substrate (B) (Foto: L. Moeller)

Fig. 3



A B

Foaming intensity in digestate from a biogas plant using renewables after addition of 2 % (w/w) coarse grain and soya (0.5, 2 and 4 mm, respectively) after 23 hours test duration (A); Experiment with triticale groats as substrate (B) (Photo: F. Krieg)

of 0.5 mm, 2 mm and 4 mm (**Figure 1**). The intensity of the foam formation was tested by mixing 2 % (w/w) coarse grain into active fermentation material from a renewable raw material (RRM) plant (biogas plant 1), where this material had been passed through a sieve with a mesh size of 5 mm to ensure homogeneity. This mixture was allowed to stand for 20 hours at 37 °C. A control with no addition of coarse grain was also prepared so that no bias in the results occurred due to foam formation in the fermentation material itself. The foam formed was then evaluated. The intensity of foam formation was expressed in percentage terms as the ratio of the foam volume to the overall volume of the experimental material at the end of the experiment. To ensure the reproducibility of results, fermentation material from biogas plant 1 was used in two repeated experiments and fermentation material from each of two other RRM plants (biogas plant 2: a primarily manure-based plant, biogas plant 3: fed only with corn and grass silage) was also used.

Samples were taken from both the foam and the fermentation material at the end of the experiments and were analysed. The concentrations of carbohydrates (glucose equivalent) and proteins were determined in both samples. In addition, the concentrations of volatile organic acids and of elements that can be eluted with water (e.g. calcium, potassium, magnesium and phosphorous) were measured in the fermentation material.

Results and discussion

The foaming tendency of the fermentation material was investigated after adding coarse grain of various grain species and with various milling coarsenesses. These experiments are important for the operators of real plants so that occurrences of foaming can be actively prevented.

In the first experiment, the influence of the concentration of coarse grain on the foaming tendency of the fermentation material was investigated at a constant milling coarseness (2 mm). It was found that increasing the amount of coarse grain added from 1 to 2 % (w/w) led to a doubling of the foaming intensity (**Figure 2**). A further increase in the concentration of the coarse grain of 1 % caused a further intensification of the foam formation (**Figure 2**, A). No foam was formed in the experiments where millet was the substrate. The addition of soya caused only a weak foam layer. The strongest foam formation was caused by wheat, rye and triticale, followed by barley and oats. The foam formed in experiments with oats was unstable, with the result that it collapsed when the bottle was removed from the water bath. All other foams were stable and remained intact during the experiment. A coarse grain concentration of 2 % (w/w) was selected for the remaining experiments as the extent of foam formation could best be observed and compared at this value.

Further experiments investigated the effect of the processing of the grain in a cutting mill on the formation of foam in the fermentation material. **Figure 3** shows the intensity of foam formation in the fermentation material from biogas plant 1 after the addition of coarse grain. In general, it was observed that the finer that the coarse grain was ground, the higher was the intensity of the foam formation. As in the case of the first experiment (**Figure 2**), a dependency of foam formation on the grain species was also observed here: Triticale and wheat caused the strongest foam formation, followed by barley, rye and oats. Soya formed only a thin foam layer. The addition of millet led to no foam formation.

The repeated experiments with fermentation material from biogas plants 2 and 3 showed that the intensity of foam formation was also dependent on the nature of the fermentation material itself. The tendency described above was confirmed in all experiments; however, the amount of foam produced increased strongly with the dry matter (DM) content of the fermentation material. In the case of the primarily manure-based biogas plant 2, 4.6 % DM was measured in the fermentation material. Significantly less foam was generally formed in this fermentation material than in fermentation material from biogas plant 1 with a DM content of 6.1 %. In the case of fermentation material from biogas plant 3, the highest DM content of 10.2 % was measured. The foam formation was the strongest here, as foam was formed even in the control sample.

For this reason, it is not possible to make general statements for all biogas plants. In certain individual cases, it is advisable to test the foaming tendency of the fermentation material in combination with the relevant substrate on site (e. g. using the Leipzig Foam Tester set [5]) to ensure that foaming can be prevented. Practical experience also shows that mixing vegetable oils (e. g. 1% soya oil) with the coarse grain not only minimises dust development during the milling procedure, but also helps to prevent foam formation. This observation has also been confirmed in laboratory experiments (not yet published).

The results of the chemical analysis of the foam and fermentation materials are summarised in **Table 1**. No foam was formed in the case of millet, while the foam collapsed before a sample could be taken in the case of oats, which meant that analysis was not possible here. Higher concentrations of protein and carbohydrates were measured in samples from the test mixtures with fine grain than in samples from mixtures with coarsely ground grain. Analyses of foams in the case of wheat,

Table 1

Analysis data of digestate and foam obtained from experiments using coarse grain of six grain species and soya (DG = Digestate)

Getreideart *Grain species*	**Mahlgrad** *Coarseness setting*	**Rohprotein** *Crude protein*		**Kohlenhydrate** *Carbohydrates*		**Acetat** *Acetate*	**Propionat** *Propionate*	**Butyrat** *Butyrate*	**Kalium** *Potassium*	**Calcium** *Calcium*	**Magnesium** *Magnesium*	**Phosphor** *Phosphorus*
	mm	g/l		g/l		g/l	g/l	g/l	mg/l	mg/l	mg/l	mg/l
		GM *DG*	**Schaum** *Foam*	**GM** *DG*	**Schaum** *Foam*	**GM** *DG*	**GM** *DG*	**GM** *DG*	**GM** *DG*	**GM** *DG*	**GM** *DG*	**GM** *DG*
Weizen *Wheat*	4	14.7	17.6	1.59	1.53	1.67	4.25	4.89	2760	174	159	24.4
	0,5	17.7	23.6	1.92	1.81	4.87	1.01	0.78	2920	284	266	19.6
Triticale *Triticale*	4	17.9	20.4	1.79	1.56	2.24	0.43	0.07	2940	143	143	47.4
	0,5	15.7	17.4	2.11	1.31	5.32	1.12	0.60	3100	226	222	25.6
Roggen *Rye*	4	17.8	17.1	1.72	1.70	2.47	0.43	0.18	3020	216	172	25.4
	0,5	19.3	18.6	1.81	2.05	4.65	1.13	0.49	2780	234	204	19.9
Gerste *Barley*	4	19.3	16.6	1.87	2.50	0.93	0.09	0.00	3040	148	210	11.0
	0,5	20.7	19.6	2.12	2.19	4.46	0.80	0.44	3100	246	288	8.02
Hafer *Oats*	4	20.1	-	1.79	-	2.99	0.52	0.26	2900	197	167	28.4
	0,5	19.0	-	1.66	-	5.95	1.14	0.39	2900	208	193	14.8
Soja *Soya*	4	24.5	31.1	1.70	2.28	3.19	0.65	0.07	3240	166	212	11.2
	0,5	21.4	25.2	1.93	2.12	3.18	0.61	0.07	3120	202	226	4.14
Hirse *Sorghum*	4	18.6	-	1.06	-	0.15	0.00	0.00	2760	122	109	38.6
	0,5	23.5	-	1.35	-	0.82	0.08	0.04	2780	101	105	14.5

triticale and soya showed increased concentrations of protein compared to the associated fermentation material.

The overall carbohydrate content was similarly high in most cases in the fermentation material and in the foam – e.g. the carbohydrate concentration for coarsely ground wheat grain in the fermentation material and in the foam was 0.5 to 0.6 g/l (**Table 1**). However, differences in the starch content, which represents the highest fraction of carbohydrates in grain [6], were identified upon closer examination: a higher starch concentration was measured in the foam than in the fermentation material (FM) in samples with wheat and triticale as substrate – wheat: 0.20 g starch/100 g FM compared with 0.69 g starch/100 g foam; triticale: 0.14 g starch/100 g FM compared with 0.75 g starch/100 g foam. In contrast, the same starch concentration was detected in the fermentation material as in the foam in the sample with barley – 0.24 g/100 g FM as compared to 0.22 g/100 g foam. This is probably due to the differing starch content in the relevant coarse grains – wheat grain: 55.2 g/100 g, triticale grain 49.5 g/100 g, barley grain: 39.45 g/100 g. Only 23.2 g starch/100 g was measured in millet grain. This is also reflected in the lower carbohydrate content of the fermentation material samples from the mixtures with millet (**Table 1**). It can thus be concluded that starch plays an important role in foam stabilisation, as no foam was formed after the addition of millet grain, which contains little starch relative to other types of grain, to the fermentation material.

Investigations in the area of food technology into the foaming tendency of ground rye products have shown that a water-soluble protein is responsible for foam formation, while other components either have a foam-stabilising (e.g. fructosans) or foam-destabilising (e.g. pentosanes) influence [7]. Other investigations have shown that the content of proteins and pentosanes is lower in white flour than in brans or whole-grain flour [8]. Microscopic analyses have shown that starch was enriched in foamed white flour in the foam liquid, which led to greater foam stability [8]. The analysis results presented in **Table 1** indicate that these substances are also significant in foam formation in the process of anaerobic fermentation in biogas plants.

The relatively high concentrations of volatile organic acids, primarily of butyrate and propionate (**Table 1**), are indicators of organic overloading of the fermentation biology. In the case of millet, which produced no foam, the lowest concentrations of acetate, propionate and butyrate were measured. In veterinary medical investigations, a relationship between bloating in rumen and the concentration of elements such as potassium, calcium and magnesium has been identified [9]. No clear tendency can be detected here for potassium (**Table 1**). However, similarities were identified for calcium and magnesium: their concentrations in the fermentation material were lower in each case for foaming substrates with coarsely ground grain than for finely ground grain. This does not apply only in the case of millet, which does not demonstrate foam formation. The opposite tendency was observed for phosphorus: the finer the coarse grain, the less phosphorus was measured.

Conclusions

Based on the results, it can be concluded that it is necessary to consider the milling coarseness of grain as a preventive measure against excessive foam formation. In general, the finer the coarse grain, the more the fermentation material will foam in a biogas plant. For this reason, the milling coarseness selected for the grain should not be too low. In addition, it has been observed that the intensity of foam formation is also strongly dependent on the dry matter content of the fermentation material. It is thus necessary to test the foaming tendency of substrates in combination with the relevant fermentation material on site.

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