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Using an electronic nose for determining the spoilage of vacuum-packaged beef

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Abstract

The use of an electronic nose in the quantitative determination of the degree of spoilage of vacuum-packaged beef was evaluated. Beef from four different slaughterhouses was sliced, vacuum-packaged and stored at 4°C for 8 weeks. Samples were withdrawn for bacterial (aerobic bacteria, lactic acid bacteria, *Brochothrix thermosphacta*, *Pseudomonas* and *Enterobacteriaceae*) and sensorial analyses and analysis of the volatile compounds during the storage period. A trained panel was used for the sensorial evaluations. The volatile compounds were analysed using an electronic nose containing a sensory array composed of 10 metal oxide semiconductor field-effect transistors, four Tagushi type sensors and one CO_2-sensitive sensor. Four of the 15 sensors were excluded due to lack of response or overloading. Partial least-squares regression was used to define the mathematical relationships between the degree of spoilage of vacuum-packaged beef, as determined by the sensory panel, and the signal magnitudes of the sensors of the electronic nose. The mathematical models were validated after 6 months using a new set of samples. The stability of the sensors during this period was examined and it was shown that the sensitivity of five of the 11 sensors used had changed. Using the six remaining sensors, the signal patterns obtained from the meat from the different slaughterhouses did not change over a period of 6 months. It was shown that the degree of spoilage, as calculated using a model based on two Tagushi sensors, correlated well with the degree of spoilage determined by the sensory panel ($r^2 = 0.94$).

Keywords: Electronic nose; Spoilage; Vacuum-packaged beef

1. Introduction

The shelf-life of meat may be defined as the time elapsing between production and the time of spoilage. The spoilage of meat is a sensorial quality and may consist of off-odours and off-flavours or discoloration (Egan, 1983; Dainty and Mackey, 1992; Borch et al., 1996). For vacuum-packaged beef, off-odours resulting from bacterial activity determine the shelf-life. The odour that is produced during the spoilage process is characteristic and has been described as dairy, sour and putrid (Edwards et al., 1985; Borch et al., 1996). Some odours may persist, such as the putrid odour, while the dairy and sour odours are often of a less persistent character. Both

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the prediction of product shelf-life during the development of new products and the determination of the remaining shelf-life of meat during storage are desirable. For these purposes, a method for quantifying spoilage is needed. The direct quantification of spoilage may be performed by a sensory panel. However, this is not a practicable method in routine analyses.

The method currently used for determining the status of meat, with respect to spoilage, is analysis of the total count of bacteria. An obvious drawback with a bacteriological method is the incubation period of 1–2 days that is required for colony formation and, additionally, the lack of correlation between the degree of spoilage and the total count of bacteria (Gill, 1983; Borch et al., 1996). Instead, the growth of specific spoilage bacteria can be analysed. However, no specific spoilage bacteria could be identified in the case of vacuum-packaged beef (Borch et al., 1996). Similar conclusions have been drawn with respect to the spoilage of vacuum-packaged cold-smoked salmon (Truelstrup Hansen et al., 1995), while *Photobacterium phosphoreum* and *Shewanella putrefaciens* have been put forward as the specific spoilage bacteria of vacuum-packaged fish from temperate marine waters (Dalgaard, 1995; Gram and Huss, 1996).

Chemical compounds may be used as spoilage indicators. In previous studies, acetate, ethanol, D-lactic acid, putrescine and cadaverine have been put forward as possible spoilage indicators in vacuum-packaged meat and meat products (Edwards et al., 1985; de Pablo et al., 1989; Borch and Agerhem, 1992). The use of chemical compounds in meat as spoilage indicators involves laborious sampling and extraction procedures, which may be avoided in the analysis of volatile compounds from meat. Furthermore, in the case of off-odour spoilage, the relevant compounds are expected to be found among the volatile rather than the nonvolatile compounds. Gas chromatography combined with mass spectrometry (GCMS), was used to identify the volatile compounds associated with the spoilage of vacuum-packaged pork (Edwards and Dainty, 1987) and beef packaged in a vacuum or a modified atmosphere (Jackson et al., 1992).

The analysis of volatile compounds may also be performed using an electronic nose. This instrument consists of an array of non-specific electronic chemical sensors combined with a pattern recognition routine (Gardner and Bartlett, 1994). Similarly to the human nose, the electronic nose recognises odour patterns, rather than specific compounds (Pelosi, 1989). The potential of electronic noses within the food industry has been demonstrated in various areas, e.g. classifying the microbial quality of grains and estimating the quality of ground meat (Winquist et al., 1993; Jonsson et al., 1997). The principal application of the electronic nose has been in the field of classification, i.e. qualitative analyses.

2. Material and methods

The purpose of the present study was to evaluate whether an electronic nose could be used in the quantitative determination of the degree of spoilage of vacuum-packaged beef. Partial least-squares regression (PLS) was used to define mathematical relationships between the degree of spoilage of vacuum-packaged beef, as determined by a sensory panel, and the signal magnitudes of the sensors of an electronic nose.

2.1. Meat packaging and storage

Freshly deboned beef strip loins were vacuum-packaged at four Swedish slaughterhouses (A–D) and transported to the laboratory at chill temperature. The loins were used in the development of mathematical models which described the relationships between the degree of spoilage, as determined by a sensory panel, and the composition of the volatile compounds, as determined using an electronic nose, of vacuum-packaged beef strip loins. Meat from two of the slaughterhouses (A and D) was used for the validation of the models.

The meat was cut into 1-cm slices, and slices originating from the same slaughterhouse were rubbed together in order to spread the naturally acquired contamination evenly. This procedure was performed in a laminar flow cabinet using sterile tools. Subsequently, the pieces were packed in vacuum pouches of 20×30 cm (PA/PE-E 20/70,5, Schur-pack Multiflex, Flensburg, Germany) with O_2 and CO_2 transmission rates of 4 and 14 cm^3 m^{-2} 24 h^{-1} atm^{-1}, respectively, at 230°C and 0% RH. The pouches were evacuated and heat-sealed and the vacuum-packaged meat was stored for up to 8 weeks at 4°C. Samples were withdrawn for bacterial, sensorial and volatile compound analyses after 2, 5 and 8 weeks, when used for developing mathematical models, and after 2, 4 and 6 weeks of storage, when validating mathematical models. Bacterial and sensorial analyses were made immediately after removing the samples from 4°C, while the samples for the analysis of volatile compounds were kept at −80°C until the analysis was performed.

2.2. Enumeration of bacteria

Replicates of meat samples were analysed for aerobic bacteria (surface growth at 25°C for 5 days on All Purpose Tween (APT) agar, Becton-Dickinson, Cockeysville, USA), the number of lactic acid bacteria (growth at 25°C for 5 days on Man, Rogosa and Sharpe (MRS) agar, Oxoid, Unipath, Basingstoke, Hampshire, UK), the number of *Brochothrix thermosphacta* (growth at 25°C for 2 days on streptomycin sulphate–thallium acetate (STA) agar), the number of *Pseudomonas* (growth at 25°C for 2 days on cetrimide fucidin cephaloridine (CFC) agar) and the number of *Enterobacteriaceae* (growth at 37°C for 1 day on Violet Red Bile Glucose (VRBG) agar, Oxoid). The number of oxidase-positive bacteria were estimated on the CFC agar and the number of oxidase-negative bacteria were estimated on the STA agar.

2.3. Sensory analyses

A trained test-panel of 13 persons performed the sensory analyses. The pieces of meat were assessed for spoilage odour, acidic odour, sulphurous odour and the overall impression. The spoilage odour was described as old dish-cloth and rotten, while the sulphurous odour was defined as rotten eggs. The degrees of the different odours were determined as scores on a scale of 1 to 9, where 1 is no odour and 9 is a very strong odour. The overall impression was determined using a scale of 1 to 9, where 1 is dislike very much and 9 is like very much. Each member of the panel assessed two pieces of meat from each occasion of sampling.

2.4. Analysis of volatile compounds

The volatile compounds of the meat were analysed using an electronic nose (Laboratory of Applied Physics, University of Linköping, Sweden; Eklöv et al., 1998) containing a sensor array composed of ten metal oxide semiconductor field-effect transistors (MOSFET; University of Linköping), sensitive to, for instance, hydrogen ammonia and alcohols (Sundgren et al., 1990), four different SnO_2-based Tagushi sensors (Figaro Engineering, Japan) and one CO_2-sensitive sensor (Table 1). Samples of meat stored at −80°C were thawed at 4°C for 15–20 h before being equilibrated in closed Erlenmeyer flasks (250 ml) at 25°C for 1.5 h. The measurement set-up has been described previously (Eklöv et al., 1998). The sensory array was, for a period of 45 s, subjected to the volatiles accumulated in one Erlenmeyer flask, using an air-flow of 100 ml/min. Between each sample, the sensor signals were stabilised to the background level in the presence of air for 4 min. Three or five samples of meat from each slaughterhouse were analysed on each occasion of sampling. Each sample was analysed six times by the electronic nose.

2.5. Identification of the sensors describing the variation obtained in the sensorial traits and the development of mathematical models

The relationships between sensorial traits (*Y*-variables) and the magnitudes of the sensor signals of the electronic nose (*x*-variables), were determined using multivariate analysis (PLS, Unscramble program,

Table 1
Sensors of the electronic nose

Sensor	Type of sensor[a]	Operating temperature (°C)
S1	MOSFET Pd-65	140
S2	MOSFET Pd-350	140
S3	MOSFET Ir-90	140
S4	MOSFET Pt-50	140
S5	MOSFET Pt-90/Pd-10	140
S6	MOSFET Pd-65	175
S7	MOSFET Pd-350	175
S8	MOSFET Ir-90	175
S9	MOSFET Pt-50	175
S10	MOSFET Pt-90/Pd-10	175
S11	TGS 800	400
S12	TGS 813	400
S13	TGS 825	400
S14	TGS 880	400
S15	CO_2	

[a]MOSFET, metal oxide semiconductor field-effect transistor; Pd, Pt and Ir, gate metals of the MOSFET sensors; TGS, Tagushi sensor.

CAMO, Norway) and Pearson's correlation (SYSTAT, SYSTAT, Evanstone, IL, USA). The mean values of the sensorial traits and the sensor signals, the latter also standardised by a factor of 1/(weight of meat (g))$^{1/2}$, were used in the evaluations. The PLS was performed using cross-validation and with Y- and x-variables weighted by a factor of 1/(standard deviation). The weighted regression coefficients (b_w) and the r^2 values obtained using PLS and Pearson's correlation, respectively, were used to identify the sensors that best registered the variation recorded in the sensorial traits.

Mathematical models of the type

$$Y = b_0 + b_1 \times S_1 + b_2 \times S_2 + \ldots + b_n \times S_n$$

were developed, where Y is the degree of spoilage, b_x is the unweighted regression coefficient obtained from PLS, and S_x is the standardised (by 1/(weight of meat (g))$^{1/2}$) sensor signal magnitude of the electronic nose.

2.6. Validation of the mathematical models

The purpose of validation was to identify the mathematical model(s) that would best be able to predict the degree of spoilage. Predicted values of spoilage (Y_{pred}) were calculated using the different mathematical models and data from the analysis of volatile compounds. The calculated values were compared with corresponding observed spoilage (Y_{obs}), as measured by the sensory panel. The b_0, b_1 and r^2 values from the linear regressions of the observed and predicted degree of spoilage

$$Y_{pred} = Y_{obs} \times b_1 + b_0$$

and the RMSEP (root mean square error of prediction) values

$$\sqrt{\frac{\sum_{i=1}^{n} (Y_{i,pred} - Y_{i,obs})^2}{n}}$$

were used to evaluate the validity of the different models.

3. Results

3.1. Bacterial analyses

The bacterial growth on the meat used in the development of the mathematical models is presented in Fig. 1. Lactic acid bacteria dominated the microflora in all four series during the latter part of the storage period (Fig. 1a,b). The aerobic counts reached a maximum number of approximately 10^7 cfu cm^{-2} after 3–5 weeks (Fig. 1a). This number was reached earlier on meat collected from slaughterhouses B and D, compared to meat from slaughterhouses A and C.

Enterobacteriaceae were found in all series, but the maximum numbers differed markedly on meat from the different slaughterhouses (Fig. 1c). For meat from slaughterhouses C and D, the maximum number was just below 10^7 cfu cm^{-2} and was reached after 5 weeks of storage, while on meat from slaughterhouse B the maximum number of *Enterobacteriaceae* of 10^7 cfu cm^{-2} was reached after 3 weeks of storage. On meat from A, the numbers of *Enterobacteriaceae* varied between 0 and 10^3 cfu cm^{-2} during the entire storage period. The numbers of *Enterobacteriaceae* varied between replicates, giving a high standard deviation. *Pseudomonas* occurred sporadically at low numbers, except on meat from slaughterhouse B, where the numbers were approximately 10^2 cfu cm^{-2} during the whole storage period (data not shown). *Brochothrix thermosphacta* also occurred sporadically but never exceeded 10^2 cfu cm^{-2} (data not shown).

The growth of aerobic bacteria on the meat used for the validation of the models was similar to that on the meat used for the development of the models (Table 2).

3.2. Sensory analyses

The scores for the overall impression of the meat used for the development of the mathematical models decreased with storage time (Fig. 2a). Differences in the degrees of spoilage, acidic and sulphurous odours during the storage time were obtained (Fig. 2b–d). Meat from slaughterhouse B generally had the worst odour, while meat from slaughterhouses A and C seemed to have the best odour, according to the panel. For meat used in the valida-

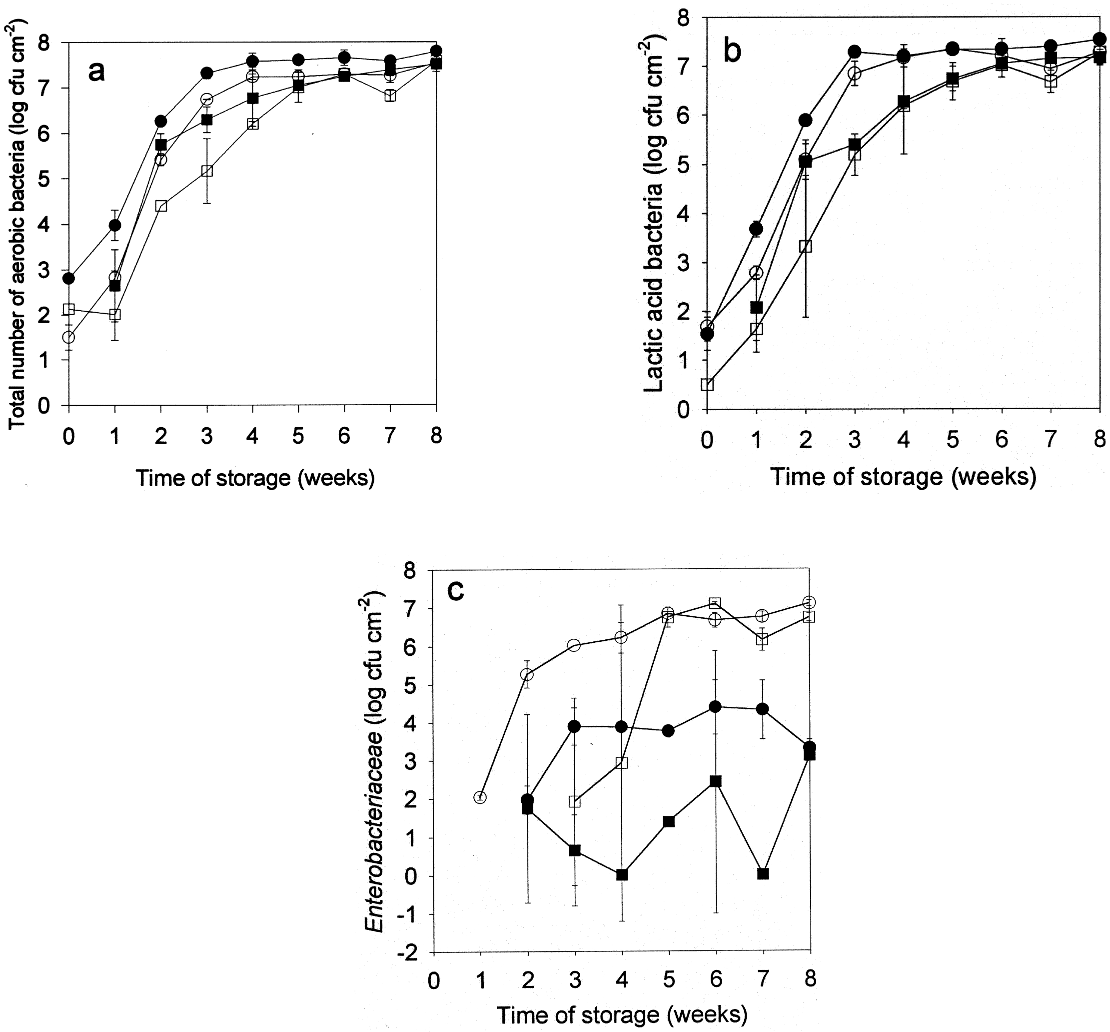

Fig. 1. Changes in the count of (a) aerobic bacteria, (b) lactic acid bacteria and (c) *Enterobacteriaceae* on vacuum-packaged beef strip loin used for the development of mathematical models. Meat was collected from four different slaughterhouses: (■) A, (●) B, (□) C and (○) D, and stored at 4°C. The error bars indicate standard deviations (S.D.), $n=2$.

Table 2
Counts of aerobic bacteria on vacuum-packaged beef obtained from slaughterhouses A and D, stored at 4°C: the meat was used for validating the mathematical models

Time of storage (weeks)	Aerobic bacteria (log cfu cm^{-2})[a]	
	A	D
2	5.1±0.1	4.4±0.0
4	6.8±0.1	5.8+0.0
6	7.5±0.1	6.8±0.2

[a]The values are means±S.D, $n=2$.

tion study, the development of odours was slow on meat from slaughterhouse D. Thus, the score for the overall impression was still high after 6 weeks of storage (Table 3). After this period of storage, the meat from slaughterhouse A had an obvious sulphurous and spoilage odour.

3.3. Analysis of volatile compounds

Three of the 15 sensors (MOSFETS S3, S6 and S8; Table 1) of the electronic nose were excluded due to limited response, or lack of response, when

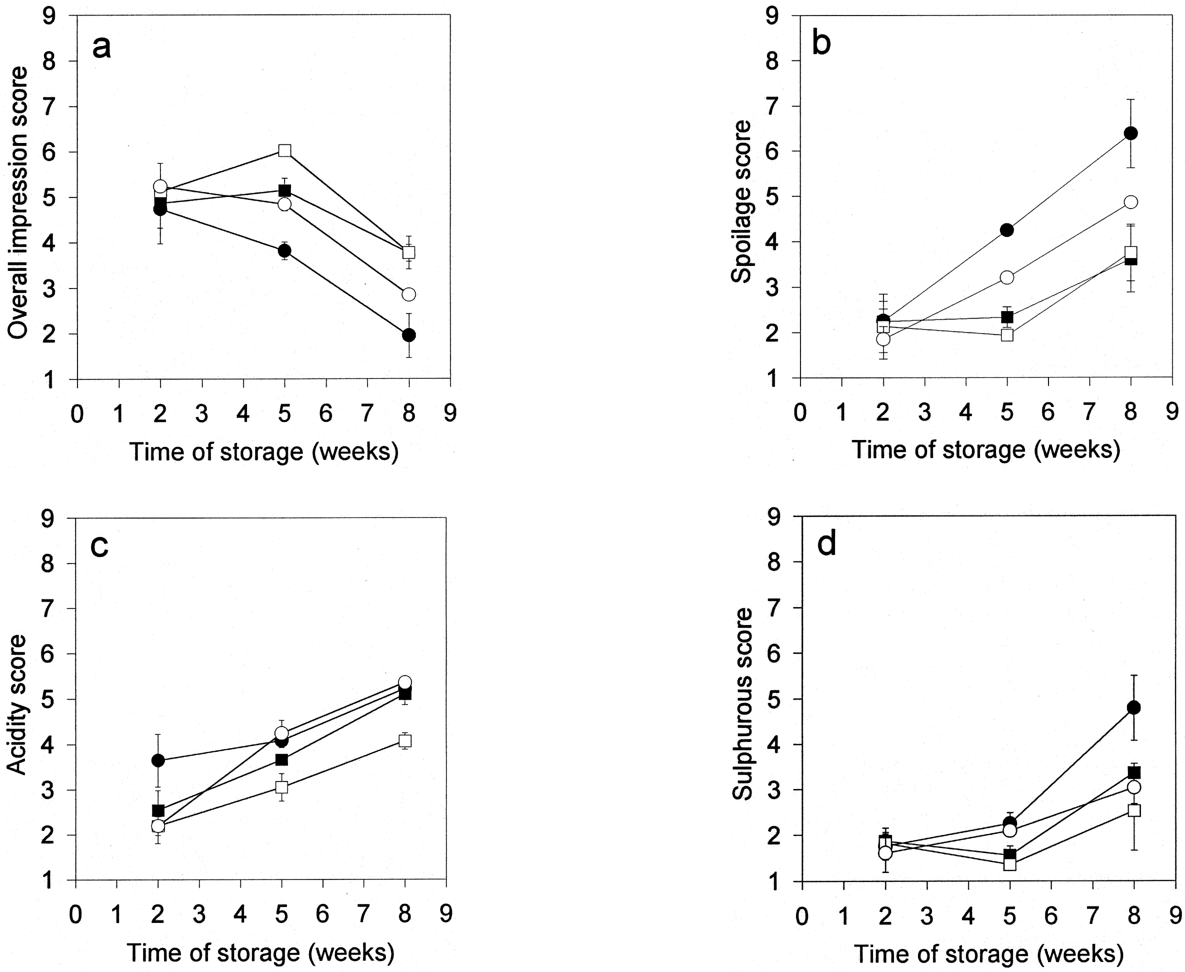

Fig. 2. Odour scores of vacuum-packaged beef strip loins used in developing the mathematical models, as measured by a sensory panel. (a) Overall impression, (b) spoilage odour, (c) acidity and (d) sulphurous odour. Meat was collected from four different slaughterhouses: (■) A, (●) B, (□) C and (○) D, and stored at 4°C. The error bars indicate S.D., $n=2$.

Table 3
Odour scores of vacuum-packaged beef, as measured by a sensory panel, used for validating the mathematical models: the meat was collected from slaughterhouses A and D and stored at 4°C

Time of storage (weeks)	Odour score[a]							
	Spoilage		Acidic		Sulphurous		Overall impression	
	A	D	A	D	A	D	A	D
2	1.6±0.0	1.9+0.2	1.8±0.4	2.0+0.3	1.6±0.3	2.1±0.2	4.0+0.4	4.2+0.8
4	2.7±0.3	1.8±0.0	2.2±0.2	1.6±0.4	2.4±0.2	1.9±0.4	3.9±0.2	4.1±0.1
6	3.8±0.7	2.4±0.3	2.3±0.5	2.3+0.2	4.0+0.4	2.0+0.2	2.6+0.2	3.8+0.5

[a]The values are means±S.D., $n=2$.

subjected to the volatile compounds from the meat. Furthermore, the CO_2-sensitive sensor (S15) was excluded, since this sensor very rapidly became overloaded. The volatiles of each sample were analysed six times using the electronic nose and the composition changed after each sampling (Fig. 3). Therefore, only the first of the measurements was used in the evaluation of the data.

There was a time-span of 6 months between the development and the validation of the mathematical models. Therefore, the stability of the sensor signals was examined by comparing the magnitude of the signals from these two occasions. It was shown that the sensitivity of sensors S2, S4, S5, S7 (MOSFETS; Table 1) and S11 (Tagushi) had changed. With respect to the MOSFETS, these changes were, more or less, a total loss of sensitivity to the volatile compounds from the meat.

Therefore, the subsequent development of mathematical models included sensors S1, S9, S10, S12, S13 and S14. Using this array of sensors, it was shown that the signal patterns obtained for meat from slaughterhouses A and D did not change significantly over a period of 6 months (Fig. 4).

3.4. Identification of sensors describing the variation obtained in the sensorial traits

Evaluation of the b_w coefficients, obtained from PLS of the relationships between sensorial traits and the standardised signals from the sensors, showed that sensors nos. S12 and S13 (Tagushi) best explained the variations seen in the sensorial traits (Table 4). Similar relationships between sensorial traits and individual sensors were obtained using Pearson's correlation (Table 4).

3.5. Mathematical models for the relationship between the degree of spoilage and the sensor signals

A number of mathematical models were developed using PLS, which described the relationships between the degree of spoilage, as determined by a sensory panel, and the standardised sensor signals of the electronic nose (Table 5). Common to all the PLS evaluations was the fact that the first principal component (PC1) mainly described changes in the degree of spoilage (Fig. 5), while the following PCs

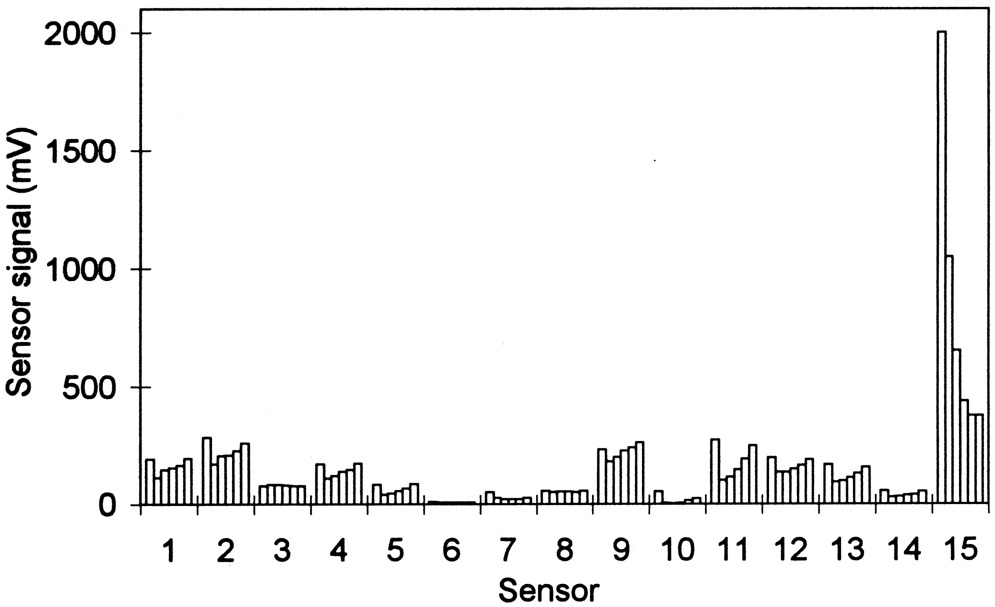

Fig. 3. Sensor signals from the electronic nose. The peaks represent six different measurements of a single sample of vacuum-packaged beef from slaughterhouse A stored at 4°C for 2 weeks.

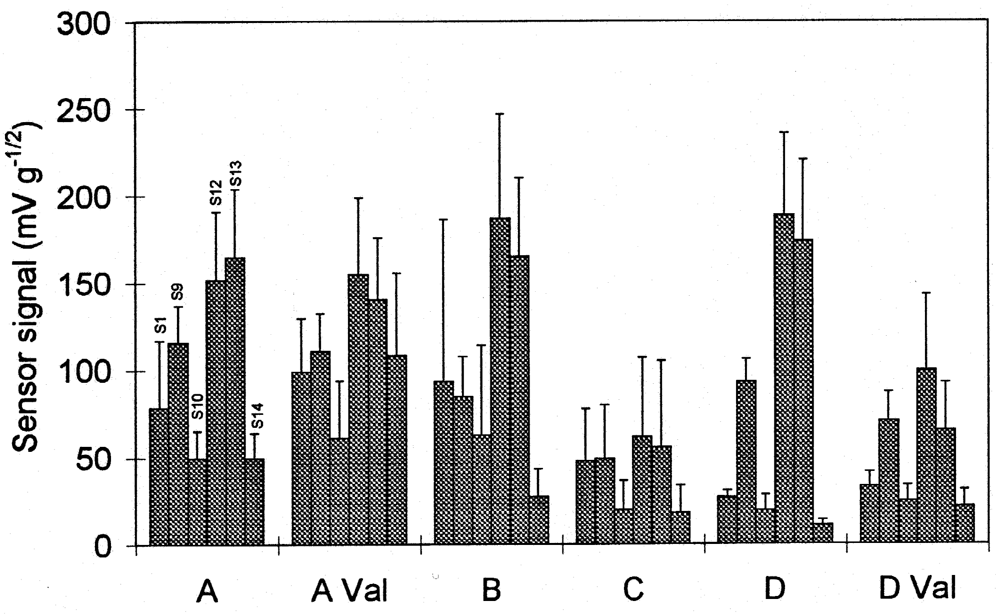

Fig. 4. Signal patterns from the electronic nose subjected to the volatile compounds of vacuum-packaged beef. Meat used for developing the mathematical models from slaughterhouses A–D (samples A–D) was stored at 4°C for 8 weeks. Meat used in the validation 6 months later from slaughterhouses A and D (samples A Val and D Val) was stored at 4°C for 6 weeks. The bars within each sample pattern correspond to standardised signals $(1/(\text{weight of meat (g)})^{1/2})$ from sensors S1, S9, S10, S12, S13 and S14. The error bars indicate S.D., $n=3$ or 5.

also described qualitative differences between meat from different slaughterhouses. Differences in the meat from the four slaughterhouses were also revealed in the signal patterns obtained from the electronic nose (Fig. 4). Since, in this study, only the relationships that were independent of the origin of the meat were of interest, only the first principal component was taken into account in the final modelling. Using only one PC, it was shown that the variance observed in the degree of spoilage could be better explained with a small number of sensors than with a larger number (Table 6).

Table 4

b_w coefficients obtained for the first principal component of PLS for the relationships between sensorial traits and standardised sensor signals and correlation coefficients for the relationships between the sensorial traits and the standardised signals of the individual sensors (Pearson's correlation)

Sensorial trait	Sensor										
	S1	S2	S4	S5	S7	S9	S10	S11	S12	S13	S14
b_w coefficient[a]											
Spoilage	0.06	0.06	0.06	0.06	0.05	0.07	0.08	0.02	0.12	0.11	0.03
Acidic	0.06	0.06	0.08	0.07	0.05	0.10	0.08	0.05	0.12	0.12	0.06
Sulphurous	0.06	0.07	0.06	0.07	0.04	0.06	0.08	0.03	0.10	0.09	0.04
Overall impression	−0.06	−0.06	−0.05	−0.06	−0.04	−0.06	−0.08	−0.02	−0.11	−0.10	−0.03
Correlation coefficient[a]											
Spoilage	0.27	0.29	0.37	0.30	0.21	0.46	0.53	0.15	0.80	0.74	0.26
Acidic	0.42	0.43	0.63	0.47	0.31	0.76	0.62	0.38	0.93	0.92	0.49
Sulphurous	0.29	0.34	0.43	0.40	0.16	0.44	0.57	0.28	0.70	0.67	0.38
Overall impression	−0.24	−0.27	−0.34	−0.26	−0.16	−0.39	−0.49	−0.16	−0.75	−0.70	−0.27

[a]Negative correlation between sensorial trait and sensor signals indicated by −.

Table 5
Mathematical models, $Y = b_0 + b_1 \times S_1 + b_2 \times S_2 + \dots + b_n \times S_n$, describing the relationships between the degree of spoilage, as determined by a sensory panel, and the sensor signal magnitudes of the electronic nose

Sensor combination	Mathematical model
S1, S9, S10, S11, S12, S13 and S14	$Y = 1.5925 + 0.0036 \times S1 + 0.0054 \times S10 + 0.0110 \times S11 + 0.0045 \times S12 + 0.0041 \times S13 + 0.0061 \times S14$
S9, S10, S12 and S14	$Y = 0.5571 + 0.0081 \times S9 + 0.0163 \times S10 + 0.0066 \times S12 + 0.0091 \times S14$
S10, S12 and S13	$Y = 1.5694 + 0.0179 \times S10 + 0.0073 \times S12 + 0.0067 \times S13$
S12 and S13	$Y = 1.6151 + 0.0094 \times S12 + 0.0086 \times S13$
S12	$Y = 1.5126 + 0.0186 \times S12$

Y is the spoilage score, b_x is the unweighted regression coefficient obtained from PLS, and S_x is the standardised sensor signal magnitude of the electronic nose (mV/(weight of meat (g))$^{1/2}$).

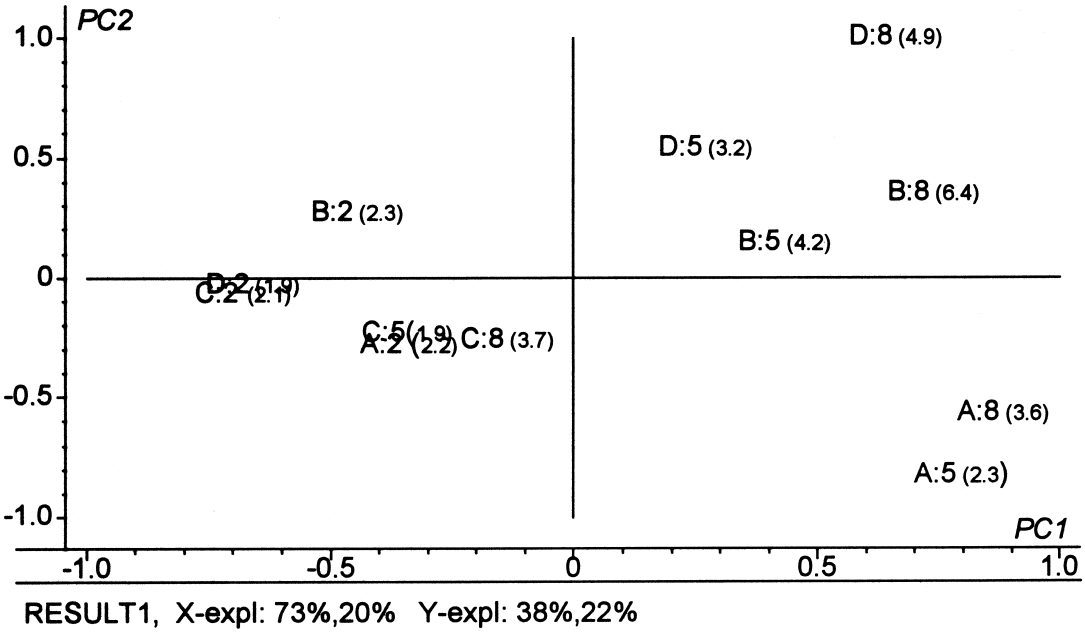

Fig. 5. Score-plot of the first and second principal components of the PLS of the relationship between the degree of spoilage and the standardised signals of sensors S1, S9, S10, S12, S13 and S14. Meat was collected from slaughterhouses A–D and stored for 2, 5 and 8 weeks at 4°C. (i.e., A:2 is meat from slaughterhouse A stored for 2 weeks). For each object, the mean value of the degree of spoilage is presented within brackets.

Table 6
Variance in Y- and x-variables explained by mathematical models, describing the relationships between the degree of spoilage (Y-variable) and the standardised sensor signals (x-variables), obtained from PLS using one or two principal components (PCs)

Sensor combination	Variance explained in Y-variables (%)		Variance explained in x-variables (%)	
	One PC	Two PCs	One PC	Two PCs
S1, S9, S10, S12, S13 and S14	38	60	73	93
S9, S10, S12 and S14	37	65	71	88
S10, S12 and S13	53	53	79	100
S12 and S13	56	66	99	99
S12	60			

Table 7
Relationships between predicted and observed spoilage scores: $Y_{pred} = Y_{obs} \times b_1 + b_0$

Sensor combination	b_1	b_0	r^2 value of regression	RMSEP[a]
S1, S9, S10, S12, S13 and S14	1.49	−0.45	0.98	0.81
S9, S10, S12 and S14	1.63	−0.67	0.98	0.96
S10, S12 and S13	1.41	−0.53	0.96	0.57
S12 and S13	1.18	−0.11	0.94	0.41
S12	1.24	−0.20	0.90	0.51

Different mathematical models, based on different combinations of sensors, were used to calculate Y_{pred}.
[a]RMSEP, root mean square error of prediction, obtained from PLS.

3.6. Validation of spoilage models

To investigate how well the different models could predict the spoilage of vacuum-packaged meat, they were validated using new samples of meat. The degree of spoilage calculated using the different models (Y_{pred}), was plotted against the degree of spoilage, as determined by a sensory panel (Y_{obs}). For good prediction, the intercept with the y-axis (b_0) and the slope (b_1) of a linear regression between Y_{pred} and Y_{obs}, should be close to 0 and 1, respectively. The best prediction was obtained on a model based on Tagushi sensors S12 and S13, where the b_0 and b_1 values were −0.11 and 1.18, respectively, and the r^2 value was 0.94 (Table 7; Fig. 6). This model also obtained the lowest RMSEP (Table 7).

Sensors S12 and S13 responded in similar ways to the spoilage odour, as assessed by a sensory panel (Fig. 7). The lowest spoilage score obtained for any of the samples was 1.6, while a spoilage score of 2.6 corresponded to a rejection of the meat by 50% of the sensory panel. In this interval, the standardised $(1/(\text{weight of meat (g)})^{1/2})$ sensor signals increased from 10 to 55 and 5 to 60 mV for sensors S12 and S13, respectively (Fig. 7), indicating that the electronic nose reacted to changes in the degree of spoilage before the level of off-odours became unacceptable.

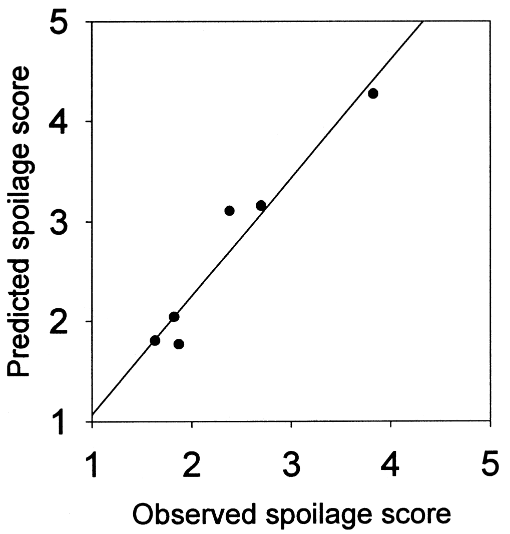

Fig. 6. Relationship between predicted and observed spoilage scores. The predicted values were calculated from a mathematical model based on the combination of sensors S12 and S13. The observed degree of spoilage was determined by a sensory panel ($b_0 = -0.11$, $b_1 = 1.18$, $r^2 = 0.94$).

4. Discussion

In the present investigation, an electronic nose was used to analyse the composition of the volatile compounds of vacuum-packaged beef to determine spoilage. It was shown that the degree of spoilage could be determined quantitatively. However, no information about specific compounds was obtained. The analysis of volatile compounds using an electronic nose provides a pattern composed of the signals from the different sensors, that reflects the spoilage odour. Since vacuum-packaged beef has a characteristic spoilage odour (Edwards et al., 1985; Borch et al., 1996), a characteristic spoilage pattern from the electronic nose should be expected. The anaerobic condition of vacuum-packaged beef will promote the growth of lactic acid bacteria and the spoilage characteristic will be dependent on the initial composition of the bacteria on the meat. *Lactobacillus sake*, when present, will give rise to sulphurous odours after prolonged storage (Egan et

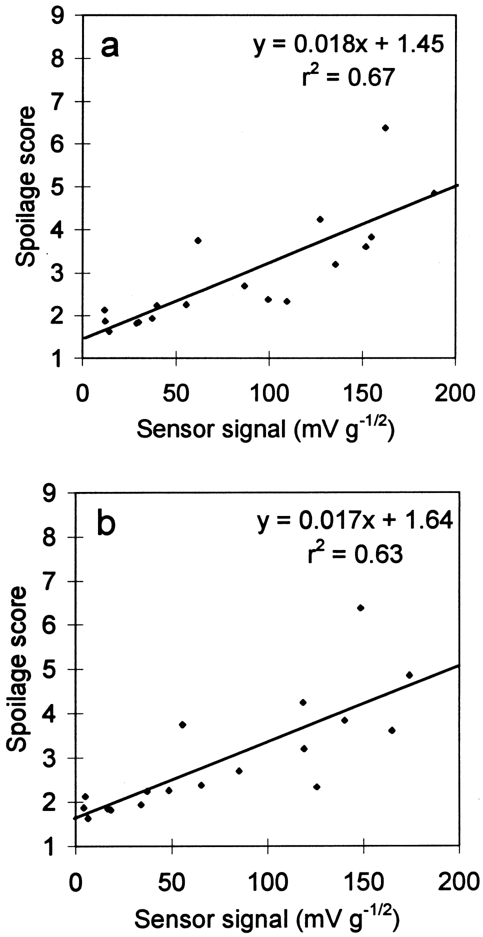

Fig. 7. Relationship between the signals of sensors (a) S12 and (b) S13 and the spoilage score, as assessed by a sensory panel. The samples originate from both the development and the validation of the model. The lines represent the linear regressions of the objects.

al., 1989), while other lactic acid bacteria do not produce such compounds. In the present study, possible variation in the spoilage odour due to different bacterial populations has been taken into account through the use of meat originating from different slaughterhouses. In fact, it was shown that the electronic nose could distinguish between spoiled meat from different slaughterhouses.

Since the sensorial spoilage of food is mostly due to microbial activity, it would seem appropriate to use specific spoilage organisms as indicators of spoilage (Dalgaard, 1995; Gram and Huss, 1996). Another alternative is to determine the concentrations of the specific chemical compounds involved in the spoilage process, one by one or as complex patterns obtained using, for instance, GC–MS. However, in the case of many types of products and storage conditions, the identity of specific spoilage organisms, and the corresponding metabolism, needs to be clarified. This is the case for vacuum-packaged beef, where the relationship between microbial growth and spoilage onset does not correlate (Gill, 1983; Borch et al., 1996). In these situations, the electronic nose may be a useful alternative, since no physiological knowledge of the spoilage process is required. Furthermore, the results are obtained within hours and the actual input of work is small. This should be compared to bacterial analyses, which take at least 1–2 days, and analyses of chemical compounds, which are often time-consuming and laborious.

Previously, electronic noses have mainly been used for classification (Winquist et al., 1993; Jonsson et al., 1997). In the present study, the electronic nose was used to quantify the degree of spoilage. However, this procedure requires that there be no drift in the sensor signals over time. This problem, and the importance of sensor calibration in quantitative analysis, has been discussed previously (Hodgins, 1996; Mielle, 1996). An important subject for future studies should be the development of calibration schemes and reference compounds relevant to different applications. In the present study, the model was validated after 6 months to ensure that there was no drift in the signals from the selected sensors over time. This type of validation is to be preferred to cross-validation, where samples are withdrawn from the original set of samples and used for validating the model. In the latter procedure, changes in sensor signals, or in the material of the samples, due to time, are not taken into account.

The multivariate character of the data obtained from the electronic nose requires a multivariate evaluation of the data. In the present investigation, PLS (Wold, 1989) was used to relate the degree of spoilage of the vacuum-packaged beef to the magnitudes of the sensor signals. PLS analysis has previously been used to predict the odour character of virgin olive oil from headspace compositions, as analysed using GC–MS (Servili et al., 1995), and principal component regression (PCR) was used in the development of a model for predicting the shelf-life of milk based on the analysis of dynamic headspace gas chromatographic data (Vallejo-Cordoba and Nakai, 1994).

The potential of the electronic nose within the food industry lies in the speed and simplicity of the method. When fully developed, the electronic nose may be used for on-line determination of the hygienic status of the meat. When using an electronic nose, a major effort is required to define the mathematical relationship that describes the application, and to validate the model obtained. Such a procedure has to be carried out in the case of each application.

It has been shown that an electronic nose could be used to quantitatively determine the degree of spoilage of vacuum-packaged beef. The model presented is based on a limited number of samples and should thus be further validated before use. However, the potential for using the composition of the volatiles, as analysed by an electronic nose, as a spoilage indicator for vacuum-packaged beef has been clearly demonstrated.

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