On Line E-Nose Technology for Safety and Quality Evaluation in Cereal Processing

Federica Cheli, Luciano Pinotti, Matteo Ottoboni, Marco Tretola, Vittorio Dell'Orto
Department of Health, Animal Science and Food Safety Milano, Italy
Email: federica.cheli@unimi.it, luciano.pinotti@unimi.it, matteo.ottoboni@unimi.it, marco.tretola@unimi.it, vittorio.dellorto@unimi.it

***Abstract* - The objective of this idea is to set up an electronic nose (e-nose) for the safety and quality evaluation of cereal products and by-products, focusing on mycotoxin contamination. The final goal is to evaluate the potential application of the e-nose technology as an on-line continuous monitoring and controlling tool in cereal processing, in particular wheat milling. E-nose could be integrated with other on-line analysis devices in a technological platform for monitoring and controlling food quality. Multi-sensor-devices and multi-sensor-data-fusion technology have a great potential value to the food industry to ensure that cereal products and by-products meet specifications according to their specific use.**

Keywords-Food safety; Mycotoxins; Electronic nose;

I. INTRODUCTION

During the last twenty years, the term food quality has assumed a new and more complex meaning. Topics such as sensory characteristics of a product (odour, colour and outer appearance), food safety, traceability or best practice are of great importance to today's food industry. Many different sensing methodologies represent fast and precise potential tools for "total quality" evaluation, assurance and compliance with labelling. The applications of the electronic nose (e-nose) are numerous in several areas related to the food industry, mainly in the field of quality and authenticity evaluation of fish, meat, milk, wine, coffee and tea.

Among the most important risks associated to cereals' consumption are mycotoxins. Mycotoxins are metabolites of fungi capable of having acute and chronic toxic effects. Globally, mycotoxins have a significant impact on human and animal health, economies and international trade [1]. Cereals and cereal by-products constitute a major part of the daily diet of humans and animals. Food processing affects mycotoxin distribution and concentration. Cereal processes reduce and concentrate mycotoxins into fractions that are commonly used for humans and as animal feed, respectively. A wide range of analytical methods for mycotoxin determination in food has been developed in recent years [2]. At the industry level, the adoption of a rapid, low-cost, high-throughput and on-line analytical approach is needed at all stages of cereal production and processing in order to guarantee the quality and safety of the production.

To develop the idea to evaluate the potential application of the e-nose technology as an on-line continuous monitoring and controlling tool in cereal processing, a step by step procedure must be designed: knowledge of e-nose characteristics and applications in the cereal industry, proper selection of an appropriate e-nose system for the specific application, analysis of the cereal milling process to identify the optimal points for the e-nose analysis, analyze the critical points for the use of the e-nose in an integrated system for quality evaluation.

II. THE ELECTRONIC NOSE

The e-nose is an instrument which comprises an array of electronic chemical sensors, with partial specificity and an appropriate pattern recognition system, capable of recognizing simple or complex volatile organic compounds' (VOCs) patterns associated to a product odour [3]. The conventional aroma analysis by gas chromatography–mass spectrometry (GC–MS) is too time-consuming, complex and labour-intensive for routine quality application. Compared to GC-MS, e-nose presents several advantages (portable, ease to use, rapid response and low costs) which make it a powerful tool for screening analysis to address the needs for routine quality testing in the food industry. Moreover, it could be easily integrated in current production processes.

Fungal spoilage induces nutritional losses, off-flavours, organoleptic deterioration often associated to mycotoxins formation. Researches have correlated fungal activity with the production of typical VOCs [5]. E-nose technique has been proposed as a new method for the detection of VOCs as indicators of potential grain spoilage, detection and differentiation of mycotoxigenic strains of fungi in contaminated grains and semi-quantitative/quantitative evaluation of mycotoxin contamination [4][5]. This latter has been done using fungal VOCs as indicators of mycotoxin presence. The use of e-nose as a screening tool for the presence of mycotoxins in food must take into accounts the maximum levels or guidance values established by legislation. Preliminary results are encouraging, showing that it is possible to use volatile compounds to predict whether the mycotoxin levels in grains are below or above maximum permitted levels (Figure 1) [6][7].

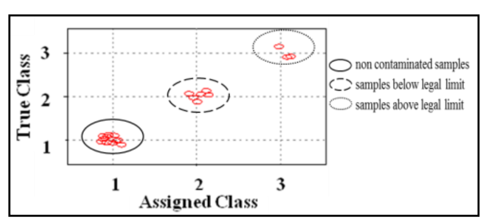

Figure 1. E-nose for the recognition of durum wheat naturally contaminated by deoxynivalenol (CART-model performance plot) (adapted from [8]).

Sampling is the greatest source of error in quantifying mycotoxin contamination because of the difficulty in obtaining samples from large grain consignments and of the uneven distribution of mycotoxins within a commodity [8]. Sampling uncertainty dominates in final uncertainty result, and then the adoption of an on-line e-nose analysis may represent an interesting analytical approach to reduce this uncertainty.

Many characteristics that directly determine the effective quality and/or safety of a food are often described by its aroma. The e-nose is able to provide a global aroma fingerprint, which reflects the aroma complexity of a product. Thus, the evaluation of the "total quality" of food, which requires the simultaneous recognition, classification, and/or quantification of several parameters, could be achieved via a method based on the features and properties exhibited by e-nose. Consequently, e-nose could be applied for both research & development purposes and in-field applications (e.g., in food industry contexts and in production plants).

A. Set the e-nose for the specific application

The suitability of an e-nose for a specific application is highly dependent on the required operating conditions (environment) of the sensor array and the composition of the target VOCs. A proper selection of an appropriate e-nose system for a particular application must involve an evaluation on a case-by-case basis. E-nose selection for a particular application must necessarily include: assessments of the selectivity and sensitivity range of individual sensor arrays for particular target VOCs (i.e., related to mycotoxin contamination, target organoleptic properties of the products), the number of unnecessary (redundancy) sensors with similar sensitivities, as well as sensor accuracy, reproducibility, response speed, recovery rate, robustness, and overall performance. Most of these steps are common points of a validation procedure. To set up the e-nose for mycotoxin analysis, naturally contaminated samples will be divided into two subsets. One of the two subsets, training set, will be used to calibrate the model, and the other one, validation set, will be used to verify the robustness of the established model. Pattern recognition systems (principal component analysis - PCA; linear discriminant analysis - LDA) will be employed to select variables and build a model to improve the sample discrimination according to mycotoxin contamination. Results may give crucial information for the development of on-line e-nose devices involving a reduction in sensor number (relative to larger bench-top laboratory instrument versions) and identifying specific sensor types in the array to optimize the performance for specific applications. An important final consideration for designing e-nose systems as a rapid screening tool for food industrial applications is the incidence, frequency and acceptable rate of false classifications. Besides mycotoxin analysis, the set up and validation protocol could be used for enhancing the performance of the sensor system for a "total quality evaluation". New ways to improve e-nose performance using better or more target-specific sensors, pattern-recognition algorithms, data analysis methods, will significantly amplify the range of applications of e-noses in the food industry.

B. An eye in the cereal milling process for on-line process e-nose analysis

Food process control necessitates real-time monitoring at critical processing points. Very schematically, the chain of the cereal milling process includes three main steps: receiving and storage of grains, production (milling process) and storage of products and by-products (Figure 2). The dry milling process of wheat is a gradual reduction process by which wheat is ground into flour or semolina, including several steps, such as cleaning and sorting, debranning and milling. At the industrial level, several on-line technological solutions for rapid and non-destructive analysis and quality control of the grain before and after milling are available, such as optical sorters, near infrared (NIR)-based analysis technology, on-line colour, contrast and ash control of cereal products.

The e-nose could be used as an on-line sensing solution at different point (Figure 2): 1) receiving and storing of grain for controlling the safety aspect (i.e., mycotoxin contamination); 2) at the end of the milling process for controlling the quality and safety of the finished product (i.e., organoleptic characteristics, mycotoxin contamination, etc.); 3) after storing before products are packaged or delivered to ensure that they meet specifications according to the specific use. E-nose data may be continuously calculated, transmitted and integrated in the process control system.

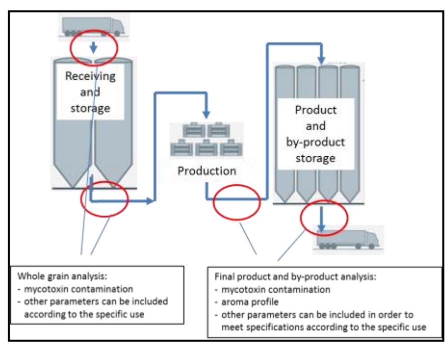

Figure 2. Schematic representation of the chain of the cereal milling process and the possible e-nose optimal points for product and process "total quality" evaluation.

III. E-NOSE IN AN INTEGRATED SYSTEM FOR TOTAL QUALITY EVALUATION

In order to achieve a "total quality evaluation" of cereal products and by-products, e-nose data should be integrated with data from several on-line technological solutions for rapid and non-destructive analysis already are available (like those mentioned before, i.e., optical sorters, NIR-based analysis technology, etc.) to create a technological platform for food process monitoring. Multi-sensor data fusion is a technology able to combine information from several sources in order to improve the monitoring process performance.

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Low-level data fusion (direct integration of the raw data of various sensors) and intermediate-level data fusion (data fusion after the feature extraction process to keep enough raw information and eliminate redundant information) will be evaluated for classification efficacy in food quality evaluation. However, the final goal is to create a high-level fusion, namely decision-making fusion, able to analyze the features from each analytical system first and then to associate these features to produce a fused result. For intelligent loops, all the data must be transmitted to the process control system for a continuous quality assurance. Alarm messages must be issued in the case of drift-away from the target value to advice the operators.

IV. CONCLUSION AND FUTURE WORK

E-nose represents a powerful tool for safety and quality evaluation in cereal processing. Despite the advantages of e-nose analysis, there are still few applications of e-nose adopted in industry. This could be attributed to the need to tune either the software and/or hardware to a specific application. Therefore, future work is needed on the materials' side (new material for better selectivity, design and development of sensors that can be used reliably over long temporal horizons), on the data analysis side (better modeling and correlation between chemical markers and the sensor response, development of data fusion analysis for the process control system for a continuous quality assurance), on the industrial side (better understanding of the industrial needs related to quality control and monitoring of food processing).

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