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USES OF ELECTRONIC NOSE IN THE FOOD INDUSTRY

ELEKTRONİK BURUNUN GIDA ENDÜSTRİSİNDE KULLANIMI

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ABSTRACT: In the food industry, it is important that great attention be paid to maintain and improve food quality. Electronic nose is one of the tools which promises to aid in this regard. It is an analytical instrument that profiles the headspace volatiles above the sample. It can be used for quality control, process monitoring, freshness evaluation, and shelf-life evaluation. In this article, uses of electronic noses in the food industry were discussed.

ÖZET: Gıda sanayiinde, gıda kalitesinin sağlanmasına ve geliştirilmesine çok önem verilmektedir. Elektronik burun, bu alanda yardım vadeden cihazlardan bir tanesidir. Gıda örneğinin uçucu bileşenlerinin profilini veren analitik bir cihazdır. Elektronik burun kalite kontrolda, üretimin takibinde, tazelik ve raf ömrünün dererlendirilmesinde kullanılır. Bu makalede elektronik burunun gıda endüstrisindeki kullanımı üzerinde durulmuştur.

INTRODUCTION

In the food industry, flavors are important, from the raw ingredients to the final product. Flavor is a major criterion for consumers to accept or reject a product, and greatly influences decisions on repeat-purchases. There are two components of flavor perception: taste and aroma. Taste occurs from the presence of nonvolatile compounds that interact with sensors in the mouth and on the tongue. Although taste is important, the flavor cannot be defined by taste alone.

Many volatile compounds are responsible for the aroma of foods, and play an important role in flavor. These volatiles contribute to the nature of the food, its product identity, and consumer preferences. They may also be responsible for the occurrence of off-flavors and taints, due to biochemical, chemical or microbial changes, or contamination(HODGINS, 1997).

Humans can detect a minimum of 10,000 odors, but the number of identifiable odors is about 50 (BARTLETT et al., 1997). A single molecule can have a distinct odor. However, most natural smells or flavors are a complex mixture of chemicals, and contain hundreds of constituents (DODD et al., 1992).

Odor molecules can be detected by humans below 1 ppb. Gas Chromatography/Mass Spectrometry is used to detect odors at low levels, but the sample must be separated into its components before identification. However, true aroma is related to the complex interaction of all volatile compounds within foods. For example, using a gas chromatograph with a sniffer port, none of the individual aromatic compounds present in cocoa smelled like cocoa to humans; however, when all of these compounds combined, the overall aroma was that of cocoa (HODGINS and SIMMONDS, 1995; HODGINS, 1997). In addition, Gas Chromatography/Mass Spectrometry is expensive, and requires a technician for operation and interpretation of the results.

Due to these constraints, sensory analysis has been used for a long time for odor evaluation. However, sensory panel responses have potential problems (reproducibility, difficulties of expression, and stability). These make it hard to compare results between different panels (BARTLETT et al., 1997; HODGINS and SIMMONDS, 1995). There is a need for an instrument that can mimic our sense of smell, and provide rapid sensory information at low cost and without sample preparation. Electronic nose (e-nose) can be an alternative in this respect.

ELECTRONIC NOSE TECHNOLOGY

In 1961, Moncrieff developed an instrument to detect odors. In 1965, studies of redox reactions of odorants at an electrode, modulation of electrical conductivity, and contact potential by odorants were published. The concept of an e-nose as a chemical array sensor system for odor classification was presented for the first time by Persaud and Dodd in 1982. Today, the e-nose has various synonyms such as artificial nose, sensor array system, and odor-sensing system.

The e-nose is comprised of : 1) an array of electronic chemical sensors having partial specificity, 2) an appropriate pattern recognition system to recognize simple or complex odors (GARDNER and BARTLETT,1994). Its main components are: sample handling mechanisms, chemical sensor arrays, signal preprocessing and conditioning, and pattern recognition. The e-nose simulates human olfactory process with fewer sensors, and a suitable software analyzes responses from sensors. Each sensor produces a time-dependent electrical signal in response to an odor. The specificity of each sensor may be low, but combinations of several specificity classes results in a wide range of information. Pattern recognition in the e-nose is equivalent to the classification of odors in the brain (GARDNER and BARLETT, 1999).

SENSORS USED IN ELECTRONIC NOSES

Conducting polymers, metal oxides, lipid layers, phthalocyanins, and piezoelectric materials are being used to manufacture sensors for odor detection. The sensor types used commercially are conducting polymers, semiconductor metal oxide chemoresistive sensors, quartz-resonator sensors, and surface acoustic wave devices (BARTLETT et al., 1997; HODGINS, 1997). Electrolytic and enzyme sensors, biosensors, platinum hot wire detectors, and fiber-optic gas sensors also have potential or have been used (SHURMER, 1990). Selectivity and sensitivity are determined by the choice of catalytic surfaces (GARDNER and BARTLETT, 1999). Sensor technology is changing rapidly, towards more sensitive, stable, and fast sensors.

Conducting polymers: They have unique electrical properties that make them suitable for gas detection. A wide range of materials can be synthesized. They respond to a broad range of organic vapors, and operate at room temperature. The main types are poly-anilines and poly-pyrrole. Volatile compounds rapidly and reversibly change the electrical conductivity of the polymer, at room temperature (GARDNER and BARTLETT, 1999). The adsorbed odor molecules are believed to cause swelling of the polymer and interfere with charge transfer in the polymer (CORCORAN, 1993). Conducting polymer sensors are nonspecific. Many compounds interact with the polymer. These sensors are small, and have low power consumption since they operate at room temperature. They have good sensitivity, typically between 0.1 and 100 ppm (BARTLETT et al., 1997). When volatile compounds are removed, sensor response rapidly recovers to the baseline. Conducting polymers are sensitive to humidity, therefore, caution should be taken when analyzing samples with different water activities.

Semiconductor metal oxide chemoresistive sensors: This type of sensors are developed from chemoresistive arrays of inorganic semiconducting materials such as oxides, and catalytic metals. Two main types have been developed: thick film metal oxides (Taguchi sensors), and thin film metal oxides, which are commonly used in commercial e-noses (Table 1). These sensors have a ceramic support tube containing a platinum heater coil. Tin-dioxide is coated on the outside of this tube along with the catalytic metal additives such as palladium or platinum. When electrical current passes through the coil, the metal oxide heats up. The reaction between the metal oxide and the vapor causes a change in electrical resistance at a fixed temperature. Chemisorbed oxygen [O^-] reacts with the odorant [R] irreversibly to produce combined molecules [RO] and liberated conducting electrons [e^-]. Electron mobility increases, and electrical conductivity of the material changes (TAN et al., 1995). This can be measured, and related to odors being monitored. These sensors operate between 300-550°C to avoid interference from water, and to aid rapid response and recovery times (GARDNER and BARTLETT, 1999). They are sensitive to combustible materials, such as alcohols, but less sensitive at detecting nitrogen-and sulfur-based odors.

Surface acoustic wave devices: These have been in research and development for 5 to 10 years (HODGINS, 1997). A surface wave with a frequency between 100 MHz and 1 Ghz is generated in a material, using a quartz resonator, which absorbs the vapors of interest. The system sensitivity is controlled by frequency. The sensor has a certain resonant frequency when it is not exposed to a vapor, and when it contacts the volatiles, there is a change of its mass, and therefore a change in the resonant frequency (BALANTINE and WOHLTJEN, 1989; HODGINS, 1997). This frequency change is the response of the sensor to the volatiles. These sensors have better sensitivity than conducting polymers(HODGINS, 1997). However, they are more selective, and a larger number of them are needed to cover all vapors that may exist in foods.

Fiber-optic gas sensors: These sensors rely on the light guiding properties of the optical fiber to carry the light from the source to the chemically sensitive layer, and then to return it to the sensor. The optical properties measured include the optical path length, luminescence, absorption, fluorescence, and reflectance. Individual fibers can be as small as 2 μm in diameter, and large bundles of fibers permit the fabrication of miniature sensor arrays; video technology can be used to measure responses from an array; measurements can be made remotely because the fiber allows transmission of light over long distances; and the devices are not subject to electrical interference (GARDNER and BARTLETT, 1999). Fiber-optic gas sensor arrays can be used to sense a range of organic vapors (DICKINSON et al., 1996; WHITE et al., 1996). A fluorescent dye, Nile Red, was used in these studies since its fluorescence spectrum and intensity is strongly dependent on the local solvation environment. The fluorescence emission from the dye changes in the presence of organic vapors that sorb into the polymer films, and can be measured. At present, the sensitivity of these sensors is not high, and there is not enough information about their lifetime, reproducibility, or stability.

COMMERCIAL ELECTRONIC NOSES

E-noses available in the market are shown in Table 1. They utilize different types of sensors and they all have different response time.

Table 1. Commercial e-noses available in the market

Commercial e-nose	Sensor type	Response time	Benchtop/portable
Airsense Analysentechnik	10 metal oxide	*NA	portable
Alpha M.O.S.	12-18 metal oxide	15-20 min	benchtop
Osmetech (AromaScan)	32 conducting polymers	5 min	benchtop
Boodhound BH114	14 conducting polymers	*NA	portable
Cyrano Sciences	32 conducting polymers	10 sec	portable
EEV (Neotronics)	12 conducting polymers	4 min	benchtop
EST	surface acoustic wave	10 sec	portable
Hewlett Packard	mass spec-based	40 sec	benchtop
HKR & Perkin Elmer QMB6 Nose	6 quartz microbalances	*NA	*NA
Kamina	metal oxide	10 min	benchtop
MOSES II (MOTECH) Lennartz Electronics sensors	8quartz microbalances and 8 metal oxides	*NA	benchtop
Nordic Sensor Tech	Mosfet (metal oxide) and MISiC (silicon carbide)	*NA	portable
RST Rostock	6 quartz crystal microbalances	*NA	portable
Sawtek	coated SAW devices	4-6 sec	portable
SMart Nose	mass spec based	*NA	benchtop
Vapor Lab	SAW devices	1 sec	portable

*NA - not available

APPLICATIONS OF ELECTRONIC NOSE IN THE FOOD INDUSTRY

The e-nose can be used for quality control, process monitoring, freshness evaluation, shelf-life evaluation and authenticity assessment. The potential applications in the food industry are virtually unlimited. Research has been performed on meat, grains, coffee, mushrooms, cheese, seafood, alcoholic and nonalcoholic drinks.

In most food companies raw materials are not frequently checked for aroma before processing. The final product is checked, and rejected if a taint or off-odor is present. This may cause difficulty in determining which supplier delivered the faulty material, which may have cost a great deal (HODGINS, 1997). The use of an e-nose as a quality control tool to check raw materials can eliminate this problem. E-nose can also be used to monitor food odors during critical stages of production to ensure that optimum processing conditions are being maintained, to monitor product deterioration during shelf life studies and during transport to retailers. It is ideal for quick Quality Control/Quality Assurance checking (HODGINS, 1997).

DAIRY APPLICATIONS

In the dairy area, sensor arrays have been used to determine the role of fatty acids in the aroma profiles of Swiss cheese (HARPER et al., 1996), and to differentiate enzyme-modified cheese slurries (JIN and HARPER, 1996). KOREL et al. (1999) used the e-nose to detect odor differences in milk due to microbial load and storage time, and correlated it to sensory panel perception. HAUGEN et al. (1997) analyzed milk quality by e-nose and sensory profiling, and classified fat content by neural network modeling of the e-nose results. They reported that the e-nose and sensory panel results showed the same ability to discriminate between milk having different fat contents. SBERVEGLIERI et al. (1998) also obtained the selective discrimination of different heat treated commercially available milks (pasteurized, UHT, and sterilized) with an array of four selected thin film semiconductor sensors. The volatiles from the milk samples were collected by dynamic headspace, and flowed directly into the test chamber containing the sensor array. The data was processed with simple principal component analysis. They stated that the results were promising for the industrial development of an e-nose for the monitoring of the milk quality.

MEAT AND POULTRY APPLICATIONS

E-nose was used for separation of ground raw and cooked samples of pork-beef mixtures by composition and freshness (TURHAN et al., 1998), used for estimation of ground meat quality, with a good possibility of predicting storage time (WINQUIST et al., 1993), and used to determine the change of the volatile fraction of cooked chicken meat during storage at 4°C (SIEGMUND and PFANNHAUSER, 1999). E-nose was also used to monitor sausage fermentation by following changes in volatiles, and to compare the e-nose results with sensory panel results. From the sensor readings the fermentation time could be predicted, and sensory results were compared with the e-nose sensor readings in the early and final stages of the process (EKLÖV et al., 1998).

SEAFOOD APPLICATIONS

E-nose has been used in differentiating odors in shrimp stored on ice (BALABAN and LUZURIAGA, 1996), storage of tuna (NEWMAN, 1998), and salmon (LUZURIAGA and BALABAN, 1999a) at different temperatures using conducting polymer sensors. KOREL et al. (2001a) analyzed the effect of lactate on tilapia fillets stored at two different temperatures over time, and detected the freshness of raw and cooked catfish fillets stored at different temperatures (2001b). E-nose was also used to monitor haddock and cod freshness (OLAFSSON et al., 1992), and to determine fish storage time (DI NATALE et al., 1996). The odor of decomposition in raw and cooked shrimp was evaluated based on e-nose readings, sensory evaluation, and ammonia levels (LUZURIAGA and BALABAN, 1999b).

FRUIT AND VEGETABLE APPLICATIONS

The e-nose has been used for determination of harvest ripeness in cantaloupes (BENADY et al., 1995), bananas (LLOBET et al., 1999), and quality assessment of packed blueberries (SIMON et al., 1996). Volatiles of citrus juice (HODGINS, 1995; HODGINS and SIMMONDS, 1995), and fresh squeezed orange juice aroma volatiles (BAZEMORE et al., 1996) have been studied. BAZEMORE et al. (1997) reported that grapefruit juices of different cultivars were discriminated using metal oxide sensors. MAUL et al. (1997) assessed the ability of an e-nose to nondestructively identify and classify tomato fruit exposed to different harvesting and postharvest handling treatments. They also analyzed the volatile profiles of ripe tomatoes harvested at different maturity and stored at different temperatures by e-nose and Gas Chromatograph. WERLEIN and WATKINSON (1997) compared the sensory quality of conventionally processed carrots, green beans, and potatoes using metal oxide sensors and sensory panels.

GRAINS AND BEANS APPLICATIONS

BÖRJESSON et al. (1996) used an e- nose to classify grains and reduce exposure of inspectors to grains contaminated with aflatoxins. JONSSON et al. (1997) analyzed samples of oats, rye, and barley with different odors and wheat with different levels of ergosterol, fungal, and bacterial loads. The odor of classes of good, moldy, weakly, and strongly musty oats was predicted with artificial neural networks. The percentage of moldy barley or rye grains in the mixtures of fresh grains was also indicated. There was a high degree of correlation between neural network predictions and measured ergosterol, fungal, and bacterial loads. HOFMANN et al. (1997) used an e-nose with 4 metal oxide sensors to follow flavor generation during toasting of wheat bread, and to follow the roasting degree of toasted wheat bread slices. Other work has been done to discriminate among coffee cultivars, coffee from different origins, and coffee aromas (AISHIMA, 1991; TAN et al., 1995; DELAURE et al., 1996).

BEVERAGE APPLICATIONS

The flavor and aroma of beer and its raw materials were monitored using e-nose technology (PEARCE et al., 1993; TOMLINSON, 1995; TOMLINSON et al., 1995; ZIMMERMANN and LECLERCQ, 1995). The aroma of pure hops and blends used in beer making were studied by LUCAS and CASTAN (1995) and WEBER and POLING (1996). VIAUX and ROBILLARD (1996) also used an e-nose to help in the determination of the technical specifications of some additives and technological aids used in the sparkling wine process. GUADARRAMA et al. (2000) evaluated the response of an array of polymeric sensors to different Spanish wines. NAMDEV et al. (1998) used the e-nose to provide a rapid and early indication of bioprocess performance by sniffing the odor of cultivation media and broth. They monitored lot-to-lot variation in ingredients and detected microbial contamination early using e-nose.

E-nose has the potential to be used in food industry since there were many researches done in this field. However, e-nose and especially sensor technology need further development in order to fulfill the need in the industry. The researches were performed under controlled conditions and the sensors used until now are generally sensitive to temperature and humidity. In order to have portable e-noses used widespread, these potential problems need to be solved.

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