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Development of a Sensor System to Classify Silage according to its Quality

The quality of silage is not only influencing the performance and heath state of cattle, but it is also subject to the European Regulation of Feed Hygiene since Jan 1st 2006 in terms of consumer protection. To evaluate the quality of silage, a chemo-sensor was tested for its suitability. First series of measurements were made in the Institute of Agricultural Engineering of Bonn University.

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Keywords

Electronic nose, quality assurance, quality of silage, odour

In cattle keeping the conservation of roughage serves the stable protection of the animal feed against spoilage and the best possible preservation of its feed value from the field to the trough. The quality of silage is usually evaluated at the time when the silo is first opened ('ensiling success'). The quality of silage is evaluated according to a points-based system, taking into account the content of undesirable substances such as butyric and acetic acid as well as the pH value of the silage [1]. It is recommended to supplement this quality evaluation by a sensory assessment [2]. In this quality evaluation by means of the human sensory system, the silage is graded according to its smell, colour and structure. Points may be deduced as a result of this sensory assessment.

A number of volatile substances produced in the fermentation process can be recognised as odours [3]. Volatile, i.e. gaseous, compounds can be measured by means of gas chromatography and mass spectrometry or a combination of both. However, the technical side of such measurements is rather complicated and it requires trained personnel with a lot of experience with data evaluation.

Alternatively, gaseous compounds can be measured with electronic sensor systems. Arrays of different sensors are used in parallel to achieve high information density. The methodology of using sensor arrays is deducted from the mode of operation of the human sense of smell, which also uses data from a limited number of olfactory cells to form complex odour impressions. An application-specific online odour measuring system (OdourVector), developed at the Institute of Agricultural Engineering of Bonn University, has successfully been used in various studies [4].

Accordingly, the aim of the present study was to test the suitability of a chemosensor for measuring silage quality parameters (ensiling success, spoilage). Whole-crop wheat silage was used as substratum in the first preliminary tests, because it may generally be expected to be quite homogeneous. The fresh material was treated with a biological silage additive (variant A = homofermentative lactobacillus, conversion of soluble plant sugar to lactic acid; variant B = heterofermentative lactobacillus, main product lactic acid, additionally ethanol, acetic acid; variant c = control group) and ensiled in 1.5 litre glass jars (n = 3). The jars were opened on fixed days during fermentation and during storage (28th, 42nd, 49th, 56th, 90th day); using a wet chemical method, the material was tested with regard to its fermentation quality (standard methods) and its content of volatile acids. In parallel, the samples were measured, using the OdourVector measuring system in order to obtain from the signal patterns of the different sensors analytic strategies with regard to the silage quality and the olfactory properties of the material.

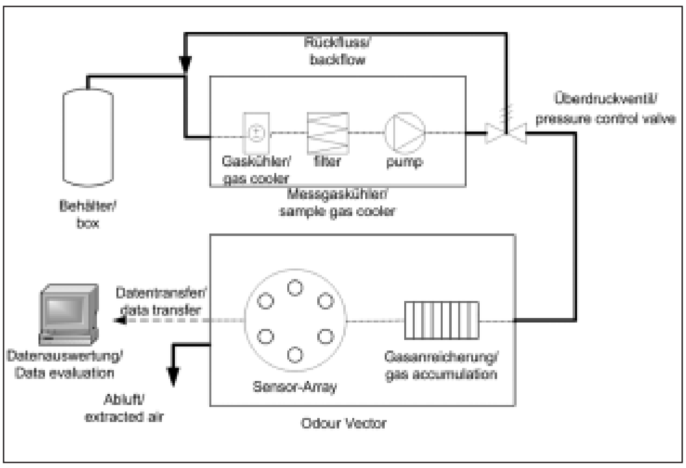

Fig.1: Principle of measuring silage quality, using the electronic odour measurement system (OdourVector)

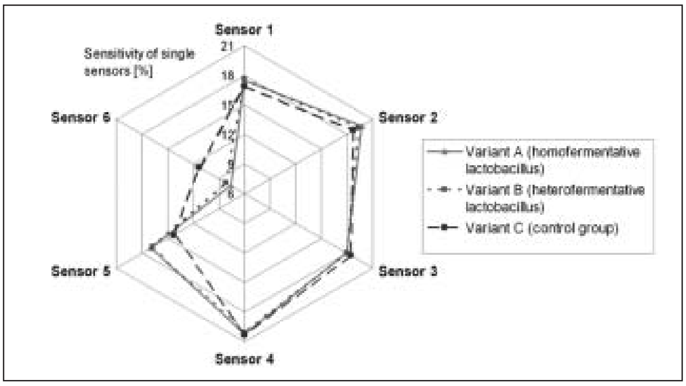

Fig. 2: Sensitivity of single sensors of the OdourVector relating to whole crop silage in various conditioning variants 56 day after ensiling

The OdourVector measuring system

For analysis with OdourVecor, the substratum is put into a closed glass container connected to a sample gas cooler via a gas tube (*Fig. 1*). The gases are fed to the measuring system proper, i.e. to the OdourVector system, through a pump and a filter. Before being measured in the sensor array, the volatile substances are accumulated within OdourVector.

OdourVector consists of a quartz microbalance (QMB) sensor module with six integrated oscillator crystals with different gas-sensitive coatings, which react to different organic target gases. Absorption of the gas molecules into the sensor coating leads to a change in frequency that can be interpreted as a sensor signal [4].

Pattern recognition is carried out to find connections or differences between individual samples. The signal strength of the individual sensors follows from the chemical composition of the samples measured. The pattern recognition method used in this study is PCA (principal component analysis) [4].

Results

The results of the gas measurements were, on the one hand, analysed with reference to radar charts depicting the capacity utilisation rates of the individual sensors. They depicted the sensitivity (relative capacity utilisation based on the sum of the signal strengths) of the respective sensors to the gases extracted from the corresponding silage samples. Conclusions on the gas composition can be drawn from the different sensor signals. For example, in *Figure 2* the results of the tests performed with the whole-crop variants (A, B, C) from the 56th day onwards are depicted in a radar chart. It is evident that the variants treated with a silage additive differ only marginally from each other with regard to the sensitivity of the individual sensors, whereas in the control group there are differences in sensors 5 and 6. Sensor 6 has a low sensitivity percentage, whereas the capacity utilisation rate is almost the same for all other sensors.

There were differences in the total signal strengths as well. In particular, it was sensors 5 and 6, which differed from the remaining four (30 - 40 Hz). Sensors 1 to 4 had similar signal strengths (60 - 80 Hz).

The aim of the mathematical evaluation of the gas measurements (PCA) is a classification of silage, by means of which the quality of the silage can be 'visualised'. With the results of the PCA for the example described here it is possible to classify the different variants as depicted in *Figure 3* in the form of ellipses.

Ellipsis 1 contains the measurement results for the control group (C). According to the wet chemical analyses, the lactic acid content was 4.6 % on a DM basis, the acetic acid content was 0.7 % on a DM basis and the ethanol content 0.7 % on a DM basis. By contrast, the acetic acid content of variant B (ellipsis 2) was comparatively high at 2.5 % on a DM basis. Moreover, the propionic acid content was higher than in the other whole-crop silage variants. The ethanol content was 0.6 % on a DM basis. One observation to be made is that a higher content of volatile fatty acids results in a higher density of the scatter plot on the right-hand side of the PCA. In this case the fatty acids are n-propanol, 2,3 butanediol and 1,2 propanediol. Ellipsis 3 contains variants of all three groups of samples with a lactic acid content of 4 % on a DM basis and an acetic acid content below 1 % on a DM basis.

Although all the whole-crop variants depicted here would be rated 'very good', according to the DLG key [1], the sensor measurements using OdourVector revealed differences between the treated variants and the control group.

Moreover, in the course of the experiments the signal strengths rose from 20 Hz to 300 Hz maximum for longer storage times.

Conclusion

Initial investigations were carried out with the aim of testing the suitability of a chemosensor system for assessing the quality of silage. Using OdourVector it was possible to identify chemical differences between samples. Volatile fatty acids in the silage, particularly lactic and acetic acid, but also ethanol, n-propanol, 2,3 butanediol and 1,2 propanediol are reflected in different patterns in the PCA. It became clear that OdourVector reacts to acids, which are also taken into account by the DLG key [1], first and foremost acetic acid. It was not yet possible to recognise characteristic patterns for the fermentation parameters of silage. One possible reason is that the quality differences between the silage variants used in the experiments were very small.

Literature

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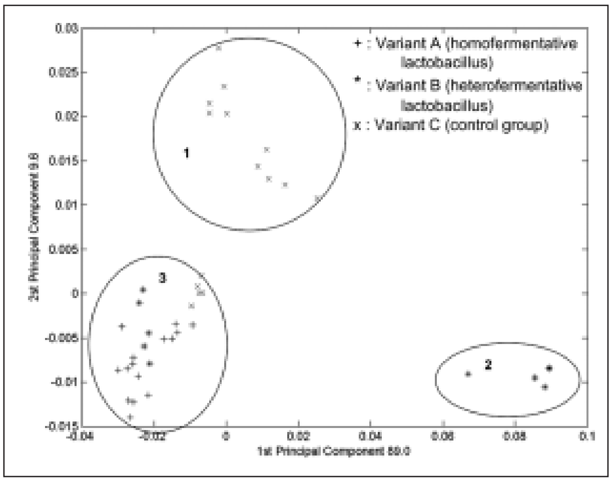

Fig. 3: Pattern recognition of an OdourVector measurement result (PCA) for analysis of whole crop silage