Two underestimated threats in food transportation: mould and acceleration

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Two important parameters are often neglected in the monitoring of perishable goods during transport: mould contamination of fresh food and the influence of acceleration or vibration on the quality of a product. We assert the claim that it is necessary to focus research on these two topics in the context of intelligent logistics in this opinion paper. Further, the technical possibilities for future measurement systems are discussed. By measuring taste deviations, we verified the effect on the quality of beer at different vibration frequencies. The practical importance is shown by examining transport routes and market shares. The general feasibility of a mobile mould detection system is established by examining the measurement resolution of semiconductor sensors for mould-related gases. Furthermore, as an alternative solution, we present a concept for a miniaturized and automated culture-medium-based system. Although there is a lack of related research to date, new efforts can make a vital contribution to the reduction of losses in the logistic chains for several products.
1. Introduction

The remote monitoring of food and perishable goods receives increasing attention by logistics experts. The demand on such monitoring systems depends on the transported goods and the importing company. The ‘intelligent container’ project is one example for a monitoring system that uses a sensor net to record temperature, humidity and gas concentrations data of, for example, CO₂, to determine the quality of a cargo in real time [1]. However, two interesting parameters that are generally neglected in the context of intelligent logistics have not yet been investigated sufficiently: the mould contamination of fresh fruits and the influence of acceleration or vibration on food products.

An example for decay triggered by acceleration events that occur during transports is beer. It is common perception that ‘fresh’ beer tastes better than beer stored for a longer period. If acceleration with specific features occurs during the transport of beer, then the flavour that normally would change only after months is now changing in just a few weeks [2]. Following several temperature-related shelf life models, described in this theme issue, a similar acceleration-related model of the ‘shelf life’—flavour stability—should be possible.

The detection of mould contamination of perishable goods is an important topic. Technologies available nowadays are not suitable for online detection during transport owing to the complexity and the sporulation behaviour of most mould species. Despite these difficulties, the development of such a device for logistic processes seems to be achievable. In this paper, two approaches for determination of mould contamination inside a container are described. One approach shows the development of gas sensors in this field of research. The second described approach shifts the standard methods for culture-based analyses of mould infections from the laboratory scale to an automated miniaturized system.

2. Acceleration in the logistic chain of beer

Acceleration can affect goods in transit in different ways. It is obvious that products can be damaged owing to acceleration that occurs during transport. However, this topic has more complexity in the logistic chain of perishable goods. For example, pressure marks on bananas caused by acceleration during transport often make cargo with such flaws non-sellable, and, even more, it is possible that the stressed bananas start ripening, and thereby produce more heat and ripening gas. Thus, the risk of losing the complete cargo owing to premature ripening increases. Examples for past research in this field are described for tomatoes by Idah et al. [3], for transports of apples in Thailand by Chonhenchob et al. [4] and for potatoes by Geyer et al. [5].

In this paper, we present another important application field of acceleration monitoring in the food chain, which has not been the focus of research so far: the transportation of beverages. In this context, a turbidity change of beer caused by acceleration is a very good example for possible application of shelf life models for automated evaluation of quality; information about vibration is also important. This example differs from past research, because we not only make a damaged/not-damaged decision, but also aim to evaluate the quantitative effect of the amplitude and frequency of vibrations on chemical processes in the beverage and thus on quality. This will be discussed in more detail in the following.

(a) Acceleration sensor technology for the logistic chain of beer

For the monitoring of beer, real-time measurements are required. A few years ago, such measurement systems were not suitable for mobile use during transport owing to the power consumption of the acceleration sensors. Acceleration measurement is critical from the point of view of required energy, because acceleration requires high-frequency measurement in contrast to other physical properties such as, for example, temperature, which only needs to be measured at intervals of 10 min or longer for transport supervision scenarios.
### Table 1. Changes in beer turbidity: results after 14 days of storage under different conditions, standard variation of the measurement ± 0.01 EBC (VLB Berlin, Germany).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Type of Movement (Hz)</th>
<th>Temperature (°C)</th>
<th>Turbidity Change (EBC) Assay 1</th>
<th>Turbidity Change (EBC) Assay 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>none</td>
<td>20</td>
<td>0.050</td>
<td>-0.003</td>
</tr>
<tr>
<td>1</td>
<td>vibration 150</td>
<td>20</td>
<td>0.020</td>
<td>-0.027</td>
</tr>
<tr>
<td>2</td>
<td>vibration 150</td>
<td>40</td>
<td>-0.290</td>
<td>—</td>
</tr>
<tr>
<td>3</td>
<td>shaking 42</td>
<td>20</td>
<td>0.530</td>
<td>0.116</td>
</tr>
<tr>
<td>4</td>
<td>shaking 0.5</td>
<td>20</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Nowadays, improved technology and decreased power consumption allow continuous measurement and long battery lifetime of measuring devices. In 2006, for example, the ACB302 by Star Micronics (New York, NY) had a power consumption of 300 µW (voltage: 3.00 V; current: 0.10 mA), totalling to 72.0 mAh per month. In 2010, the power consumption of sensor devices such as the ADXL345 by Analog Devices (Norwood, MA) was 90 µW (voltage: 3.00 V; current: 0.03 mA) totalling to 21.0 mAh per month. Nowadays, state-of-the-art accelerometers such as the ADXL362 by Analog Devices have a power consumption of 3.6 µW (voltage: 2 V; current: 1.8 µA), totalling to 1.3 mAh per month. Owing to this development in technology, the monitoring of transport processes of beverages such as beer is conceivable. In the following, the demand on such a supervision system as well as the motivation is described for the example of beer flavour stability.

#### (b) Turbidity change in beer caused by vibrations

The demand for beer brewed under strict and high-quality standards—such as the German purity law—has led to growing markets in Asia, Brazil and North America. Besides German brewers, selling their beer more and more abroad, it is a common trend that foreign craft brewers have started brewing their beer under the German purity law. However, long transport times are unavoidable in long-distance delivery export routes. The usage of preservatives or antioxidants is strictly prohibited in beer brewed under this purity law [6]. Therefore, the durability of the product is limited. Shortly after the filling process, different reactions start in the beer, causing, on the one hand, a change in taste (flavour stability), and on the other hand, the development of turbidity owing to small particle build-up by proteins and polyphenols.

After the filtration process, beer turbidity has a value of between 0.0 and 0.4 EBC-units (European Brewing Convention; table 1). In a clear bottle, a slight haze is visible to the human eye at a turbidity value of 2.0 EBC-units [7]. If beer is stored under regular conditions, then it needs six months or more until the turbidity becomes visible. Therefore, shelf life of beer is limited by turbidity to between 6 and 12 months. Storing temperatures above 20°C also reduce the shelf life.

The characteristic formation of turbidity particles is also promoted by movement (shaking and vibrating) during transport. As early as 1950, Kleber [2] described in his essay that beer samples exposed to permanent movement show faster flocculation, eventually leading to turbidity. Unfortunately, there were no systematic analyses of this apparent observation. As for the turbidity formation in the beer, two opposite trends have become apparent after preliminary investigations. Thus, low-frequency movements (shaking) promote the formation of turbidity particles (plus 0.12–0.53 EBC-units within 14 days), whereas higher-frequency movements have the opposite effect of reducing the turbidity values (up to −0.29 EBC-units within 14 days).

Sudden excessive accelerations, such as impacts or shocks, additionally may cause the breaking of glass bottles. Deterioration and breaking cause direct economic loss (loss of the commodity, additional transport costs for replacement, disposal costs and contract penalties). In addition to that, it may harm the image of the brand name and the brewing enterprise.
Therefore, it is important for German brewers to gain exact knowledge of the transportation process. Using the sensor technology of the ‘intelligent container’, the environmental conditions during the transportation can be continuously monitored, and data thereof can be logged. In particular, with new acceleration sensors, the impact of shaking and continuous vibrations can be determined. If the effect of the influences of individual quality parameters is known, then a calculation model can be developed which computes the current status of deterioration of the beers. Generally, the motion sequence during container transport is very complex and depends on the transport carrier, the infrastructure and the weather for example. However, during transportation by sea, two kinds of movement with different influences are present. These are either slow movements (0.01–1 cycles per second) owing to swell, resulting from a ship moving up and down and/or back and forth, and quicker movements (20–200 cycles per second) caused by vibrations, waves and drives. To investigate the influence on beer turbidity, different technical devices are used to simulate different types of movements (laboratory shaker for shaking, vibration plate for lower vibrations and Hi-Fi equipment for higher vibrations).

(c) Shelf life models of beer

Apart from temperature and movement, the monitoring of humidity inside the container is also important. On the one hand, continuous high humidity can cause damage to the packing. On the other hand, the sudden increase of humidity in the container can be an indication for the breaking of bottles or the bursting of cans. Nevertheless, high humidity needs fast regulation in order to prevent or at least minimize the product damages.

Additional studies are planned to demonstrate and verify the benefit of new sensor and communication technologies, especially for their application in beverage logistics. The main questions are how environmental parameters can affect the product quality; how calculation models can predict these changes of quality-related measurement data for beer supported by software; and further, how the potential of the introduction of the ‘dynamic first expire first out’ can be examined in the case of beer transportation from an economic point of view [8].

The potential for the use of autonomous quality control in logistics is examined mainly for relevant transport settings, i.e. container transport by truck (road) and by ship and train (sea and rail). Apart from quality control of the final products, also the potential for optimization of the production processes can be examined by means of ‘mobile beer maturing’.

Owing to ageing processes, beers brewed under the purity law have a competitive disadvantage compared with beers without such purity requirements. Quality assessments, i.e. the early recognition of potential quality losses aided by new sensor technologies, allow for appropriate remedial action before the delivery of goods. Consequently, better customer loyalty and increased turnovers can be expected. It is guaranteed that the products delivered by the brewery reach the customer having the expected taste and quality. Thus, the abovementioned competitive disadvantage can be minimized.

3. Possibilities of online mould detection

Every year, tonnes of perishable goods are wasted due to mould contamination. Mould can infect plants already before harvesting, but it also occurs during transport and storage. Mould contamination can affect different fruits, vegetables, dairy products, cereals and sometimes even processed food that has not been manufactured and sterilized properly. Even if mould contamination is not visible, mould and its metabolites or even toxins can be present in the food, therefore posing a hazard to human health if the food is consumed. An additional potential source can be containers or trucks contaminated with mould. Especially, cooling units are difficult to clean, so the transported goods often get contaminated by these units [9].

To avoid unnecessary transports and to reveal problems caused by diseases on plantations as early as possible during transportations, the monitoring of mould contamination is essential. One of the major European fruit importers, for example, ships 500 containers with bananas per
week from Costa Rica to Antwerp. Considering that this is only one product from one country and from only one importer, the potential for online monitoring is rather evident. Another factor forcing big fruit importers to reduce losses as much as possible is growing competition by small farmers who have started exporting their products on their own. Another possible application is the transportation of meat by trucks.

(a) Mould detection methods

At this point, no measurement principles are suitable for the supervision of containers, trailers or warehouses for the autonomous detection of mould contaminations. Presently, several principles for gathering samples from the air are known. These sampling procedures are manual. In special laboratories, these samples are plated, cultivated and the colonies counted subsequently. A classification of the species usually takes place through optical inspection by experienced operators. In figure 1, typical samples and their growth are shown.

A solution to eliminate the need for experienced operators is the MALDI Biotyper from Bruker Daltonics (Bremen, Germany). With this system, an automated identification of yeast and filamentous fungi with a mass spectrometer is possible. This method provides only an automated identification of the mould species. The sampling, however, can still be quite complicated [10].

One important procedure to ensure hygiene in hospitals and kitchens is adenosine triphosphate (ATP) determination. ATP is present in every living cell. It is the universal energy source and is important for the determination of the quantity of organic pollution (e.g. bacteria and mould) on surfaces. With the use of luciferase, an enzyme reaction starts. ATP is degraded to adenosine monophosphate, oxyluciferin and CO₂. Light is emitted owing to this reaction. The measurement devices that use this method are very small, mobile and easy to use. The sampling is manual, and it is not possible to differentiate between bacteria, moulds or other organisms [11].

In the project ‘Prosenso.net2’, it was evaluated how camera systems can be used to detect infestations of barley with basal rot directly in the field. With intelligent image processing and the right choice of camera, first successes were achieved [12].
Another laboratory-based method to classify mould species is DNA analysis combined with polymerase chain reaction (PCR). This method, however, is not suitable for mobile applications. Especially, the quantitative real-time PCR is important for the specification. Specific parts of the gene are duplicated in an enzyme reaction. The quantification is done with a fluorescence measurement during the PCR cycle. The fluorescence increases with the amount of PCR products. These systems are only used for the identification of the mould species and require substantial efforts. For mobile detection of mould contamination, this measurement principle is not suitable. Nevertheless, a currently run research project regarding this topic should be mentioned: the fungal yeast identification laboratory-on-a-chip project. This project is supported by the German government and will end in 2014. The aim of the project is the utilization of the system in medical diagnostics [13].

Another method for mould assessment is to measure the concentration of microbial volatile organic compounds (MVOCs), which are present as a metabolic by-product if mould contamination exists. Any metabolite of fungi that can elicit toxic effects is called a mycotoxin. Originally, mycotoxins produced by fungi grown on food were investigated for their health effects upon ingestion [14–16]. This is commonly done by sampling these volatile compounds on carbon-based or TENAX sampling tubes for several hours and performing combined gas chromatography/mass spectrometry (GC–MS) after elution/desorption of the compounds from the sampling tubes. While this method is more elaborate than microbiological methods, it is applicable even if a hidden mould contamination, e.g. in a storage container for cereals, is suspected, because the size of mould spores prevents them from being spread through the grains to the cooling air flow. This method requires the sampling tubes being sent to a laboratory for GC–MS measurement and data evaluation. Therefore, it is very expensive and not suitable for use in logistic chains at present. In addition, the emitted amount of these gases is very small.

None of the aforementioned systems can be used for an automated mobile online analysis of mould contamination of fresh products. In most cases, manual analysis and manual sampling by experienced operators must take place, and the measurement system is often too large. A careful preparation of the samples cannot be avoided if the classification of species should be performed in an automated way.

Another promising technology that uses a gas sensor array to detect the MVOCs emitted from the mould species is described in Wöllenstein et al. [16]. Because new sensors have been tested with regard to mould detection, the potentials will be discussed in the next section.

(b) Feasibility of mould detection by gas sensor arrays

In the following, results of a study are presented that aimed at the investigation of the applicability of arrayed metal oxide gas sensors for the determination of mould-related MVOC concentrations. This method would have the advantage of direct, onsite measurements for the fast detection and localization of mould contamination if the required detection limits can be achieved. The MVOC pattern does not only depend on the type of fungus, but also on the prevalent environmental parameters such as nutrient availability, temperature, substrate, substrate composition or humidity. Under constant nutrient and environmental conditions, MVOC patterns are specific for certain fungal strains. Over the past few years, many studies investigated different types of mould and their production of MVOCs, leading to the result that fungi are able to produce more than 50 different MVOCs. Already identified MVOCs can be attributed to a broad range of chemical substances such as alcohols, ketones, terpenes, aldehydes, alkanes, sulfurous compounds, ethers, esters or carbon acids [17]. We decided to test several different semiconductor gas sensors with five typical MVOCs: dimethyl disulfide, 3-methyl-1-butanol, 3-methylfuran, 3-octanone and 1-octen-3-ol.

Evaluated sensors included an arrayed sensor designed at Fraunhofer IPM, consisting of four different sensor materials: SnO₂, SnO₂ + Pt, WO₃ and Cr₂₋ₓTiₓO₃₋ₓ (CTO). Commercially available gas sensors from UST (Germany, Geschwenda), from Figaro (USA, Glenview) and from
Applied Sensors (Germany, Reutlingen) were used for reference and comparison. All substances were tested at different concentrations to evaluate the response of different sensor materials to the MVOCs. Dimethyl disulfide and 3-methyl-1-butanol were tested with the gas measurement set-up in a single gas chamber at four different concentrations. The gas flow was set to 11 min⁻¹, and all measurements were performed in synthetic air (20% O₂/80% N₂) at 0% relative humidity and 24°C. 3-Methylfuran, 3-octanone and 1-octen-3-ol were evaporated at defined concentrations in headspace flasks prior to injection into a measurement chamber with the gas sensors inside. These measurements were performed in ambient air/humidity and at room temperature of 24°C. Additionally, a headspace flask was filled with the odours of mouldy grapes, and 100 µl was transferred to the measurement chamber under the same experimental conditions used for the liquid samples. Concentration series of all five MVOCs were recorded with the IPM sensor array as well as the commercial sensors (UST, Figaro, Applied Sensors). Figure 2 exemplarily shows the results for the IPM sensor array.

The concentration series was used to determine the limit of detection (LOD) of the five test substances. From the recorded data (sampling rate of 1 Hz), the signal intensities were extracted for each sensor and plotted against the respective concentration applying a log–log scale. The LOD was determined using the 3σ-value of the baseline and is given in the graphs. All data are evaluated and represented using MICROCAL ORIGIN (version 6.1). Resistance values are normalized for better comparison.

The data show that all test substances can be detected with all sensors under the test conditions with detection limits clearly below 1 ppm. For the conversion of the amount-of-substances fraction (ppm/ppb) to normalized mass concentration, the molar mass is significant. For example, 1 ppb/1 ppm of 3-methyl-1-butanol (88.15 g mol⁻¹) corresponds to 3.663 µg m⁻³/3.663 mg m⁻³ (20°C, 1 bar).

The sensor-specific LOD for each substance is given in the graph legends. Within the IPM sensor array, the CTO sensor shows the highest sensitivity to all five MVOCs, followed by the SnO₂ sensor except for dimethyl disulfide, where SnO₂Pt seems more suitable. In comparison, the WO₃ sensor shows lower sensitivity to all MVOCs. Among the commercial sensors, the TGS 826 (Figaro) shows the highest sensitivity towards the test substances, except to 1-octen-3-ol. A variation in the operating temperature of the sensors did not lead to improved performance (data not shown). In conclusion, these results demonstrate the ability of all tested sensors to detect the five MVOC substances at low ppb levels. The mouldy grapes were tested under the same experimental conditions. The results are depicted in figure 2; four of six sensors detected the odours with signal intensities, whereas the WO₃ and SnO₂Pt sensors did not respond.

It can thus be assumed that the concept of MVOC detection with semiconductor gas sensors seems feasible. However, measurements of real mould samples would be necessary to elucidate the reactive MVOC profile (not the overall MVOC profile), and whether the sensitivity of the gas sensors is sufficient to detect these reactive MVOCs from mould samples. Because the WO₃ and SnO₂Pt sensors did not recognize the real mould sample, one of the next steps is to include a modification and optimization of the CTO and SnO₂ sensors (e.g. SnO₂Pd), or the use of different materials, to complete a four-sensor array applicable to MVOC detection, with low sensitivity towards interfering substances and changes in ambient humidity. Another crucial aspect would be the implementation of a suitable air sampling unit to ensure ideal sensor performance at low MVOC concentrations.

This technology shows promising potential for the future. One goal will be to find a solution of how measurement can take place without influences from the environment, i.e. cross selectivity to other MVOCs, and how it can be ensured that small amounts of gases can be detected, if a cooling unit is venting the container, and thereby decreasing the concentration of the relevant gases.

An alternative approach, which is based on the sampling of mould spores and the evaluation on a culture medium instead of detecting MVOCs, and therefore less sensitive towards air ventilation, is discussed in the next section.
(c) Concept for an automated culture-medium-based system

The approach discussed in this section is based on the concept of sampling the mould spores on a culture medium to cultivate and to count the colonies subsequently (figure 1). The sampling and the classification of the species are the most critical and difficult procedures in the process that only experienced operators can perform.

The aim is to automate these procedures which are crucial for the evaluation of mould contaminations. An innovative idea is proposed for the automation of the sampling, by opening a membrane at a specified moment using a current pulse to expose the culture medium to the...
Figure 3. Schematic of the sporulation of mould inside a container filled with fruits; the air flow forced by the cooling unit leads the fungal spores from the fruits to the mould sensor. (Online version in colour.)

container air. The opening of a membrane with a current pulse was first described in Roth et al. [18,19]. The air flow forced by the cooling unit from a container causes the mould spores to scatter inside the container. The mould sensor system samples the mould spores from the forced air flow (figure 3). Due to the fact that the sampling is done by gathering the sample from the air flow, other biomasses potentially polluting the sampling medium can largely be avoided.

For an automated evaluation of the mould contamination, only a few mould species are interesting. Which mould species are dominant in a container strongly depends on the country of origin and the perishable goods that are transported. The growth of the dominant mould can be accelerated with an optimized culture medium but at the same time the growth of other mould species can be inhibited. Besides a specific growth rate, the right culture medium can be used to benefit particular behaviour of some mould species. One example is creatine agar (CREA) that is shown in figure 4. In figure 4a, three different mould species are shown which have different growth rates on CREA. One species changes the pH value that causes discoloration of CREA. Figure 4b shows the different colony appearance of one mould species on two different culture media. Other examples can be found in Samson et al. [20].

The combination of more than one culture media can lead to a kind of fingerprint for interesting mould species. Thus, with the combination of electrochemical and visual measurement methods and the right culture media, a classification of the mould contamination and even the mould species seems to be possible in the future.

The measurement itself can be done using a camera. The growth rate as well as changes in colours can be observed. In addition, for example, the pH value and changes in the conductivity of the culture medium can be measured.

One interesting method that can be evaluated for mould detection is a measurement principle that has been developed by Spiller et al. [21]. With this system, the increase of the biomass owing to bacteria cultivation can be measured indirectly by measuring the change of the impedance in suspension. Owing to the huge differences of the physiognomy and growth behaviour of mould and bacteria, the results are not simply transferable; however, it provides an idea of what a detection system may look like in the future (figure 5).

In short, the mentioned opportunities will lead to an online measurement system for logistic processes that automates both sampling and evaluation of the mould contamination inside a container. However, this is only possible with comprehensive knowledge of the dominant mould species harmful for the transported perishable good. The right combination of the culture medium and the measurement procedure (e.g. pH value or growth rate) is therefore absolutely mandatory.
Figure 4. (a) Creatine agar (CREA); left: the mould species does not grow on CREA; middle: mould species has a good growing rate and changes the pH value of the CREA; right: the mould species shows a good growing rate on CREA but does not change the pH value. (b) Different behaviour of Emericella nidulans on different culture media; left: on DG-18 the mould colonies are green; right: on malt extract-agar the mould colonies are white-yellow. Source: BMA Labor GbR.

Figure 5. Schematic of the measurement system for bacteria detection (impedance measurement) and an array of 10 sensors were developed with the membrane dimensions: $1.53 \times 1.53$ mm$^2$; filling volume: 1536 µl. Adapted from Spiller et al. [20].

First field tests showed that sporulation of Fusarium, which is one of the most important mould species in banana transports, shows a fast growth rate and the sporulation starts within only a few days. According to the time a banana container is in transit from Costa Rica to Antwerp (14 days), contamination can be detected during the transportation with such a system. A problem in the logistic chain of bananas might be the bags in which the bananas are packed, because they might inhibit the sporulation. This will not be a problem in the logistic chain of other fruits that are transported without being packed in a bag (e.g. pineapples).

4. Conclusion and outlook

In this paper, we showed that new sensor technologies for automated monitoring of food transports are not only necessary but also technically feasible. The presented case study for beer demonstrates that the monitoring of vibration and mechanical shocks is not only important for fresh fruits, but also for processed foods such as beverages.

Strong competition in food production and high cost pressure require a general minimization of the share of fruits and beverages discharged owing to quality losses during transport.
Especially, breweries with high quality standards and strict product purity regulations need to prevent challenged flavour stability owing to events during transport. In order to be competitive in the future, new technologies must be explored and identified to enable less cost-intensive production and higher quality than potential competitors.

To achieve these goals, the development of an intelligent supervision system measuring temperature, humidity and gas composition of the environment of a cargo is mandatory. With shelf life models, these parameters can be interpreted to predict the remaining shelf life of the product at any time during transport. However, particularly for the two abovementioned groups of producers, this is not enough.

For breweries, it is important to include acceleration as a further parameter for shelf life modelling to predict uncompromised taste and thus the drinkability of their beer products. The drinkability of beer is reduced drastically if specific accelerations occur during transport. More investigation in this field is absolutely imperative. The rising export of German beer, brewed in strict accordance with the German purity law, especially to the Far East drives the need to think about reorganizing production processes, for example by shifting the maturing process into the transport phase. The required supervision of the process can be provided by enhanced remote monitoring systems.

For fruit importers, an important issue is the development of an automatic sensor system that evaluates the mould contamination inside containers with perishable goods and foodstuffs, providing the following benefits:

- cooling units potentially polluted with harmful mould species will be discovered prior to loading;
- problems on the plantation caused by mould can be revealed much earlier;
- unnecessary transports will decrease; and
- no container with mouldy fruits will be delivered to customers.

Current methods for mould detection are based on offline analyses by laboratory tests. In this paper, we showed the general feasibility of systems for mould detection that can be directly installed in containers or operated as mobile devices. We identified two candidate technologies, although both technologies are still in their early development phase.

The first approach is based on a miniaturized device for automated sampling on a culture medium of a forced air flow in a container. An alternative solution combines the measurements of a combined set of micro-fabricated gas sensors. Both technologies require further research efforts. They will help understand the occurrence, the cause and the effects of mould in containers in a more in-depth manner and can make an important contribution to the reduction of food waste and losses.

Funding statement. The research project ‘MaUS’ is supported by the Federal Ministry of Education and Research, Germany, under reference number 031A257A-D.

References


