Journal of Food Engineering 133 (2014) 23–29

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Development of methodology for assessment of shelf-life of fried potato wedges using electronic noses: Sensor screening by fuzzy logic analysis

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ARTICLE INFO

Article history:
Received 4 September 2013
Received in revised form 29 January 2014
Accepted 12 February 2014
Available online 20 February 2014

Keywords:
Electronic nose
Fried food products
Shelf-life study
Fuzzy logic analysis
Mahalanobis distance

ABSTRACT

Development of a methodology for rapid assessment of shelf-life of fried potato wedges were carried out using electronic noses (e-noses) with metal oxide gas sensors. Fuzzy logic analysis was applied for the first time for screening the sensors and it was found that four sensors were more specific for detecting volatile organic compounds from fried potato wedges. Data obtained from these screened sensors concluded that fried potato wedges had shelf-life of 3 days when stored in inert atmosphere of nitrogen in Ziploc pouches at 23 ± 2 °C. Mahalanobis distance method was adopted for quantifying the extent of spoilage and was correlated to peroxide values and free fatty acid content obtained by biochemical assays. Since, this methodology accurately and rapidly predicted the shelf-life of fried potato wedges; it could be also applied for fast and reliable estimation of shelf-life of various fried food products.

1. Introduction

Fried potato wedges are globally consumed as a very popular deep fried snack owing to their crisp texture, flavor, color and mouth-feel (Van Loon et al., 2007). However, the major problem encountered with fried potato wedges is during their storage owing to their propensity to deteriorate consequent to microbial infestation and by biochemical reactions, primarily by lipid oxidations. These oxidative reactions decrease their nutritional quality with simultaneous generation of potentially toxic products (Nawar, 1997). Currently, global strategic research agenda emphasizes PAN (Preference, Acceptance and Need) analyses of food products, hallmarked as the key characteristics that lead consumer choices for a given food product (Schweiger, 2013). These characteristics are primarily governed by food product formulation and design and also by the product shelf-stability. To ascertain the latter, it is necessary to monitor the spoilage pattern of food products with time (Nawar, 1997). Conventionally, spoilage of lipid-rich products are determined through microbial and biochemical assays, which are time consuming, less reliable and of low sensitivity. Electronic nose (e-nose) technology, which works by mimicking the human olfactory system, is widely used in food industries for effective and convenient process monitoring, shelf-life investigation, freshness evaluation, authenticity assessment and quality control for cooking and fermentation processes (Peris and Escuder-Gilabert, 2009; Chatterjee et al., in press). Vinaixa et al. (2005) used this technology for directly detecting rancidity in potato crisps, foregoing the problems associated with conventional biochemical assays. Wide et al. (1997) applied this technology, in fusion with tactile and auditory sensors for studying ageing and quality of potato chips. This work endeavored to extend the application of e-nose technology in detecting spoilage in fried potato wedges, which with their higher oil and moisture content pose additional challenges in data acquisition and analyses.

The objective of the current investigation is to develop a methodology to predict the shelf-life of fried potato wedges using an e-nose system, equipped with metal oxide gas sensors which are sensitive towards a wide range of volatile gases. Generally for a particular food system, certain sensors are more specific and sensitive than others. Therefore, it is better to screen the most appropriate sensors for a particular food system for accurate estimation of shelf-lives of foods. It has also been reported by several authors that with large number of sensors, the discrimination indices in principle component analysis are generally poor and better discrimination indices are obtained when number of sensors

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Abbreviations: AOAC, Association of Analytical Communities; AR, analytical reagent; C-DAC, Centre for Development of Advanced Computing, Kolkata, India; CFC, chlorofluorocarbon; FFA, free fatty acids; meq, Milliequivalent; PAN, Preference, Acceptance and Need; PV, peroxide values; TFN, triangular fuzzy number; TOC, total organic carbon; VOCs, volatile organic compounds.

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http://dx.doi.org/10.1016/j.jfoodeng.2014.02.009
0260-8774/

are reduced to 4–6 (Mildner-Szkudlarz et al., 2008; Aparicio et al., 2000; Garcia-Gonzalez and Aparicio, 2004). Since it is not known whether all e-nose sensors used in this work are specific for VOCs generated from fried potato wedges; for more reliable and accurate estimation of shelf-life of fried potato wedges, we have screened a few sensors which are more sensitive towards VOCs of our sample matrix by applying fuzzy logic analysis. Fuzzy logic is an important tool used to eliminate subjectivity in linguistic data obtained from organoleptic judgment of food products by a panel of semi-trained to trained members. It has been successfully employed in ranking of food products, based on quality attributes (Zang and Litchfield, 1991; Chakraborty et al., 2011). Analogously, we considered the sensor responses as panel responses and their relative importance was judged using fuzzy logic. This work reports for the first time on the application of fuzzy logic tool in screening and ranking e-nose sensors for fried potato wedges from the intensities of their signal responses.

A spoilage index was developed for fried potato wedges from its Mahalanobis distance from the non-spoiled sample dataset. In order to arrive at a holistic conclusion on the shelf-life of fried potato wedges, biochemical assays for estimation of peroxide values (PV) and free fatty acid (FFA) content (which are considered to be effective indices for detection of rancidity and spoilage in lipid-rich food products) were carried out in tandem with e-nose analysis and were correlated with the Mahalanobis distance. These correlations would enable the user to directly predict the conventional rancidity parameters of fried potato wedges from e-nose data, forgoing biochemical assays. To the best of our knowledge, there are no reports till date on the development of a methodology for estimation of shelf-life of deep fried potato wedges using e-nose and on selection of sensors for spoilage detection, employing fuzzy logic analysis.

2. Materials and methods

2.1. Materials

Potatoes *Solanum tuberosrum* (*Kufri Jyoti* variety), refined soybean oil and Ziploc pouches (20 μm thickness, self-sealable) (M/s UFLEX Ltd., USA) were purchased from the local market of Jadavpur in Kolkata, West Bengal, India. All chemicals used for analysis were of AR grade.

2.2. Preparation of potato wedges

The fresh raw potatoes were washed in distilled water, peeled and were cut into definite dimensions (70 × 10 × 10 mm) using a French fry cutter (M/s Jas Enterprises, Ahmedabad, India). The wedges were initially blanched with distilled water at 90 °C for 2 min and thereafter blanched again with 0.2% potassium metabisulphite (w/v) at 90 °C for 12 min, with a delay of 2 min between the consecutive processes. Following blanching, the potatoes were dried (to maximum moisture content of 50%) in a tray drier at 65 °C for 60 min (optimized through several trials) before frying.

2.3. Frying of potato wedges

Frying of potato wedges were carried out in an electric deep fat fryer (M/s Shiva Kitchen Appliances, Kolkata, India) using the protocol for deep frying of potato wedges previously standardized in our laboratory (Ghosh et al., 2012), with little modifications. Since, most metal oxide gas sensors of e-noses are moisture sensitive, attempts were made to reduce the moisture content of fried wedges to minimum. Hundred grams of potato wedges were fried at 170 °C for 10 min in 1 L soybean oil to reduce the moisture content to $\leqslant$20%, which was determined by drying 2 g of sample to constant weight at 95–100 °C in a hot air oven in accordance to AOAC official method 934.01 (AOAC, 2006). The wedges were then placed in a strainer to drain off excess oil and then air cooled. The wedges were subsequently placed on blotting paper to remove the excess oil from their surface (Ghosh et al., 2012).

2.4. Storage of potato wedges

The potato wedges were packed in self-sealable Ziploc pouches (M/s Johnson & Johnson Ltd., Mumbai, India), flushed with nitrogen and stored at room temperature (23 ± 2 °C) for 10 days. To detect the rancidity profile of the fried potato wedges, the e-nose system was trained using deliberately rancid wedges. These training sets of potato wedges were prepared by keeping 'control wedges' (non-spoiled) in an accelerated rancidity chamber for 1, 2, 3, 4 and 5 days. This rancidity chamber is an incubator to render wedges deliberately rancid. The chamber is equipped with UV light to promote oxidation of the wedges at constant temperature of 40 ± 2 °C. On completion of the ageing treatment, the samples were removed from the same, flushed with nitrogen and stored in a conservation chamber provided with an inert atmosphere of nitrogen at constant temperature of 23 ± 2 °C, to maintain the final rancidity stage (Vinaixa et al., 2005).

2.5. E-nose analysis for determining spoilage in potato wedges

E-nose analysis of fried potato wedges were carried out at an interval of one day, for a storage period of 10 days. The e-nose system (Fig. 1) was equipped with an array of eight metal oxide gas sensors such as TGS 816, TGS 823, TGS 830, TGS 832, TGS 2600, TGS 2610, TGS 2611 and TGS 2626 (M/s, Figaro, USA) that respond to a wide range of VOCs (Bhattacharya et al., 2008; Michishita et al., 2010; Sapirstein et al., 2012). The response of the eight sensors of an e-nose for a wedge sample was determined from the $\Delta R/R$ value, which is the change in the resistance of metal oxide sensor due to the VOCs of potato wedges with respect to the base value (Bhattacharyya et al., 2007a). The base value of potato wedges is the resistance shown by the sensors due to VOCs of freshly (non-spoiled) batch of prepared wedges.

Optimization of the e-nose process parameters such as batch size of wedges, dimension of wedges and heating time were fixed through preliminary trials. Potato wedges (10 × 10 × 10 mm) of fifty grams were charged into a 100 ml glass vial and heated for 350 s at 50 °C. The headspace generation was carried out for 30 s to ensure adequate concentration of VOCs released by the wedges in the sample holder by blowing regulated flow of TOC grade air on the sample. Sampling time was kept constant for 50 s, where the sensor array was exposed to a constant flow of VOCs through pipelines inside the electronic nose. Purging operation was carried out for 300 s, where sensor heads were cleared with the blow of fresh air so that the sensors go back to their baseline values. The e-nose system was previously calibrated with a set of deliberately-rancid potato wedges as discussed earlier. The responses shown by the sensors due to the VOCs of these batches were selected as standard odor profiles of rancid potato wedges having different degrees of rancidity (Vinaixa et al., 2005).

2.6. Ranking of sensors using fuzzy logic

In order to screen the metal oxide gas sensors that are most sensitive towards VOCs generated from the spoiled wedges, ranking of the sensors was carried out by applying fuzzy logic analysis in accordance to the method of Chakraborty et al. (2011) and Ghosh and Bhattacharjee (in press), with little modifications. The signal responses ($\Delta R/R$) of 8 sensors were collected from 6 batches of