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Studies on the usability of ecovio® bio bags in dry fermentation

Untersuchungen zur Prozessgängigkeit von ecovio® Bioabfallbeuteln bei der Trockenfermentation

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Abstract

Kitchen waste is subject to rapid microbial degradation. The use of ecovio®-bio bags stabilizes kitchen waste by a silage effect. As a result, the yield of the biogas potential of the resource kitchen waste is optimized. The barrier function of ecovio®-bio bags is advantageous during the collection of biowaste; it is greatly reduced by mechanical action in waste collecting trucks. For use of biowaste in a dry fermenter the barrier function of ecovio®-bio bags should be completely destroyed. Tests in a full scale mesophilic dry fermentation unit confirm that the biogas production will not be adversely affected. Post-composting of the resulting digestate fully disintegrates ecovio®-bio bags within 39 days: visually there was no disturbing influence on the quality of composted digestate through ecovio®-bio bags.

Zusammenfassung

Die in Haushalten anfallenden Küchenabfälle unterliegen einer raschen mikrobiellen Alterung. Der Einsatz von ecovio®-Bioabfallbeuteln bewirkt durch einen Silageeffekt eine Konservierung des Küchenabfalls. Dadurch wird die Abschöpfung des Biogaspotenzials der Ressource Küchenabfall optimiert. Die bei der Erfassung und Sammlung von Bioabfällen erwünschte Barrierefunktion von ecovio®-Beuteln wird im Sammelfahrzeug durch mechanische Einwirkung stark reduziert. Für eine Nutzung des Bioabfalls im Trockenfermenter sollte eine möglichst weitreichende Aufhebung der Barrierefunktion von ecovio®-Beuteln realisiert werden. Erprobungen auf einer Praxisanlage bestätigen, dass die Biogasbildung dann bei einer mesophilen Trockenfermentation nicht negativ beeinflusst wird. Bei der Nachrotte des anfallenden Gärrestes wurden die ecovio®-Beutel innerhalb von 39 Tagen weitreichend desintegriert: Visuell war kein störender Einfluss auf die Qualität des kompostierten Gärrestes durch ecovio®-Beutel erkennbar.

1. Introduction

The collection of domestic kitchen waste using compostable bags made of the bioplastic ecovio® improves cleanness and reduces health risks both in the home and in the removal of biowaste [1]. Biowaste collected in ecovio® bags has proved extremely feasible for recovery in a number of industrial composting plants without causing any negative impact on the quality or quantity of the biowaste collected or on the compost produced [2, 3].

Changes are currently being seen in the recovery of biowaste. Biowaste composting, which has long been the predominant method used, is increasingly being replaced by a combination of biowaste fermentation and post-composting. These changes to processes can affect the usability of bio bags. The polymers in ecovio® bags and other compostable bioplastics are quickly attacked and degraded by aerobic microorganisms [4]. Under the anaerobic conditions present in fermentation plants, extensive biodegradation is only observed under particular general conditions [5-7], leading to a need to clarify whether the anaerobic stability of the ecovio® bags affects the anaerobic degradation of the biowaste. Digestate also has lower contents of biodegradable components than biowaste. Much shorter rotting times are used for the biological stabilization of the digestate due to post-composting than in biowaste composting, so it was investigated whether ecovio® bio bags are sufficiently disintegrated during the post-composting of digestate.

2. Quality of collected biowaste

Domestic kitchen waste contains high levels of readily microbially degradable constituents which increase even further if cooked food residues are also collected as biowaste. Very high levels of bacteria and fungi develop even during the short periods when kitchen waste is stored in the home [1]. Its metabolic activity means that biowaste continues to steadily degrade in organic waste bins so that any at one- to two-weekly intervals collected biowaste takes on the appearance of fresh compost with a very strong odor. As part of a health study program, it was found that kitchen waste collected in ecovio® bio bags appeared to prematurely degrade to a lesser degree than the same type of waste collected without using bags [1]. Studies were therefore conducted to provide clues on what effect ecovio® bio bags have on the premature degradation of kitchen waste compared to kitchen waste collected loose.

To do this, kitchen waste with a specific composition[1] was produced. 75 % of the kitchen waste consisted of raw kitchen waste and 25 % of cooked kitchen waste. The vegetable-based content was 95 %. The constituents were reduced to sizes typically found in kitchens. 10-liter collection containers were then filled with quantities of 2.75 kg using ecovio® bio bags, placed in bagless boxes and stored for three days at 20 °C. The ecovio® bags were then closed and storage simulated in an organic waste bin for a further 7 and 14 days at 20 °C (average summer temperature in Germany).

Kitchen waste collected without using bags was then packed under practical conditions in organic waste bins and mixed with additional garden waste. This creates a well-structured mixture that makes it possible to provide a comparatively good supply of oxygen during subsequent storage in the organic waste bin. To simulate these conditions, the kitchen waste collected without using bags was stored by packing

1 Percentages by mass; green salad: 20; white cabbage: 10; tomatoes: 10; cucumbers: 10; potatoes (raw): 10; wholegrain cereal: 5; soya meal: 10; potatoes (cooked): 10; sweetcorn: 10; meat (cooked): 5

loose at heights of up to a maximum of 5 cm in covered troughs for 7 and 14 days. Recessed grips on the side were used to provide an exchange of air with the ambient air. Comparable conditions are set up with loose packing in organic waste bins in which regularly-spaced openings in the bins also allow air access.

The fresh kitchen waste had a water content of 76.7 % and the organic content of the dry matter was 94.7 %. After 3 + 7 days, 55.4 % of the kitchen waste collected without using bags and then stored loose remained; after 3 +14 days, only 31.0 % of the initial mass remained. The change in mass was due mainly to the loss of water, but the organic content had fallen by up to 42.2 %. After 17 days, the water content was 55 %, a typical level for municipal biowaste.

The waste mass in the kitchen waste stored in ecovio® bags on the whole hardly changed. After 3 + 7 days, 92.2 % and after 3 + 14 days 90.5 % of the initial mass of the waste remained. The organic matter determined as loss on ignition fell by only ~30 %. The lower loss of organic matter is the result of a silage effect; the pH values of the kitchen waste stored in ecovio® bags fell from an initial pH of 5.7 to 4.2 and had a commensurately perceptible fermentation acid odor. The kitchen waste stored loose, on the other hand, had a pH of 7.5 after 3 +14 days and a very strong moldy/musty odor.

The positive effect of the ecovio® bio bags on the losses of biogas formation potential that occurred during the collection of kitchen waste was quite noticeable. A biogas formation potential of 204 NL biogas per kg of fresh mass was determined for fresh kitchen waste. A roughly 30 % loss of biogas formation potential was observed even in the first three days ("Storage of waste in a kitchen storage container"). Kitchen waste collected without using bags and stored loose for a further 7 to 14 days was quickly further degraded by microbial action. Only 46.1 % of the initial biogas formation potential was still present over 7 days and just 33.4 % after 14 days following simulated storage in an organic waste bin. Kitchen waste in contact with the ambient air is thus subjected to very rapidly progressing degradation. Kitchen waste collected in ecovio® bags, on the other hand, exhibited a significantly lower loss of biogas formation potential. If sealed and placed in an organic waste bin, 61.1 % of the biogas formation potential available from the beginning was achieved after 7 days and 51.4 % after 14 days. Compared to the kitchen waste collected without using bags and stored loose, after 3 + 7 days the kitchen waste stored in ecovio® bags showed a biogas formation potential that was 32 % higher and after 3+14 days 54 % higher.

The losses of biogas formation potential reduced by ecovio® bags increase the energy yield of the "kitchen waste" resource. It can also be expected that the conserving action silage effect produced in ecovio® bags to a large extent reduces the release of greenhouse gases.

3. Opening bags in the collection vehicle

Bio bags aim to minimize any direct contact between the user and the biowaste being disposed of when used in the home. This barrier function is also useful when it is disposed of in collection containers (organic waste bins): any contamination on the inside of the organic waste bins is reduced and there is lower biogenic air contamination when the organic waste bins are opened and emptied.

Considerable mechanical forces act on the biowaste contained in bio bags when the organic waste bins are emptied into collection vehicles, during transport (compression and/or mixing in the biowaste vehicle) and during the unloading process, and as a result of this mechanical pre-damage of the bio bags delivered to biowaste treatment plants can be expected. The ensuing loss of barrier function is desirable for subsequent biowaste treatment: biological biowaste treatment processes provide good accessibility for the biowaste (ventilation and moisture regulation during composting; inoculation and release of biogas during fermentation). This aspect is particularly important for any biowaste treatment processes using the biowaste delivered as input material without any previous shredding and/or preparation.

The extent of any mechanical pre-damage to be expected under normal practical conditions to bio bags delivered to the biowaste treatment plant was determined in a model trial conducted under practical conditions where it was assumed that up to half of the biowaste collected in organic waste bins is composed of kitchen waste collected in bio bags and garden

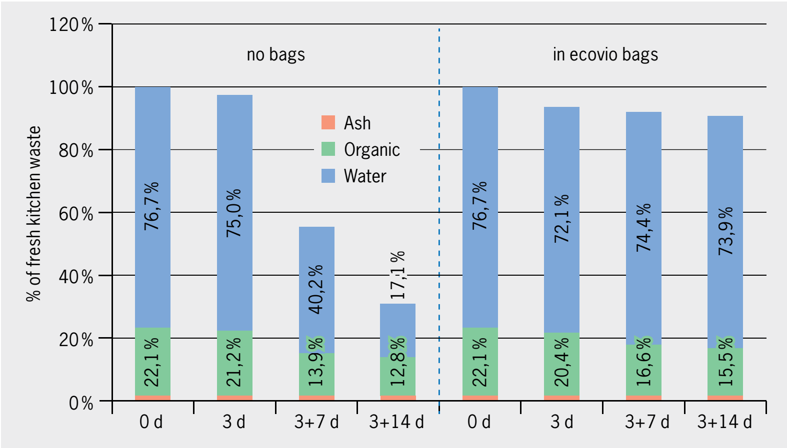


Figure 1
Composition of kitchen waste stored without bags and in ecovio® bags for up to 17 days

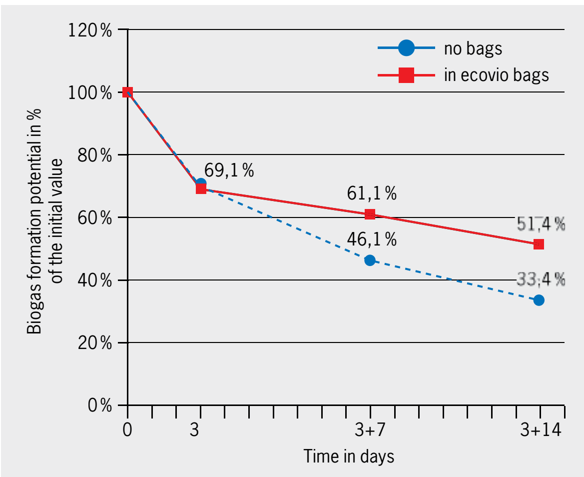
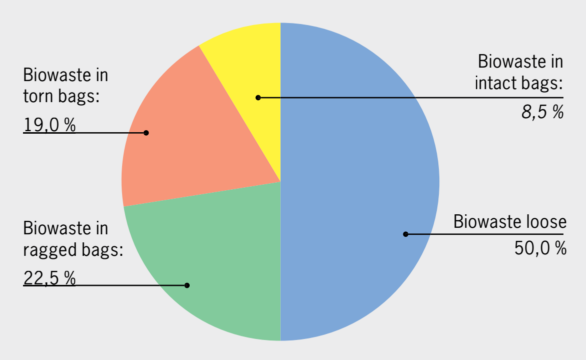


Figure 2
Remaining biogas formation potential of kitchen waste

Figure 3
Percentage of biowaste contained in bio bags after delivery



waste collected loose. 100 ecovio® bags were filled with pre-shredded municipal biowaste and placed in 240-liter biowaste bins with equal quantities of loose biowaste. A total of approximately 2 m^3 biowaste was used to fill the bio bags and biowaste bins. The filled organic waste bins were then placed outdoors for 14 days at autumn temperatures (night-time temperature 0.6–14.9 °C; daytime temperature 12.5–24.4 °C). The biowaste bins were then emptied by a biowaste collection vehicle (MAN vehicle with rotating drum) and delivered to the treatment plant. After the unloading process, the percentage of the bio bags at the delivery point that already had a reduced barrier function was investigated.

Evaluations showed that the barrier function was affected in 83 % of the bio bags; 38 % of them were torn and 45 % of them were ripped or only fragments found. Only 17 % of the bio bags were visually undamaged. Since the total filling quantity of the organic waste bins was double the quantity of biowaste filled in bags, only 8.5 % of the biowaste was completely contained in bags at the time of delivery (Figure 3) and consequently 91.5 % of the biowaste was not completely contained in bio bags at the time of delivery. The biowaste collected in bio bags itself should therefore be accessible, even in the treatment plants for biodegradation processes that do not pre-shred the biowaste delivered. This is often the practice in the dry fermentation of biowaste.

4. ecovio® bags in dry fermenters

The Abfallwirtschaftsbetrieb München (AWM) (Munich Waste Management Center) was used as an example of a dry fermentation plant to examine whether the fermentation of biowaste is affected if some of it is collected in ecovio® bags. The AWM has operated a dry fermentation plant supplied by BEKON with an overall capacity for treating 25,000 Mg/a biowaste since 2007. Biowaste delivered there without any significant preparation with already anaerobically fermented reflux material is mixed at a ratio of around 1:1 and fed into garage-like reactors which are fitted with percolate irrigation and a drainage system to lead off any leachate and with underfloor heating. The biogas produced is collected in the roof area and then passed to a combined heat and power plant. The biowaste normally remains in the anaerobic reactor for four weeks.

Wire mesh containers with an effective volume of approximately 0.8 m^3 were filled with various trial materials (Table 1) and placed in a dry fermenter. The biowaste delivered to the treatment plant which had been filled unchanged in onion bags was used as the reference sample. An identical volume of biowaste, half of which was filled in ten ecovio® bags, was used as the trial variant ecovio A. Two bags remained unchanged and four bags each were cut with a knife (simulation of shredded bags) or ripped (simulation of ragged bags). The material prepared in this way was intended to represent biowaste collected in bags at the time of delivery with "normal pre-damage" to the bags. ecovio variant B was intended to represent biowaste collected in bags that was additionally pre-shredded after delivery. Bio bags were therefore cut into ten parts and mixed with biowaste. The three prepared biowaste variants were placed in onion bags and incorporated with a mixture of biowaste and digestate reflux in wire mesh containers.

When the four-week mesophilic fermentation was complete, the wire mesh containers were removed from the dry fermenter. Comparative tests on the contents of the onion bags gave an indication of whether "normally pre-damaged" and "shredded" ecovio® bags had affected the anaerobic degradation of the biowaste.

At the time of the trial, the biowaste delivered had high contents of leaves and green waste as well as a noticeably large number of stones. The loose biowaste exposed in onion bags as a reference sample in the anaerobic fermenter was predominantly wet when removed and the digestate had an earthy odor very characteristic of ammonia. The overall impression was that of an extensively anaerobically stabilized digestate.

The digestate of trial variant ecovio A taken from the onion bags with "normally pre-damaged" bags produced a somewhat different picture. It was visually apparent that the digestate coming from the contents of the bags had a significantly drier effect than the waste exposed outside of bags in the anaerobic reactor. The mechanical damage to the bags was obviously not enough to produce consistent moistening of the contents of bags lying on top of one another. In sensory terms, there was a perceptible sour odor (which was particularly apparent around the ecovio® bags) but no ammonia odor.

The visual and sensory impression of the digestate of trial variant ecovio B was virtually the same as that of the biowaste treated anaerobically without using bags (reference sample). The shredded ecovio® bags had not impeded the moistening of the biowaste. The

Table 1
Trial variants exposed in the dry fermenter

Variant	Reference "no bags"	ecovio A "normal pre-damage"	ecovio B "shredded"
Biowaste content	Onion bags filled with biowaste	Ten ecovio® bags 2/3 filled with biowaste were mechanically pre-damaged under actual conditions, mixed at a ratio of 1:1 with loose biowaste and placed in three onion bags	Ten ecovio® bags were each cut into ten parts and mixed with typical quantities of biowaste. The mixture was mixed 1:1 with biowaste and placed in three onion bags.
Incorporation	Two to three onion bags of one variant were incorporated at a ratio by quantity of 1:1 with a mixture of 50 % biowaste and 50 % fermentation reactor reflux in a wire mesh container. The trial variants were separated by partition walls.		

only noticeable feature was that pieces of the bags adhering on top of one another had a strong odor of fermentation acids. The digestate itself had an earthy odor very characteristic of ammonia.

As expected, the film of the ecovio® bags of both trial variants did not show any visually apparent changes. The pH values of the digestate of the trial variants were almost the same (reference: 7.47; ecovio A: 7.10; ecovio B: 7.16), although up to 50 % of the biowaste filled in onion bags from treatment variant ecovio A was present in bags. Despite the high proportion of film, there was no consequent relevant acidification of the anaerobically exposed biowaste observed.

However, the differences arising in analyses of the residual biogas formation potential of the digestate for the trial variants were quite pronounced (Table 2). For the trial, the ecovio® contents were pre-separated because any impact on the anaerobic degradation of the biowaste was to be checked.

Table 2 also contains data on untreated biowaste and digestate from biowaste fermentation plants for comparison purposes. Untreated biowaste delivered to biowaste treatment plants has a biogas formation potential of ~80–120 Nm^3/Mg wet mass. A typical dry matter content of 35 % and an organic dry matter content of 75 % can be used to calculate the biogas formation potential of untreated biowaste shown in the table. The digestate produced in biowaste fermentation has a much lower residual biogas formation potential than untreated biowaste. The large number of process variants and the processed biowaste, however, means that the biogas formation potential of digestate can vary quite considerably.

The biogas formation potential based on the dry matter (DM) and in particular that based on the organic dry matter (ODM) content primarily are suitable as the basis for comparison (Figure 4).

The digestate of the biowaste treated in the dry fermentation reactor for four weeks without using bags (reference) showed a biogas formation potential of 153 Nm^3/Mg ODM which is 50–60 % lower than figures for untreated biowaste. The biogas formation potential is also in the typical range of digestate from other biowaste fermentation plants.

The biogas formation potentials of the digestate of trial variants ecovio A and B were also in the normal range for digestate from biowaste fermentation plants, although the biogas formation potential of the digestate of trial variant A at on average 218 Nm^3/Mg ODM was significantly higher than that of the reference sample (on average 153 Nm^3/Mg ODM). It was apparent that the anaerobic degradation processes were significantly obstructed if 50 % of the biowaste was filled in "normally pre-damaged" ecovio® bags during exposure in dry fermentation. With trial variant ecovio B, however, the shredded ecovio® bags did not impede the anaerobic degradation processes. The digestate only had a biogas formation potential of on average 133 Nm^3/Mg ODM which was in fact still below the figure for the digestate of the reference sample.

In the interests of achieving an extremely high yield for the biogas formation potential, the idea was for biowaste collected in ecovio® bags to be mechanically processed before use in a dry fermenter until a significant level of opening and shredding of the bags is achieved. The results illustrate that shredded bags can also mean no problems with biogas formation if up to 50 % of the biowaste fermentation has been collected in bags.

Parameter	*Untreated biowaste*	*Digestate#*	*Digestate reference*	*Digestate ecovio A "normally pre-damaged"*	*Digestate ecovio B "shredded"*
Nm^3/Mg WM	80–120*	20–50	27.6	45.1	33.0
Nm^3/Mg DM	229–286	65–145	112	168	111
Nm^3/Mg ODM	305–381	114–270	153	218	133
Methane content [%]	58–65	65–71	70	68	68

*: Data from [8]; # Tests on ten digestates from different biowaste fermentation plants

Table 2
Biogas formation potential of the digestate of the trial samples (reference, ecovio A and B) compared to typical untreated biowaste and digestate from biowaste fermentation plants

5. Disintegration of ecovio® bags during post-composting

Bags made of ecovio® are very readily degraded in direct biowaste composting [2]. Complete aerobic biodegradation to mineral end products [9] was found with the polyester ecoflex®, but clarification was needed on

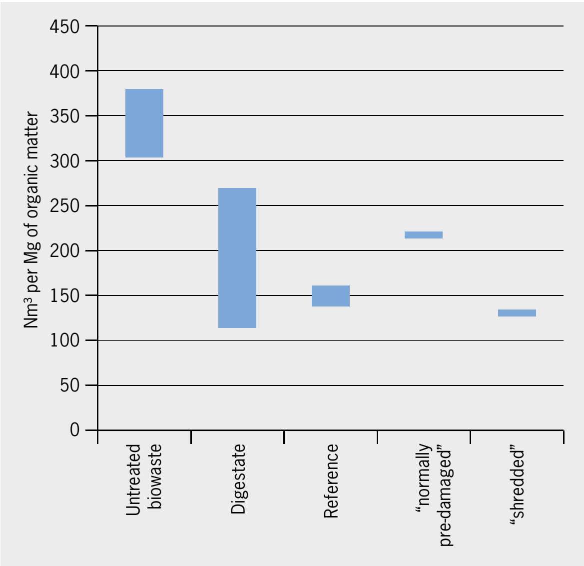


Figure 4
Biogas formation potential of the organic matter of typical untreated biowaste and digestate compared with figures for digestate of the trial samples

Variant	Reference "no bags"	ecovio A "normally pre-damaged"	ecovio B "shredded"
Biowaste content	Onion bags filled with rotting material (9 parts digestate, 1 part green waste)	Ten new ecovio® bags 2/3 filled with rotting material were mechanically pre-damaged under actual conditions, mixed with loose rotting material at a ratio of 1:1 and placed in three onion bags	Ten ecovio® bags were each cut into ten parts and mixed with typical quantities of rotting material. The mixture was mixed with rotting material at a ratio of 1:1 and placed in three onion bags
Incorporation	Two to three onion bags of one variant were placed in the side of triangular clamps for 39 days. The onion bags were removed and again exposed before the clamps were turned after 7 and 28 days. It can be seen that the contents of the onion bags during exposure were not thoroughly mixed in the rotting clamp. The rotting temperature was in the range of on average 65.3°C (54.1 – 71.5°C); the ambient temperature was on average 9.0°C (3.6 – 17.6°C).		

Table 3
Trial variants exposed in triangular clamps

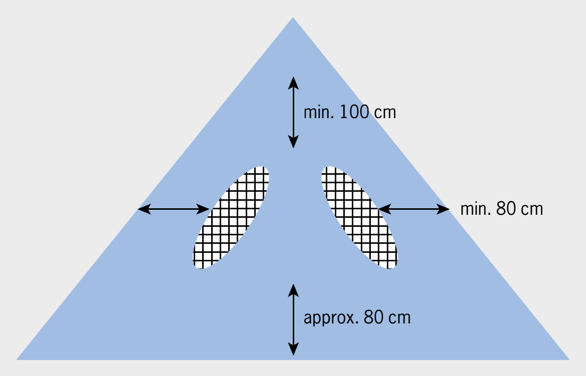


Figure 5
Diagram showing the exposure of the trial samples in a triangular clamp

whether the biological degradation processes during post-composting of digestate from dry fermentation at the fermentation plant in Munich was still sufficiently pronounced. The biodegradable fraction of the digestate is significantly smaller than that of untreated biowaste, which means that around six weeks is sufficient for post-composting digestate. After leaving the anaerobic fermenter, the digestate is briefly stored on a temporary basis so that any excess leachate can drain off. The digestate is then mixed with green waste at a ratio by quantity of 9:1 and placed in triangular clamps. The rotting material is turned several times, but not actively ventilated.

The variants listed in Table 3 were used for the trial. It is important to note that new ecovio® bags were used for variants ecovio A and B. In practice, bags are passed to post-composting where the biowaste constituents (moisture, fermentation acids, microorganisms, etc.) have a destabilizing effect during collection of the biowaste and fermentation for more than five weeks, which would accelerate biodegradation of the bags during post-composting even further.

Confirmed: Very good degradability of ecovio bags in different variants of the investigations.

The rotting mixture exposed in the triangular clamp without using bags in onion bags as a reference sample had the appearance of a moist compost with a high fibrous and woody content when removed. The tacky fine-particle content covered a number of stones. In addition to the earthy, compost-like odor, there was a strong ammonia odor.

The compost from onion bags of trial variant ecovio A in which approximately 50 % of the rotting material was initially exposed in mechanically "normally pre-damaged" ecovio® bags still contained extremely fine residues of some bags, but these residues were still very soft and could be crumbled between the fingers. Following a final thorough mixing of the contents of the recovered onion bags, these fragments were no longer recognizable as such. The visual impression of the compost was then no longer any different from the compost of the reference sample.

The compost produced from rotting material with the addition of shredded ecovio® bags (trial variant ecovio B) contained some visible residues of the ecovio® bags. The most visible were thin and decomposed rapidly, but there were also some residues that were still quite stable. Closer examinations showed that these were double-layer sections produced when the bags were cut around the folds and in some cases by folding over single-layer sections of the bags. It can, however, be assumed that these double-layer sections are avoided when filled bags are shredded. The particles adhering to the surfaces of the bags would then avoid two layers of film directly adhering to one another and consequently make all the film surfaces accessible to microbial degradation. Although all the bag residues were left in the compost, they were no longer visually recognizable after the final thorough mixing of the compost, as would also have happened with mechanical turning.

Control trials of compost material parameters confirmed the visual impression (Table 4). With one exception, there was no recognizable effect of the ecovio® bags on the compost material parameters examined. The only notable point was that compost produced with the addition of ecovio® bags exceed the maximum temperature of 30°C for a rotting level of V (finished compost) by a few degrees (ecovio A: 32°C; ecovio B: 34°C) and should therefore be classed as finished compost with a rotting level of IV. It is important to bear in mind here that the trial samples exposed in onion bags in the rotting clamp could not be thoroughly mixed at the turning times, which somewhat delayed the biological stabilization and final biodegradation of the ecovio® residues. In practical applications, the rotting material would all be turned and tests on the compost quality would be carried out on the final prepared composts (after eliminating impurities and foreign matter).

6. Conclusion

Various partial studies looked at important aspects that need to be taken into consideration in the use of ecovio® bags for collecting biowaste and their utilization in a dry fermentation plant:

- ecovio® bio bags stabilize the domestic biowaste collected due to a silage effect:
  - Acidification reduces the losses of biogas formation potential during collection of the biowaste.
  - As a result of acidification, the desired barrier function of the ecovio® bags during biowaste collection should be eliminated before they are used in dry fermentation through extensive pre-shredding of the bags.
- Shredded ecovio® bio bags do not have a negative effect on the biogas formation in a dry fermentation reactor.

Parameter	*Reference "no bags"*	*ecovio A "normally pre-damaged"*	*ecovio B "shredded"*
pH	8,4	8,2	8,1
Salt content (g KCl/L WM)	4,29	4,27	4,36
Bulk density (g/L WM)	670	640	650
Dry matter (%)	40,8	38,9	38,9
Loss on ignition (%)	52,4	54,6	55,2
Degree of rotting	V	IV	IV
Viable seeds (1/L)	0	0	0
Salmonella in 50 g	Negative	Negative	Negative

Table 4
Compost quality parameters of the trial samples

- ecovio® bio bags are disintegrated during the post-composting of digestate from dry fermentation until they have no further visual adverse effect in the compost.

The results of the partial studies provide an important basis for an industrial investigation of ecovio® bio bags in dry fermentation plants.

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