

Electronic Nose and GC-MS to Investigate the Volatile Component of an Italian Traditional Pasta

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ABSTRACT

The present work investigated the possibility of combining headspace sampling–solid-phase microextraction with gas chromatography–mass spectroscopy (GC-MS) analysis and an array of semiconductor gas sensors to study the volatile fraction of traditional Italian cereal foods. In particular, it studied a pasta recognized as typical by the Italian laws and made with a semolina obtained from a toasted durum wheat. The GC-MS analysis allowed the identification of several volatile compounds, almost always in small concentrations, in raw materials and in fresh and dried pasta. The data deriving from the application of the GC-MS and electronic nose analyses were submitted to principal component analysis to evaluate the suitability of these techniques for emphasizing differences due to composition and/or processing. These preliminary results showed that both the analytical techniques allowed good discrimination among the meals but not among the pasta samples.

Even if native grains are characterized by low levels of volatile compounds (22), they generally need to be processed before consumption. Flavors form during operations such as milling, enzymation, germination, fermentation, extrusion, drying, and cooking. Yet very little research has been done on the flavor of wheat and its derivatives.

Sayaşlan and coworkers (18) determined the nature of the volatiles in wheat starch, finding that the most abundant compounds were 2-ethyl-1-hexanol, benzaldehyde, and hexanal and that the level of aldehydes (deriving from the lipid peroxidation) was the highest, followed by those of alcohols, ketones, benzenes, esters, and terpenes. Heiniö and coworkers (9) investigated the flavor of breads obtained by mixing wheat flour with flours derived from milling rye grains into different fractions. They found

that the endosperm fraction induced a mild flavor in the resulting bread, whereas the rye bran fraction produced an intense bitter flavor and aftertaste.

Major interest has been shown in the effect of heat treatment on volatile formation in cereal derivatives. Fors and Eriksson (7) found that extrusion of malt induced the formation of alkylpyrazines, which are characterized by roasted and nutty odors. These substances generally have high flavor thresholds and therefore contribute to the product odor only if formed in large amounts (2). In a malt beverage obtained from roasted sorghum, Lasekan and coworkers (13) found 28 volatile compounds such as pyrazines, furans, aldehydes, ketones, esters, and alcohols. Rychlik and Grosch (17) toasted slices of wheat bread in order to identify the principal potent odorants formed during the toasting. Compounds such as 2-acetyl-1-pyrroline, (*E*)-2-nonenal, 3-methylbutyric acid, 4-hydroxy-2,5-dimethyl-3 (2H)-furanone, methional, and 2,3-butanedione were recognized as responsible for the toasted flavor.

An interesting application of toasting on whole cereal grains is represented by toasted wheat pasta, a product listed among the Italian traditional foods (3). This product is also widely known beyond the Italian border and is analogous to other tradition-

al cereal products such as kavut (12). It is produced from a mixture of semolina and/or wheat flour and a whole meal derived from toasted durum wheat grains.

Among the analytical techniques suitable for investigating the volatile fraction of cereal products, gas-chromatography (GC), coupled with a flame ionization detector (FID) or a mass spectrometer (MS), is used the most. In fact, it is a very precise, well-established, and reliable analytical technique, but on the other hand it is expensive, time-consuming, and doesn't allow in-situ analysis.

Another device, the electronic nose, represents a promising tool in the fields of quality control and authenticity assessment (8,19). There is tremendous interest in developing such multisensor devices for specific application in the food industry, and numerous works are reported in the literature (19). Like the human nose, an electronic nose consists of an array of chemical sensors that, although unable to detect specific volatiles, can identify a large spectrum of odors and are able to provide a real-time digital fingerprint of the volatile fractions. In addition, their lack of selectivity is overcome by the application of pattern recognition techniques (4,20). The electronic nose does not give information about the identity or the sensory properties of the compounds responsible for flavor. Instead, it supplies the so-called "aroma pattern" that should be characteristic of the investigated matrix. The next step should be a coupled system, GC plus electronic nose, for headspace analysis (16). Until now, use of the electronic nose in the cereal sector has been limited to control of the microbial quality of grains (11,15) and the classification of grains (1). An interesting study on the use of an electronic nose to evaluate the optimal cooking time of rice was made by Sinelli and coworkers (21). The results confirmed the feasibility of this technique to follow the aroma profile during cooking.

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The present work reports only the preliminary results obtained by using a combination of headspace sampling–solid-phase microextraction (HS-SPME), GC, and MS analysis and a semiconductor gas sensor array both to investigate the volatile fraction responsible for the flavor of the toasted durum wheat derivatives and to discriminate among samples differing in composition and processing.

MATERIALS AND METHODS

Production of the Toasted Durum Wheat Whole Meal

Semolina and toasted durum wheat meal were supplied by a local producer. The toasted whole meal was taken from the same lot of durum wheat grains used to produce the semolina. Toasted whole meal was made according to the following procedure. Cleaned wheat grains were arranged on a steel tray that was placed into direct contact with a wood fire. After being roasted, the grains were cleaned again and moistened. After 8 hr, they were ground.

Pasta Production

Pasta in the form of “gnocchetti” was produced in a pilot plant consisting of an extruder (Sercom) and a dryer (Afrem International, Lyon, France) as follows.

Traditional pasta (TP), 100 g, was made from 68 g of semolina and 32 g of water. Toasted durum wheat pasta (BWP), 100 g, consisted of 68 g of a mixture of semolina and a whole meal deriving from toasted durum wheat (8:2) and 32 g water. Toasted durum wheat and egg pasta (BWPE), 100 g, consisted of 68 g of a mixture of semolina, a whole meal deriving from toasted durum wheat, and soft wheat flour (4:4:2), sodium chloride (0.1%, based on the dry ingredients), and 32 g of whole eggs. The temperature of the added water was 41°C. The kneading time was 30 min. The extrusion pressure was 60–80 bar.

Half of the fresh pasta was stored at –18°C until analysis, whereas the remaining half was dried (1 hr at 80°C followed by 4 hr at 90°C) in order to investigate the changes in the composition of the volatile compounds induced by drying.

Samples of raw materials and fresh and dried pasta were submitted to the following analyses:

Gas-Chromatographic Analysis

The samples were analyzed for determination of the volatile compounds by static headspace sampling–solid-phase microextraction (SHS-SPME), GC, and MS. SPME 50- μm carboxen-polydimethylsiloxane fibers were used and exposed to

5-g samples in 20-mL gas-tight vials for 20 min at 22°C. After this, the fiber was desorbed in a split/splitless injector equipped with deactivated SPME glass inserts, and analyses were conducted on a 30-m \times 250- μm i.d. \times 0.25- μm polyethylene glycol column (HP INNOVAX). A GC system (HP 6890 series) was coupled with a mass selective detector (HP 5973). Injection was split 5:1, with a 5-min relay time. GC conditions were 40°C for 5 min, to 150°C at 4°C/min, then to 250°C at 15°C/min. The injector temperature was 250°C, and the helium flow was 1 mL/min. The transfer line was held at 260°C. Spectra were produced in the electron impact mode at 70 eV. Compounds were identified by comparison with National Institute of Standards and Technology reference spectra. The mass range was 30–350 atomic mass units (amu); the solvent delay time was 4 min; the threshold was 150; and the scan rate was 4.45 scans per second.

Electronic Nose

The sensor array used in this work was composed of seven sensors prepared according to the sol-gel technique. They were thin film sensors based on undoped In_2O_3 (indium oxide) and on Rh- (rhodium), Pd- (palladium), Ni- (nickel), and Os- (osmium) doped SnO_2 (tin oxide).

To investigate the gas-sensing properties of the samples, a gas-sensing test bench for electrical-conductance measurements in controlled atmospheres was used. The prepared metal oxide semiconductor sensors were introduced into a test cell, which was placed in series with a multichannel mass flow programmer. The programmer was connected to several mass flow controllers used to set a constant flow of dry air–nitrogen coming from certified bottles.

During the gas-sensing tests, all the sensors operated at a temperature of about 300°C. The sensor temperature was controlled by varying the direct-current voltage across the Pt-heater and reading out the absorbed current according to calibration curves. The electrical characteristics of the oxide films were obtained by measuring the electrical current flowing through films by a biased constant-voltage (2 V) detector and an electrometer equipped with a multiplexer.

For all the measurements, the following experimental setup was used. The baseline was acquired in a dry air–nitrogen atmosphere in a continuous total flow of 100 standard cubic centimeters per minute (sccm) (50 sccm of air and 50 sccm of nitrogen). Next, to measure the response of the sensors to the volatiles produced by pasta samples, the vial headspace was

stripped by means of a deviation of the 50-sccm nitrogen flow for 15 min, while maintaining the 50 sccm of dry air constant. In this way, the volatile compounds in the vial headspace were collected and added to the dry airflow before it entered the sensor chamber. Hence, the electrical signals of the sensors were acquired for 15 min under exposure to the sample volatiles and for the next 20 min under exposure to the reference gas flow for recovery. For each sample, this cycle was repeated many times in order to collect a sufficient amount of data to be useful for the subsequent analysis. Here, the response of the sensors was defined as $I_{\text{headspace}}/I_0$, where $I_{\text{headspace}}$ is the electrical current exposed to the vial headspace after 15 min and I_0 is the electrical current in the reference gas flow.

Statistical Analysis

Principal component analysis (PCA) was applied to the sensor array data using Winstat, version 6.0 (Statsoft, Tulsa, USA), software to show differences among the samples.

RESULTS AND DISCUSSION

Table I reports the percentages of the volatile compounds detected and identified in the raw materials and the fresh and dried pasta. The GC profiles (not reported) of the two meals were quite different and showed great variety among volatiles (a large number of compounds but characterized by low concentrations). For some of these compounds, it was difficult to judge whether they derived from the foodstuffs or, instead, from external sources of contamination. The most abundant volatiles identified in semolina were, in decreasing order (Table I), benzaldehyde, hexanal, iso-propyl alcohol, ethanol, and ethyl decanoate. The toasted whole wheat meal was rich in acetic acid, 1-hydroxy-2-propanone, 2-furanmethanol, ethyl decanoate, and furfural.

Ethyl decanoate, ethanol, methoxyphenyloxime, hexanal, and 2-butanone were the most represented volatiles among those identified in fresh pasta (TP) made of semolina. Among fresh pasta samples, those made of toasted whole wheat meal (both BWP and BWPE) produced the highest concentrations of volatile compounds and the most complex volatile profiles in the headspace. In fact, through oxidation and the Maillard reaction, the toasting of the grain produced a lot of volatile compounds ascribed to the classes of aldehydes, ketones, alcohols, esters, furans, and pyrazines. In particular, the most abundant compound was eucalyptol, followed by 2-ethylhexanol, 3,7-dimethyl-

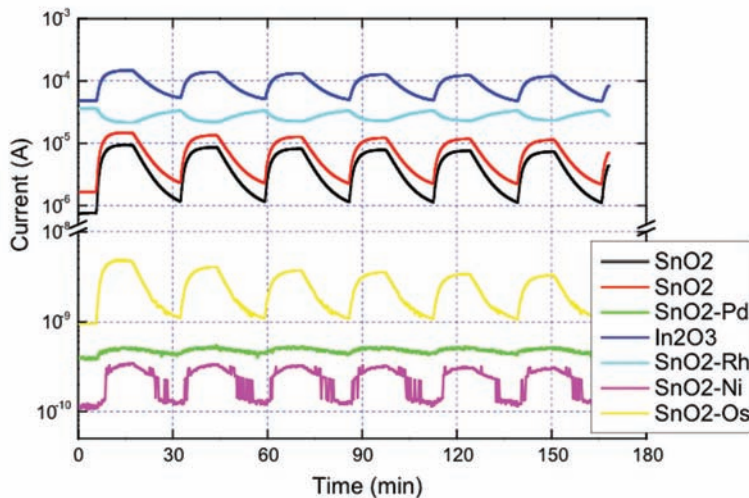
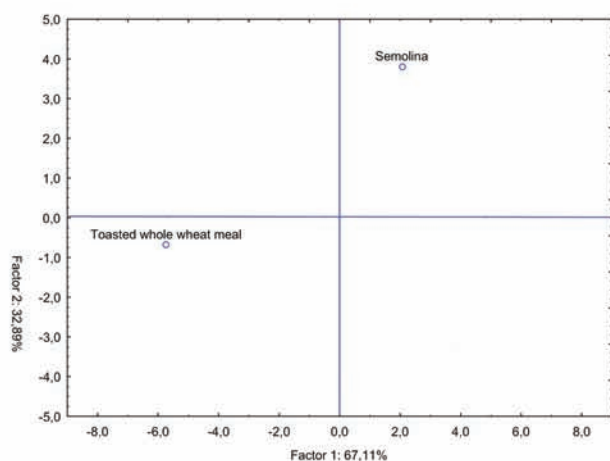


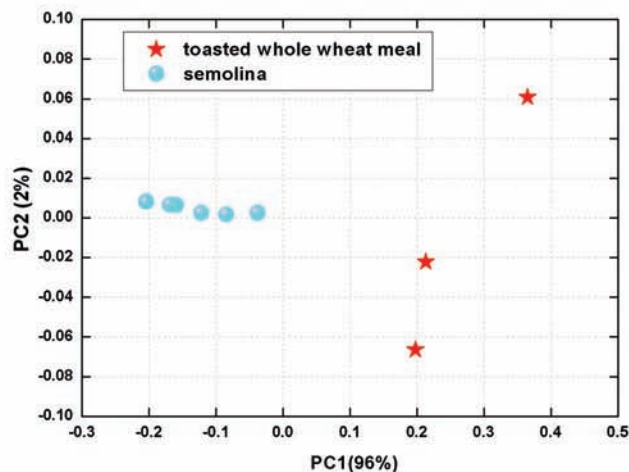
Fig. 1. Example of dynamic responses of the electronic nose to pasta sample. The metals listed were used in various sensors.

1,6-ottadien-3-ol, 2,2,4,6,6-pentamethyl-*ep*tane ethanol, and 3-hydroxy-2-butanone. Furthermore, low percentages of other volatiles were identified, such as compounds belonging to the terpene hydrocarbons (α -pinene, 3- and 4-carene, and limonene, besides the already cited eucalyptol), deriving from the wood used during the roasting (but also naturally present in the grains), pyrazines, and furans. Pyrazine derivatives (10) having a characteristic nutty, coffee, chocolate smell have been classified as potent odorants in toasted products, thus contributing to the product flavor even if present in small amounts.

The dried pasta showed a lower amount of volatiles than the fresh pasta, probably as a consequence of their evaporation during drying. In the dried TP, ethyl

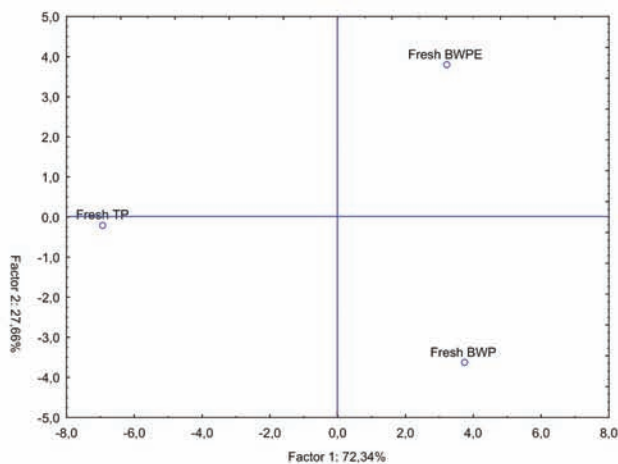


a)

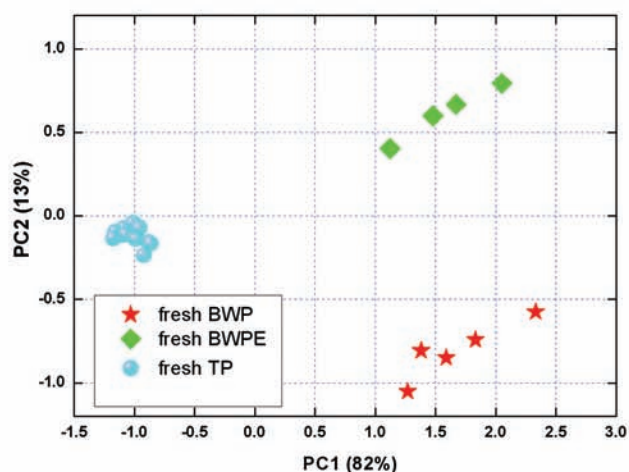


b)

Fig. 2. Projection on the factor-plane of the GC-MS (A) and electronic nose (B) data for the meals. PC = principal component.



a)



b)

Fig. 3. Projection on the factor-plane of the GC-MS (A) and electronic nose (B) data for the fresh pasta samples. TP = traditional pasta, BWP = toasted durum wheat pasta, BWPE = toasted durum wheat and egg pasta.

decanoate and acetic acid were detected in large amounts, followed by 2,2'-oxy-bis-ethanol and methoxyphenyloxime. The most representative compound identified in dried BWP samples was tetrahydrofuran, a typical product of the reaction between amino acids and carbohydrates that occurs during roasting (14), whereas the dried BWPE mainly contained ethanol and 2-furanmethanol.

Figure 1 shows a typical dynamic response obtained from the exposure of the sensor array to a pasta sample. The picture shows very reproducible and stable responses, with n-type behavior for all the sensors except for the Rh-SnO₂-based sensor. Moreover, the two identical undoped-SnO₂-based sensors show, as expected, very similar behavior, particularly in terms of reproducibility. The sensors have different baseline values, starting from 10⁻¹⁰ for the Ni-SnO₂-based sensor to 5×10⁻⁵ for the undoped-In₂O₃ sensor. The response has a value from I_{headspace}/I₀ = 1.1 in the case of Rh-SnO₂ for flour samples to I_{headspace}/I₀ = 8.1 in the case of undoped-SnO₂ for BWPE.

The responses obtained with this sensor array, together with those deriving from the GC-MS, were shown in some PCA plots. Only the Pd-SnO₂-based sensor was excluded from the analysis because it gave redundant information. The plot of the results of the PCA applied to the GC-MS analysis shows good separation between the clusters of semolina and toasted whole wheat meal on the basis of the first factor (Fig. 2), according to the sensor array data set. On the basis of the first factor, it was

also possible to distinguish the fresh TP from the samples containing the toasted meals but not the fresh BWP from the fresh BWPE (Fig. 3). They were discriminated on the base of the second factor, which described about 27 and 13% of the explained variance in the case of GC-MS and the electronic nose, respectively. The sensitivity of the applied methods was not very high in the case of the dried samples (Fig. 4) due to the leveling of the volatile contents as a consequence of drying. In fact, TP and BWP were not distinguishable from each other on the basis of the first factor, although BWPE was separated from them, probably as a function of the potent odors in the eggs. The lower ability of the two techniques to discriminate the pasta samples could also be due to the changes in the polar or hydrophobic interactions between the functional groups of the volatile compounds and the starch matrix. Delarue and Giampaoli (6) found that specific heat treatments increase, for example, the starch's retention of 3,7-dimethyl-2,6-octadien-1-al as a consequence of its glass transition. Another factor affecting the release of volatiles from cereals and thus the ability of a technique to discriminate samples on the basis of their aroma profiles could be the product's water content. According to Clawson and coworkers (5), for the same product, different volatile profiles correspond to different moisture levels. For example, the authors found a constant release of hexanal and an increasing release of 2- and 3-methyl buta-nal and pyrazines as the water content increased.

CONCLUSIONS

HS-SPME-GC/MS permitted identification of the volatile compounds in the headspace of typical Italian wheat meals and pasta and the compounds responsible for the toasted odor. All the gas sensors, except for an Rh-SnO₂-based sensor, showed very reproducible and stable responses. HS-SPME-GC/MS and the electronic nose allowed a satisfying discrimination between wheat meals, whereas the fingerprints of the pasta samples were less useful. In the case of the pasta, it can be presumed that processing (mixing, kneading, and drying) caused physical modifications of the carbohydrate matrix and induced changes in its retention properties toward volatile compounds that affected the volatile headspace composition. Furthermore, the changes in product water content during kneading and drying could have affected the volatile release rate. In addition, for the dried pasta, the drying could have produced a leveling effect on volatile compounds, allowing their evaporation and degradation. Thus, the unsatisfactory ability to discriminate between samples does not seem due to inherent limitations of the two techniques but to the sample composition and the interactions between the food matrix and volatiles. Studies are in progress for other types of pasta products in order to bypass the above-mentioned limitations and allow the use of two techniques that seem to be very promising for quality and authenticity assessment.

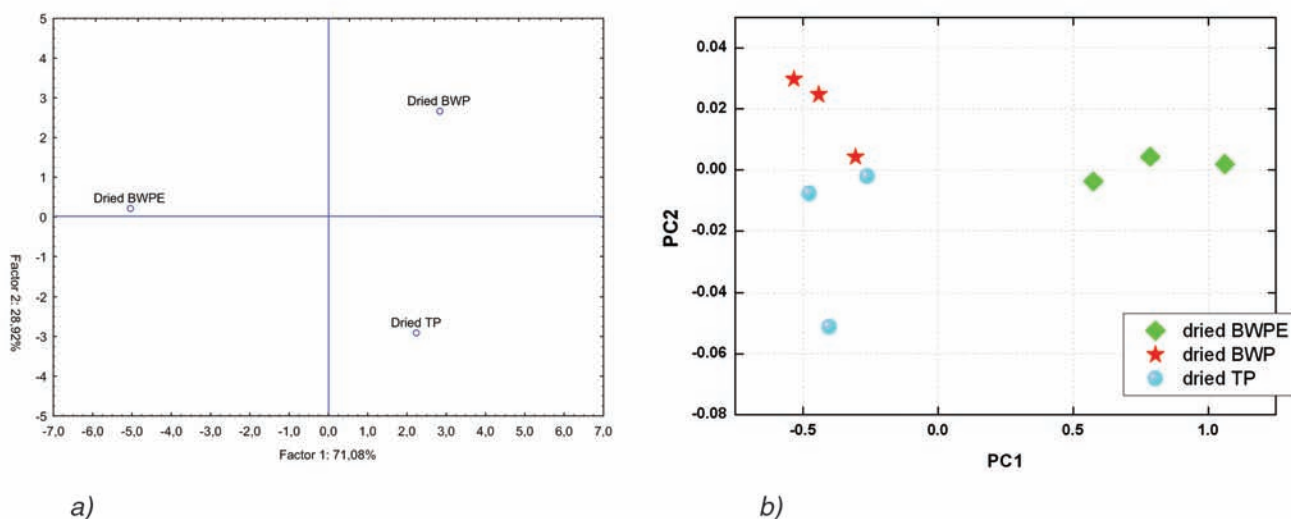


Fig. 4. Projection on the factor-plane of the GC-MS (A) and electronic nose (B) data for the dried pasta samples. TP = traditional pasta, BWP = toasted durum wheat pasta, BWPE = toasted durum wheat and egg pasta.

Table I. Percentage abundances of the volatile compounds identified by means of GC-MS^a in meals and fresh and dried pasta

Peak No.	Retention Time (min)	Volatile Compounds	Meals		Fresh Pasta ^b			Dried Pasta ^b		
			Toasted Whole Wheat Meal	Semolina	TP	BWP	BWPE	TP	BWP	BWPE
1	2.195	Tetrahydrofuran	-	0.76	-	0.66	0.23	-	32.25	3.14
2	2.31	Butanal	-	-	-	0.24	-	-	-	-
3	2.414	Ethyl acetate	2.37	-	-	0.29	0.10	-	-	-
4	2.537	2-Butanone	2.51	1.28	4.65	0.62	0.25	-	-	1.83
5	2.647	2-Methylbutanal	0.85	-	-	0.33	0.20	-	-	-
6	2.702	3-Methylbutanal	1.79	0.87	-	1.22	0.76	-	-	2.23
7	2.896	Iso-propyl alcohol	2.93	6.53	-	0.63	0.51	0.30	0.75	1.50
8	2.986	Ethanol	1.78	6.30	7.99	3.10	3.06	1.19	0.95	5.92
9	3.202	2,2,4,6,6-Pentamethyl-eptane	-	-	1.29	4.34	3.24	-	-	-
10	3.661	2,3-Butanedione	0.26	-	-	1.46	0.61	-	-	-
11	4.249	α -Pinene	0.93	-	-	1.02	1.23	0.50	0.39	-
12	4.879	Toluene	0.78	2.32	1.21	0.82	0.5	0.79	0.67	2.93
13	6.168	Hexanal	0.84	6.68	4.97	2.9	1.8	1.14	0.18	-
14	6.656	2-Methylpropanol	-	-	-	0.10	0.38	-	-	-
15	7.234	2-Propen-1-ol	0.23	-	-	-	-	-	-	-
16	7.676	3-Carene	-	-	-	0.39	0.46	-	-	3.93
17	7.705	4-Carene	0.26	1.19	-	-	-	-	-	-
18	8.045	1-Butanol	-	-	1.40	0.49	0.30	-	0.18	-
19	8.423	1-Penten-3-ol	0.20	-	1.02	1.46	0.88	-	-	-
20	8.865	Limonene	0.29	0.24	-	0.44	0.49	-	-	-
21	9.185	Eucalyptol	0.58	0.34	2.19	16.81	29.66	-	-	-
22	9.550	Pyrazine	1.97	1.67	-	-	-	-	-	2.43
23	10.173	1,6,6-Trimethylcyclohexene	-	-	-	-	-	3.84	0.67	4.25
24	10.551	1-Pentanol	0.06	2.84	2.01	0.95	0.45	-	0.08	2.26
25	10.732	Methylpyrazine	1.93	1.39	1.03	1.21	1.33	-	-	-
26	11.210	3-Hydroxy-2-butanone	1.38	0.74	1.26	2.93	3.37	-	-	-
27	11.546	1-Hydroxy-2-propanone	6.68	0.42	-	1.70	2.73	0.46	0.18	-
28	11.879	2,5-Dimethyl-pyrazine	0.25	-	-	0.27	0.17	-	-	-
29	12.002	2,6-Dimethyl-pyrazine	-	-	-	0.45	0.35	-	-	-
30	12.105	Ethyl-pyrazine	-	-	-	-	0.14	-	-	-
31	12.286	1-Butoxy-2-propanone	-	-	-	-	-	-	-	-
32	12.350	2,3-Dimethyl-pyrazine	-	-	-	0.47	0.26	1.82	0.41	3.47
33	12.761	2,4-Dimethylfuran	0.33	-	-	0.26	0.15	-	-	-
34	12.832	1-Hydroxy-2-butanone	-	-	-	0.26	0.11	-	-	-
35	12.967	2-Hydroxy-2-butanone	0.40	-	-	-	-	-	-	-
36	13.068	2-Ethyl-6-methylpyrazine	-	-	-	0.16	0.21	-	-	-
37	13.132	4-Hexenyl (Z)-butanoate	0.05	-	-	0.47	0.41	-	-	-
38	13.194	Nonanol	-	-	-	-	-	-	0.24	1.74
39	13.423	2-Ethyl-3-methylpyrazine	-	-	-	-	-	-	-	-
40	14.276	1-Otten-3-ol	0.10	-	0.53	0.45	0.53	-	-	-
41	14.483	Benzaldehyde	-	9.65	-	-	-	-	-	-
42	14.463	Acetic acid	13.92	-	2.48	2.49	2.67	9.38	1.95	-
43	14.557	Furfural	4.35	-	-	1.44	1.78	-	-	-
44	14.699	Diallyl disulfide	-	-	-	0.60	0.97	-	-	-
45	14.941	2-Ethylhexanol	1.58	2.13	2.11	4.31	5.20	-	0.59	4.17
46	15.232	1-(2-Furanyl)-ethanone	-	-	-	0.35	-	-	-	1.08
47	15.439	3-Methyl-2-cyclopentenone	0.39	-	-	0.25	0.29	-	-	-
48	15.868	3,7-Dimethyl-1,6-ottadien-3-ol	2.42	1.46	0.83	4.29	5.85	0.79	0.16	1.89
49	17.228	Ethyl decanoate	4.50	4.92	8.46	2.56	1.47	15.77	3.66	-
50	17.671	2-Furanmethanol	5.74	-	2.35	2.32	3.50	1.15	0.36	5.54
51	18.608	2-Ethylbenzenamine	-	-	-	-	-	0.76	0.1	0.67
52	19.405	Methoxyphenyloxime	2.29	-	5.83	0.32	0.42	5.06	7.02	-
53	19.816	2-Phenylethyl-propanoic acid	-	-	-	0.06	-	-	-	-
54	20.278	Eptanoic acid	0.50	-	0.75	0.15	-	-	-	-
55	20.675	Benzyl alcohol	-	-	-	0.09	-	-	-	-
56	21.027	Hydroxytoluene butylate	-	-	0.36	0.47	-	1.61	0.30	1.57
57	21.146	Phenylethyl alcohol	0.28	0.50	0.88	0.20	0.10	1.27	0.76	1.67
58	21.925	1-(1H-Pyrrole-2-yl)ethanone	-	-	-	0.12	-	-	-	-
59	22.012	2,2'-Oxybisethanol	2.36	-	1.10	0.12	0.13	7.79	1.19	3.42
60	22.275	4-Methylphenol	-	-	-	0.19	-	-	-	-

^a Gas chromatography-mass spectrometry.^b P = traditional pasta, BWP = toasted durum wheat pasta, BWPE = toasted durum wheat and egg pasta.

References

1. Borjesson, T., Eklov, T., Jonsson, A., Sundgren, H., and Schnurer, J. Electronic nose for odor classification of grains. *Cereal Chem.* 73:457, 1996.
2. Bredie, W. L. P., Mottram, D. S., Hassel, G. M., and Guy, R. C. E. Sensory characterization of the aromas generated in extruded maize and wheat flour. *J. Cereal Sci.* 28:97, 1998.
3. Cabinet Decree 18/08/2000. Ministero delle Politiche Agricole e Forestali, Ordinary Supplement of the Off. J. Ital. Republic no. 194, 21 Aug., 2000.
4. Cimato, A., Dello Monaco, D., Distante, C., Epifani, M., Siciliano, P., Taurino, A. M., Zuppa, M., and Sani, G. Analysis of single-cultivar extra virgin olive oils by means of an electronic nose and HS-SPME/GC/MS methods. *Sens. Actuat. B* 114:674, 2006.
5. Clawson, A. R., Linforth, S. T., Inghan, K. E., and Taylor, A. J. Effect of hydration on release of volatile from cereal foods. *Lebensm. Wiss. Technol.* 29:158, 1996.
6. Delarue, J., and Giampaoli, P. Study of interaction phenomena between aroma compounds and carbohydrate matrixes by inverse gas chromatography. *J. Agric. Food Chem.* 48:2372, 2000.
7. Fors, S. M., and Eriksson, C. E. Pyrazines in extruded malt. *J. Sci. Food Agric.* 37:991, 1986.
8. Gardner, J. W., and Bartlet, P. N. *Electronic Noses: Principles and Applications*. Oxford University Press, Oxford, 1999.
9. Heiniö, R. L., Liukkonen, K. H., Katina, K., Myllymäki, O., and Poutanen, K. Milling fractionation of rye produces different sensory profiles of both flour and bread. *Lebensm. Wiss. Technol.* 36:577, 2003.
10. Hye Sung Ko, Tae Hwan Kim, He echo, Ji-Yeon Yang, Young-Suk Kim, and Hyong Joo Lee. Aroma active compounds of bulgogi. *J. Food Sci.* 70:517, 2005.
11. Jonsson, A., Winqvist, F., Schnurer, J., Sundgren, H., and Lundstrom, I. Electronic nose for microbial quality classification of grains. *Int. J. Food Microbiol.* 35:187, 1997.
12. Karaoglu, M. M., and Kotancilar, H. G. Kavut, a traditional Turkish cereal product: Production method and some chemical and sensorial properties. *Int. J. Food Sci. Technol.* 41:232, 2006.
13. Lasekan, O. O., Lasekan, W. O., and Idowu, M. A. Flavour volatiles of 'malt beverage' from roasted sorghum. *Food Chem.* 58:341, 1997.
14. National Pollutant Inventory (NPI). Emission estimation technique manual for snack foods roasting and frying industry. Published online at www.npi.gov.au/handbooks/approved_handbooks/pubs/fsnack.pdf, 1999.
15. Olsson, J., Borjesson, T., Lundstedt, T., and Schnurer, J. Volatiles for mycological quality grading of barley grains—Determinations using gas chromatography-mass spectrometry and electronic nose. *Int. J. Food Microbiol.* 59:167, 2000.
16. O'Sullivan, M. G., Byrne, D. V., Jensen, M. T., Andersen, H. J., and Vestergaard, J. A comparison of warmed-over flavour in pork by sensory analysis, GC/MS and the electronic nose. *Meat Sci.* 65:1125, 2003.
17. Rychlik, M., and Grosch, W. Identification and quantification of potent odorants formed by toasting of wheat bread. *Lebensm. Wiss. Technol.* 29:515, 1996.
18. Sayaslan, A., Chung, O. K., Seib, P. A., and Seitz, L. M. Volatile compounds in five starches. *Cereal Chem.* 77:248, 2000.
19. Schaller, E., Bosset, J. O., and Escher, F. 'Electronic noses' and their application to food. *Lebensm. Wiss. Technol.* 31:305, 1998.
20. Siciliano, P. Preparation, characterization and applications of thin films for gas sensors prepared by cheap chemical method. *Sens. Actuat. B* 70:153, 2000.
21. Sinelli, N., Benedetti, S., Bottega, G., Riva, M., and Buratti, S. Evaluation of the optimal cooking time of rice by using FT-NIR spectroscopy and an electronic nose. *J. Cereal Sci.* 44:137, 2006.
22. Zhou, M., Robards, K., Glennie-Holmes, M., and Helliwell, S. Analysis of volatile compounds and their contribution to flavor in cereals. *J. Agric. Food Chem.* 47:3941, 1999.

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