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Research Article

Evaluation of Smart Portable Device for Food Diagnostics: A Preliminary Study on Cape Hake Fillets (*M. capensis* and *M. paradoxus*)

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The new smartphone-based food diagnostic technologies offer significant advantages over traditional methods as they can be easily applied in various steps of the agrifood supply chain including household use and also in the food recovery field for charitable purposes, aimed at helping to reduce food waste. Further advantages include the low cost, the minimal equipment, and nonspecialized personnel required. This study evaluated the performance of two instrumental measurements of the sensors: an electronic nose (PEN3; WinMuster Airsense Analytics) and a smart portable device (FOODsniffer; ARS LAB US). The preliminary study was conducted on cape hake fillets. In order to test the performance of PEN3 and FOODsniffer, total volatile basic nitrogen (TVB-N) values were considered as the reference. Principal component analysis (PCA) and Pearson's correlation were performed in order to compare PEN3 with TVB-N, and for the FOODsniffer evaluation, a one-way ANOVA was carried out. A significant correlation was shown between PEN3, first component, and TVB-N ($r = 0.92$, $P = 0.01$). The ANOVA results also confirmed a good agreement between FOODsniffer, TVB-N ($F = 519.9$, $P = 0.01$), and PEN3 ($F = 143.17$, $P = 0.01$). Our simulation results confirmed good performance in both methods.

1. Introduction

Aquatic products (mainly fish, aquatic molluscs, and crustaceans) have a critical role in the food system, providing nearly 3 billion people with at least 15% of their animal protein intake [1]. In the EU, the 2011 per capita consumption of protein from fish and seafood was 6.6 grams per day, covering 7% of the total protein intake [2]. Meat and animal proteins (excluding fish and seafood) represented 52% of the total, while vegetal proteins (43.4 grams per capita per day) covered 41% [2].

The main commercial fish species consumed in the EU are tuna (2.58 kg/capita), cod (2.40 kg/capita), and salmon (2.09 kg/capita). The consumption of cod has increased by 9% since 2013 [2]. The FAO estimates that 30% of all the fish and seafood produced in the Europe was lost or wasted in 2009 [3]. There are several reasons for food waste in the fishing industry, including (i) losses in primary fish and seafood production due to discard rates of marine catches, (ii) a large proportion of purchased fish and seafood wasted by consumer households, and (iii) high distribution losses due to deterioration during fresh fish and seafood distribution [3].

The development of new technologies applicable at the different steps of the food supply chain can thus offer significant advantages not only for food business operators [4–6].

Electronic noses, which have already been tested considerably in various fields [7–15], provide a rapid and predictive response and represent a valid support compared to the traditional more time-consuming laboratory methods.

The electronic nose is a directly applicable method that requires minimum sample pretreatment and no specific consumables or reagents and is able to provide rapid analysis [5]. Furthermore, this approach is not invasive and consequently does not alter the product. For this reason, recently, the interest and application of E-nose in food industry, such as (i) quality control, (ii) process operations monitoring, (iii) shelf-life determination, and (iv) spoilage evaluation, have increased considerably [5, 16]. Based on the classical definition given by Gardner and Bartlett [16], the electronic nose is "an instrument which comprises an array of electronic chemical sensors with partial specificity and an appropriate pattern-recognition system, capable of recognising simple or complex odours" [17, 18]. The E-nose system consists of several components, such as specific hardware with sensors, electronics, pumps, air conditioner, flow controller, and dedicated software for hardware monitoring, data preprocessing, and statistical analysis. Such characteristics make the E-nose a device able to mimic the human olfactory perception and to provide a digital odour print of the sample, which can be processed by appropriate statistical software. An E-nose gas sensor array shows sensitivity toward certain classes of compounds (volatile organic compounds (VOCs)) produced by the main spoilage organisms. The alteration in the pattern of VOCs is indicative of the degradation processes occurring in the products [5].

Smartphone sensors, on the contrary, could be easily used by unskilled personnel such as volunteers in charity organizations and final consumers [19].

The emerging need to reduce food waste but also to ensure food security to people in food poverty has led to the development of new technologies in the food business, aimed not only at preventing food losses and waste in the primary production, processing, distribution, retail, and food services but also at improving the quality of products recovered by charities [20–23].

In the third sector such as food banks, where the work is done by volunteers without specific training in the food field, the objective is to provide valid support in order to guarantee a safe second life to the food recovered [24].

Fishery and aquaculture products, together with other animal and vegetable proteins, are also an important source of protein and thus an essential component of a healthy diet. For this reason, these products are also essential in the diet of people in food poverty [12].

The aim of this study was to explore whether an electronic nose [25] (PEN3) could be used as a fast screening method for food business operators and as a support for official laboratory methods (TVB-N). In addition, the FOODsniffer (ARS LAB US) [26] was evaluated for its potential use as an easy-to-use sensory tool both at the domestic level and for volunteers working for charities in order to evaluate the acceptability of the products for consumption by the needy.

The two portable sensing devices were evaluated on cape hake fillets taking the measured TVB-N values into consideration as the reference (gold standard). In fact, the European Commission defined the TVB-N as the reference method and in the Decision of 8 March 1995 fixed the TVB-N limit values for three categories of fishery products [27]. In this work, the cape hake fillets were assessed in terms of their TVB-N values and were measured with PEN3 whenever the FOODsniffer revealed variations.

2. Materials and Methods

2.1. Sample Collection and Experimental Design. Experiments were performed at the Food Inspection Laboratory of the Department of Health Animal Science and Food Safety in Milan (Italy). One batch of cape hake (*Merluccius capensis/Merluccius paradoxus*) was collected. The batch contained fish caught in the Southeast Atlantic Ocean (FAO area 47), produced and frozen by a company based in Walvis Bay, Namibia (company specializing in the catching and marketing of frozen seafood products in the international market), and imported by an Italian company that distributes frozen food to wholesalers, industry, and mass caterers.

The batch contained fish fillets that were already skinless and portioned into individual fillets with a medium weight of 90–110 g (thawed weight 85–100 g).

Before being analysed, each fillet was washed with sterile, distilled, and deionized water in order to remove the glazing, and the fillets were then left to thaw overnight under a controlled temperature (0–4°C). In order to reproduce the use at the domestic level, the defrosting procedures were carried out as provided in the product's specifications (Table 1).

On the first day of storage (day 1), 8 fillets were tested with all three methods: FOODsniffer, PEN3, and TVB-N. Subsequently, for six consecutive days (from day 2 to day 7), eight fillets were measured with the FOODsniffer, and when the FOODsniffer detected variations, the fillets were assessed in terms of their TVB-N and were measured with PEN3 to confirm the results. In this study, the variations detected by the FOODsniffer occurred on storage days 3 and 7. Figure 1 summarizes the experimental design.

2.2. FOODsniffer. FOODsniffer (ARS LAB US), created by scientists and researchers of the Kaunas University of Technology, in cooperation with the company ARS LAB, is a new and fast device used to assess the freshness of food of animal origin and specifically patented for the meat matrix [26, 28]. FOODsniffer was designed to detect whether a product (i) is fresh, (ii) can be safely eaten after cooking, or (iii) is spoiled.

FOODsniffer rapidly estimates the quality and safety of the raw material correlating them to the levels of volatile organic compounds present in the tested matrix, through a gas sensor system including at least two metal-oxide semiconductor sensors configured to measure NH_3 and CH values. The technology is based on the detection of low concentrations of volatile compounds that are associated with deterioration.

The device is composed of a metal-oxide sensor system adapted to respond to the speed of changes in the concentration of volatile compounds, a processor designed to receive and process signals incoming from the sensor system

Table 1: Product specifications.

Shelf life	
Production date/ freezing date	7 July 2015
Best before end	7 July 2017
Conservation methods	
−18°C	18 months
−12°C	1 month
−6°C	1 week
0–4°C	3 days
Preparation method	Allow the product to thaw at room temperature or at refrigeration temperature; once defrosted, the product must not be frozen again and must be consumed within 24 hours

and to turn them into a sequence of electrical signals on the basis of variation in the concentration of volatile compounds, and a Bluetooth device which, according to the algorithms in synchronization with the cloud, provides the user result to mobile devices (tablets or smartphones) [26].

The protocol used for the sample analysis was drawn up according to the FOODsniffer user manual.

FOODsniffer is controlled through a dedicated smartphone app which can be operated by nonspecialized personnel. It provides information on the level of freshness of raw materials: satisfactory (fresh), acceptable (to be consumed after cooking), and unsatisfactory (spoiled). FOODsniffer results are qualitative outputs also associated with colours: green (fresh), orange (to be consumed after cooking), and red (spoiled). FOODsniffer was tested in order to evaluate its potential use as an easy-to-use sensory tool both at the domestic level and for charity volunteers to assess whether a food product is fit for consumption.

2.3. Electronic Nose System. The Portable Electronic Nose PEN3 (WinMuster Airsense Analytics, Schwerin, Germany) was used in this study. It has 10 metal-oxide sensors, and Table 2 lists all the sensors used and their applications. Each sensor is sensitive to a specific group of compounds, and its response is expressed as resistivity (ohm) [25].

The instrument (PEN3) consists of three units: (i) a sampling and washing unit, (ii) a chamber, consisting of an electrochemical gas sensor array, and (iii) a pattern-recognition system. During the analysis, eight fillets were kept at a constant temperature in a thermostatic water bath at 18 ± 2°C to prevent the effects of temperature fluctuation and in order to create the correct headspace. All the fillets were cut into pieces of equal weight (approximately 10 g), and each one was placed in a small sealed glass vial with a capacity of 100 ml. Each analysis was repeated twice. The sealed glass vials containing the fillets were connected to the PEN3 with a probe. The headspace gas in that vials was pumped from the sampler through the sensor array at 400 ml/min. Before and after each measurement, the sensors were cleaned by air using carbon filters. Sensor response data were recorded every second. The analysis protocol was defined by setting up the E-nose parameters (flow rate, duration of measurement, etc.) according to the manufacturer's instructions. The analysis of each fillet lasted 640 seconds. The set of signals derived from the electronic nose during the analysis takes the form of a pattern. The pattern data were analysed using WinMuster (version 1.6.2., 17 May 2014, copyright Airsense Analytics GmbH).

2.4. Chemical Analysis. Eight fillets were prepared for the analysis of TVB-N levels according to Regulation (EC) no. 2074/2005 [29].

In brief, 10 g (±0.1) of the fillet was blended with 90 ml of perchloric acid 6%. Subsequently, 50 ml of the filtrate was introduced into an apparatus for steam distillation, and to check the level of alkalinisation of the extract, several drops of phenolphthalein were added. Before extraction and steam distillation, a few drops of silicone antifoaming agent and 6.5 ml of sodium hydroxide solution were added. The steam distillation was regulated so that around 100 ml of the distillate could be produced in 10 minutes. The distillation outflow tube was submerged in a receiver with 100 ml of boric acid solution, to which three to five drops of the indicator solution were added. After distillation, the volatile bases contained in the receiver solution were determined by titration with a standard hydrochloric solution. Each analysis was repeated twice as required by Regulation (EC) no. 2074/2005. The method applied is correct if the difference between the duplicates is not greater than 2 mg/100 g. For the blind test, 50 ml of perchloric acid solution was used instead of the extract.

Finally, the TVB-N concentration was calculated using the following equation:

$$\mathrm{TVB-N}\left(\frac{\text{expressed in mg}}{\text{100 g of sample}}\right) = \frac{\left(V_1\,(\text{vol. of 0.01 HCl solution in ml for sample}) - V_0\,(\text{vol. of 0.01 HCl solution in ml for sample})\right) \times 0.14 \times 2 \times 100}{M\,(\text{weight of the sample in g})}. \quad (1)$$

2.5. Statistical Analysis. The data obtained from TVB-N values (gold standard), PEN3 (E-nose), and FOODsniffer were subjected to statistical analyses. The aim was to determine whether the three analysis methods could be considered as being equally reliable in evaluating the freshness of the fish. For each sample (cape hake fillets),

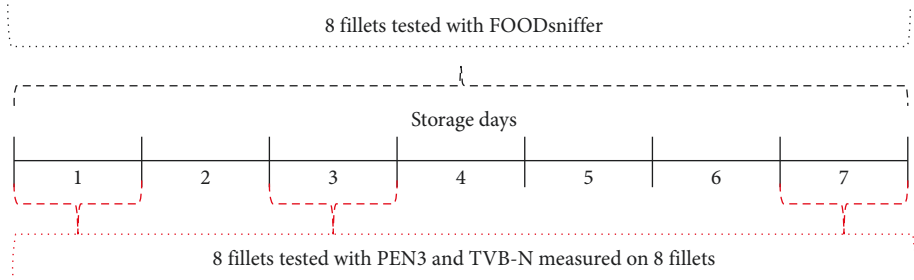

Figure 1: Experimental design.

Table 2: Sensors and their applications in PEN3.

Number in the array	Sensor name		General description	Reference
R1	W1C	Aromatic	Aromatic compounds	Toluene, 10 ppm
R2	W5S	Broad-range	Very sensitive, broad-range sensitivity, reacts on nitrogen oxides and ozone, very sensitive to the negative signal	NO_2, 1 ppm
R3	W3C	Aromatic	Ammonia used as a sensor for aromatic compounds	Benzene, 10 ppm
R4	W6S	Hydrogen	Mainly hydrogen, selectively breath gases	H_2, 100 ppb
R5	W5C	Arom-aliph	Alkanes, aromatic compounds, less polar compounds	Propane, 1 ppm
R6	W1S	Broad-methane	Sensitive to methane (environment) ca. 10 ppm, broad range similar to no. 8	CH_4, 100 ppm
R7	W1W	Sulphur-organic	Reacts on sulphur compounds (H_2S 0.1 ppm), otherwise sensitive to many terpenes and sulphur organic compounds, which are important for smell (limonene and pyrazine)	H_2S, 1 ppm
R8	W2S	Broad-alcohol	Detects alcohols, partially aromatic compounds, broad range	CO, 100 ppm
R9	W2W	Sulphur-chlor	Aromatic compounds, sulphur organic compounds	H_2S, 1 ppm
R10	W3S	Methane-aliph	Reacts on high concentrations >100 ppm, sometimes very selective (methane)	CH_4, 10 ppm

data coming from each sensor of the electronic nose (PEN3) were analysed taking 10 seconds out of 400 seconds of the total analysis, according to the stability of the sensor responses. These values were then aggregated with the average to obtain a single measure. A principal component analysis (PCA) was also performed to extract a single indicator of freshness to be compared with TVB-N. To verify the FOODsniffer evaluation, a one-way ANOVA was carried out. All statistical procedures were carried out using IBM SPSS Statistics 24 (SPSS Inc., Chicago, IL, USA).

3. Results and Discussion

3.1. Chemical Results. Figure 2 shows the plot of TVB-N values which presents a linear behaviour over time. After being defrosted, the TVB-N values were found to increase in all fillets during storage until they reached a maximum value after 7 days of storage, corresponding to the days in which fishes are judged unfit for human consumption according to the limits provided by Regulation (CE) no. 2074/2005. Regulation (CE) no. 2074/2005 defines the limit values in relation to species. For species belonging to the Merlucciidae family, the expected limit value is 35 mg/100 g flesh. This result is in line with the product's specifications, which recommends a storage not exceeding three days at a temperature between 0 and 4°C and consumption within 24 hours after thawing.

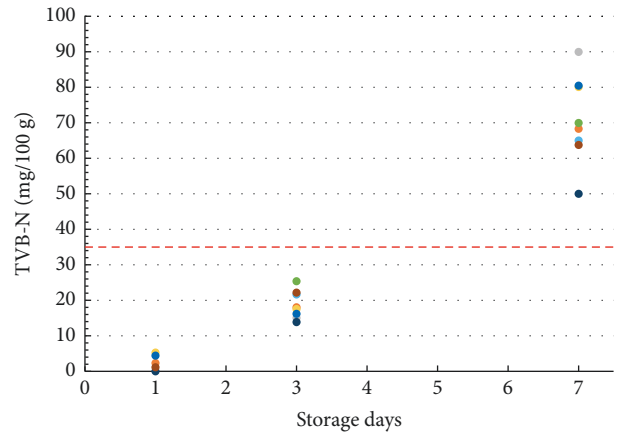

Figure 2: Measure of TVB-N on the fillets.

3.2. PEN3 (E-nose) Results. The effect of the number of storage days on the array response was evaluated. As a first step, radar plots were obtained to observe whether pattern differences were developed between samples analysed in different storage days. Figure 3 shows the change of the signal generated by the sensor array to different storage days (T1, T3, and T7). As can be seen, the E-nose provided a very well-differentiated odour print useful to discriminate between samples. Indeed, the radar plots show a clear pattern

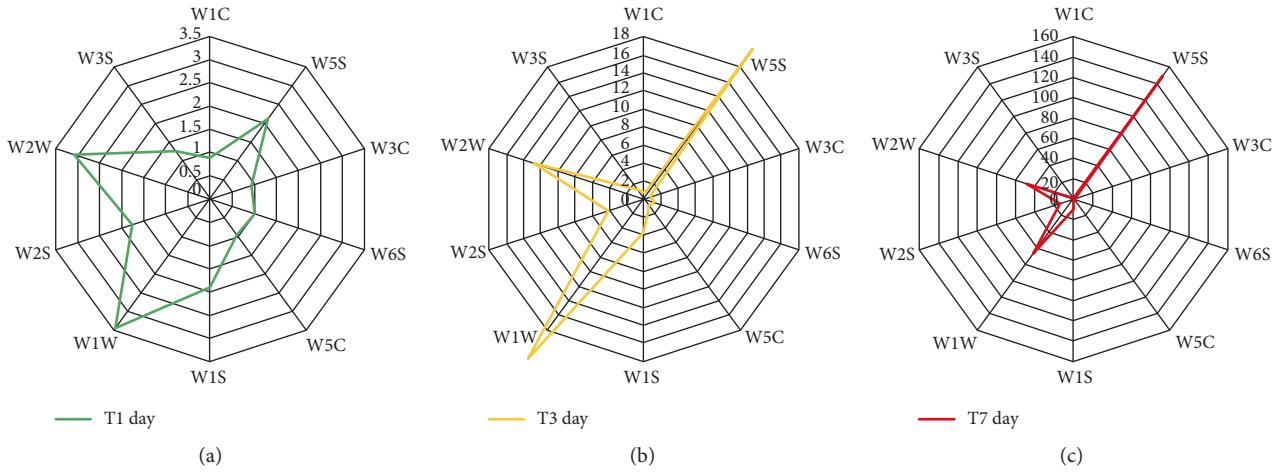

Figure 3: Radar plot extracted from sensor array responses at days 1 (a), 3 (b), and 7 (c) (expressed in ohm).

variation among T1, T3, and T7 days of storage. As mentioned by Rahman et al. [30] and several other authors, an E-nose is useful in many industrial processes, such as food safety. In fact, in the food industry, an E-nose is one of the best methods for (i) agrifood quality monitoring, (ii) freshness and shelf-life evaluation, and (iii) investigating and differentiating between different types of products [30]. As highlighted by Haddi et al. [31], the different sensor responses could be due to changes in the concentration of the volatile organic compounds emanating from each type of food products [32]. The significant differences found among the samples analysed on different days are explained by the physical, chemical, biochemical, and microbiological changes typical of the fish spoilage processes. The PEN3 sensitivity allows us to recognise the variation of VOCs emitted by the samples without giving details of specific compounds such as biogenic amines. To quantify the presence of amine compounds, the most common method would be the high-performance liquid chromatography (HPLC) [33], but the aim of this paper was to evaluate the performance of the E-nose and FOODsniffer.

3.3. Analysis between PEN3 (E-nose) and TVB-N. The measures obtained by the different PEN3 (E-nose) sensors were strongly correlated; thus, from the PCA, we had a very good result extracting a single dimension, with 93% of the variance explained, which can be considered as a single indicator of freshness for the PEN3 (E-nose). Comparing PEN3 (E-nose), the first component, and the chemical analysis results (TVB-N), the Pearson correlation between these methods was evaluated, obtaining a strong and significant correlation ($r = 0.92$, P value $= 0.01$), thus confirming that the two measures are reliable alternatives. Figure 4 shows the experimental results on a two-dimensional plane, which identifies each observation obtained with FOODsniffer. It shows that three distinct groups of odours, which correspond to satisfactory, acceptable, and unsatisfactory levels, respectively, are well distinguished, in line with the results found by PEN3 (E-nose) and by TVB-N.

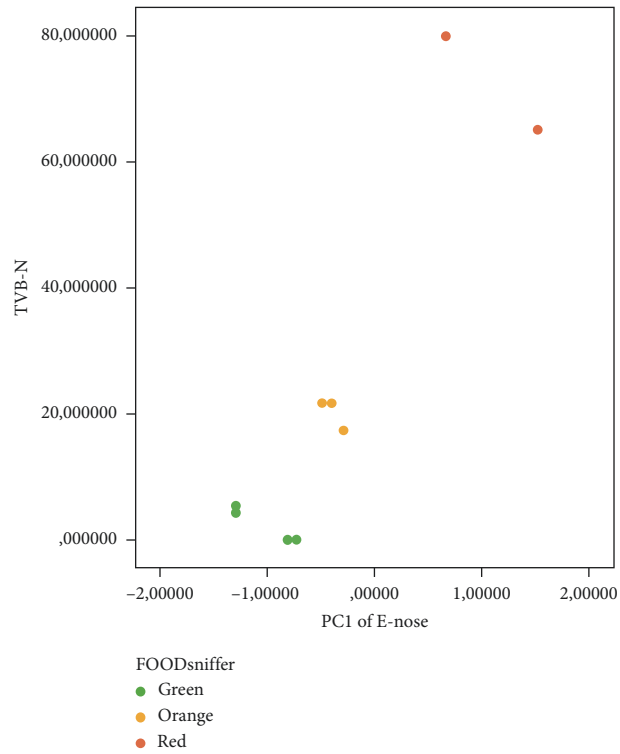

Figure 4: PCA.

Analysing the link between the individual sensors of PEN3 (E-nose) and the TVB-N results, a strong correlation can be seen (min = 0.65 in W3S and max = 0.98 in W1W) (Table 3).

Some of the sensors (W1C, W3C, and W5C) show significantly negative correlation coefficient values, thus indicating that as the values of TVB-N increase, the sensor signals (W1C, W3C, and W5C) decrease.

3.4. FOODsniffer (ARS LAB US) Results. FOODsniffer provides a categorical evaluation of fish freshness: green, orange, and red alerts, which correspond to satisfactory,

Table 3: Correlations between the PEN3 sensors and TVB-N values.

		R1 (W1C)	R2 (W5S)	R3 (W3C)	R4 (W6S)	R5 (W5C)	R6 (W1S)	R7 (W1W)	R8 (W2S)	R9 (W2W)	R10 (W3S)
TVB-N	Pearson's correlation	**−0.940****	0.911**	**−0.934****	0.769**	**−0.903****	0.884**	0.983**	0.887**	0.964**	0.648**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001

**Correlation is significant at the 0.01 level (2-tailed).

Table 4: Descriptive statistics.

	FOODsniffer	Mean	Std. error	95% confidence interval	
				Lower bound	Upper bound
TVB-N	Green	1.188	0.782	−0.662	3.037
	Orange	20.648	0.689	19.018	22.277
	Red	68.813	2.430	63.066	74.559
R1 (W1C)	Green	0.878	0.013	0.846	0.910
	Orange	0.673	0.035	0.590	0.756
	Red	0.242	0.017	0.202	0.282
R2 (W5S)	Green	2.157	0.139	1.828	2.487
	Orange	20.394	0.833	18.425	22.362
	Red	147.926	11.079	121.729	174.123
R3 (W3C)	Green	0.928	0.007	0.911	0.946
	Orange	0.832	0.015	0.796	0.868
	Red	0.478	0.023	0.424	0.532
R4 (W6S)	Green	1.029	0.056	0.897	1.160
	Orange	1.131	0.011	1.106	1.155
	Red	1.326	0.011	1.299	1.353
R5 (W5C)	Green	0.970	0.012	0.942	0.997
	Orange	0.916	0.006	0.903	0.930
	Red	0.661	0.023	0.608	0.715
R6 (W1S)	Green	1.896	0.175	1.482	2.309
	Orange	3.544	0.152	3.185	3.902
	Red	10.141	0.787	8.279	12.003
R7 (W1W)	Green	3.428	0.178	3.007	3.849
	Orange	21.763	0.269	21.128	22.398
	Red	66.042	0.810	64.127	67.958
R8 (W2S)	Green	1.746	0.124	1.452	2.039
	Orange	4.078	0.270	3.439	4.718
	Red	13.328	1.092	10.746	15.911
R9 (W2W)	Green	3.095	0.140	2.763	3.427
	Orange	13.021	0.242	12.448	13.594
	Red	47.899	1.526	44.290	51.508
R10 (W3S)	Green	1.274	0.053	1.149	1.399
	Orange	1.312	0.012	1.283	1.340
	Red	1.546	0.047	1.435	1.658

acceptable, and unsatisfactory levels of freshness, respectively. The qualitative nature of this measure does not enable the correlation between its results and those obtained by PEN3 (E-nose) or TVB-N to be evaluated. To overcome this, for the FOODsniffer, we performed a one-way analysis of variance (ANOVA).

The ANOVA results confirmed a good agreement between FOODsniffer, TVB-N ($F = 519.9$, $P = 0.01$), and PEN3 (E-nose) first component factor ($F = 143.17$, $P = 0.01$).

As reported in Table 4, the lower and upper limits enable a value range to be defined for TVB-N and for individual sensors of PEN3 (E-nose), in relation to the change in classification of the FOODsniffer.

4. Conclusions

In this preliminary study, FOODsniffer and PEN3 were evaluated on the basis of their predictive performance in the food diagnostics field.

These results confirmed that a smart portable device associated with good prevention practices could potentially be useful to reduce food waste in the agrifood supply chain and especially for household use and also in the food recovery field for charitable purposes. FOODsniffer proved to be a valid and easy tool to use for nonspecialized personnel such as charity volunteers. However, further laboratory tests associated with studies to test the practical feasibility of using food sniffers by such volunteers are necessary.

As already highlighted in other studies, PEN3 confirmed its excellent performance in supporting traditional laboratory methods and proved to be a useful fast screening method for food business operators.

The development of new technologies is crucial in order for Europe to take effective action against food waste and reduce food poverty for the benefit of social, economic, and environmental sustainability.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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