6 Quality assessment of aquatic foods by machine vision, electronic nose, and electronic tongue

Figen Korel and Murat Ö. Balaban

6.1 Introduction

The increase in demand for seafood products has catalyzed the desire for higher standards regarding safety and quality issues. Since seafoods are perishable, freshness is a major quality parameter to be considered [1,2]. There is no unique freshness or spoilage indicator for seafood, therefore combinations of selected indicators need to be used to evaluate freshness [3,4]. An important and widely used method to determine freshness is sensory evaluation [5]. The Quality Index Method (QIM) uses a demerit point scoring system [6] based on the evaluation of the important sensory attributes (odour, texture, and appearance) of fish and other aquatic foods. The sensory quality is expressed by the sum of the demerit points, and a linear correlation between these points and the storage time is used to predict the freshness of the target seafood [5,7,8]. The QIM has been developed for various seafood species and products, such as Atlantic mackerel (*Scomber scombrus*), horse mackerel (*Trachurus trachurus*), European sardine (*Sardina pilchardus*) [9], gilthead seabream (*Sparus aurata*) [10], farmed Atlantic salmon (*Salmo salar*) [11,12], and cod (*Gadus morhua*) [13], etc. Even though QIM is fast and reliable in determining the freshness of seafood, it still requires experts to evaluate the quality attributes. Alternatively, appearance, odour, and taste can be measured by machine vision system (MVS), electronic nose (e-nose), and electronic tongue (e-tongue), respectively.

In this chapter, the measurement of visual, odour, and taste quality of seafood using MVS, e-nose, and e-tongue is discussed. A few literature examples are given for all techniques, some of which are given from research conducted in our own laboratories.

6.2 Visual quality

Visual quality of seafood includes appearance (size, shape, and colour) attributes. These have a direct influence on the seafood's value and acceptance. One of the methods of measuring them is by using a MVS, which consists of a digital camera to acquire images, an illumination system (e.g. a light box with fluorescent bulbs as lighting source), and computer software to analyze the image [14,15]. This is a rapid, objective, repeatable, and non-destructive method,

Handbook of Seafood Quality, Safety and Health Applications
Edited by Cesarettin Alasalvar, Fereidoon Shahidi, Kazuo Miyashita and Udaya Wanasundara
 ISBN: 978-1-405-18070-2

and has been recognized as the most promising approach to objective evaluation of visual quality of seafood, with many successful applications. For the industry, the implementation of an on-line inspection system can increase speed, efficiency, and accuracy along with cost reduction.

6.2.1 Visual quality determination based on size and shape

Fish is sorted according to species, size, and quality after harvesting. This is performed manually, and is a labour-intensive and expensive process. Sorting can be accomplished continuously, automatically, and reliably using MVS or computer vision system (CVS). Common carp (*Cyprinus carpio*), St. Peter's fish (*Oreochromis* spp.), and grey mullet (*Mugil cephalus*) have been successfully separated using images of fish swimming in an aquarium [16]. Besides sorting of fish, CVS has been used to describe the rigor contractions of unstressed and stressed Atlantic salmon (*S. salar*) and Atlantic cod (*G. morhua*) fillets by monitoring the transient two- and three-dimensional changes in the geometry [17]. This method has been found suitable for industrial purposes. A method for quality grading of whole Atlantic salmon (*S. salar*) has also been developed using CVS [18], based on the external geometrical information from fish images.

Shrimp quality inspection relies on subjective sensory evaluation and routine sorting, counting, and weighing performed by trained inspectors. The uniformity ratio (UR) is calculated by taking the weight ratio of the largest 10% of shrimp to the smallest 10%. The inspectors determine visible defects (melanosis-black spots formed by the polyphenol oxidase enzyme), foreign materials, shell parts, and missing pieces (tails or segments). A MVS has been developed to determine the count and UR of whole, headless, peeled-tail-on, and peeled-tail-off white shrimp (*Paneus setiferus*) and headless, peeled-tail-on, and peeled-tail-off tiger shrimp (*Paneus monodon*) [19]. A similar experimental set-up has been used for whole, headless, peeled-tail-on, and peeled-tail-off white shrimp (*P. setiferus*) [20]. The authors concluded that this system could be used industrially if there were no shrimps touching or partially blocking each other.

Oysters are mostly sold by volume and grading is important for pricing. This is performed by humans and is labour-intensive and time-consuming. Predicting the volume or weight of oysters by MVS could be beneficial. Several studies have been performed to sort and grade oyster meat with MVS [21] to predict the volume by using a laser-line based method, and to obtain the thickness information by the shape of the laser line on the meat [22]. The volumes (overall, shell, and meat) of oysters from Florida, Texas (*Crassostrea virginica*) and Alaska (*Crassostrea gigas*) have also been measured using the Archimedes principle. The top- and side-view images of whole oysters were captured by MVS and the actual view areas have been calculated by calibrating their pixel area with that of a known reference square. The view area information was used to predict whole oyster volume and weight, and meat volume and weight. The r^2 values for the predicted oyster volumes were 0.85, 0.92, and 0.64 for oysters from Florida, Texas, and Alaska, respectively [23].

6.2.2 Visual quality determination based on colour

Colour is determined by colorimeters, spectrophotometers, and MVS. During the last two decades, the popularity of MVS increased due to its advantages. It can measure the colour of a sample whether it is small or very large in size, and irregular in shape. For example, a shrimp may be too small to cover the viewing aperture of a colorimeter, or a salmon may be too

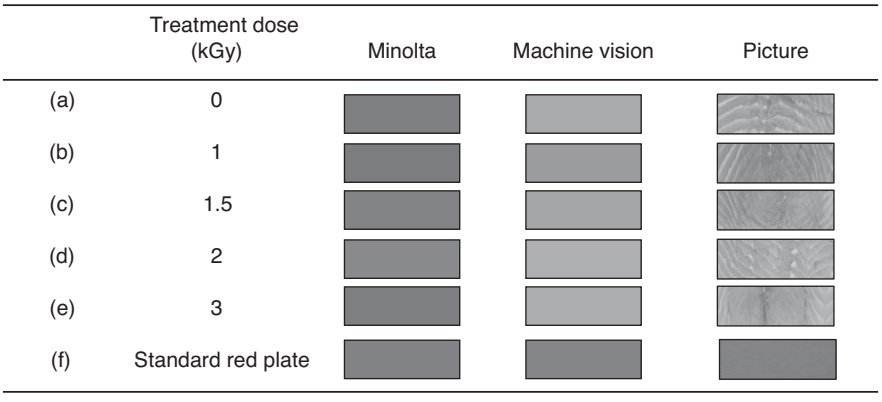

Fig. 6.1 Irradiated salmon colours measured by Minolta and machine vision system and their actual pictures. Adapted with permission from Yagiz *et al.* [26]. For a colour version of this figure, please see the colour plate section.

large to be measured all at once, requiring an average of several measurements to represent the actual salmon colour. These average L^* (lightness/darkness), a^* (redness/greenness), and b^* (yellowness/blueness) values may not give the actual colour of the sample [15]. MVS can determine L^*, a^*, and b^* values for each pixel of an image and analyze the entire surface of homogeneous and nonhomogeneous shapes and colours of samples. MVS also provides the colour spectrum and other visual attributes of the sample [24,25]. The performance of a hand-held Minolta colorimeter and a MVS in measuring the colour of Atlantic salmon (*S. salar*) fillets treated with different electron beam doses (0, 1, 1.5, 2, and 3 kGy) was compared [26]. The average L^*, a^*, and b^* values measured by MVS resulted in orange colours very close to that of the original sample (Fig. 6.1). On the other hand, average L^*, a^*, and b^* values measured by Minolta resulted in purplish colours. The standard red plate readings were similar for both systems. The reason for this difference is not known and needs to be investigated. The authors suggest visually comparing the average colours reported by any system against the actual sample colour.

Muscle colour is an important factor in consumer perception of meat quality [27]. Consumers mostly associate colour with freshness, better flavour, and high product quality [28]. Processing techniques and packaging conditions affect seafood colour. High pressure processing could extend the shelf-life of seafood; however, this process causes a change in the colour of rainbow trout (*Oncorhynchus mykiss*) and mahi mahi (*Coryphaena hippurus*) [29]. The high pressure processing in combination with cooking treatment was also found to affect the colour of Atlantic salmon (*S. salar*) [30]. Changes in the colour of salmon fillets have also been investigated during thermal sterilization processes [31]. A CVS was used to determine accurate colour and to measure shrinkage. Colour of salmon fillets change during thermal processing, since heating denatures the myoglobin and oxidizes carotenoid pigments [32] in the muscle of salmon, and colour changes from red to pale pink, as reflected in CIE L^*, a^*, and b^* values. The colour of fresh tuna treated with gas (4% CO, 20% CO_2, and 10% O_2), irradiation (1 or 2 kGy), or combination of gas and irradiation has been evaluated with MVS [14]. The R (Red), a^*, and hue parameters of the tuna samples have been measured. CO exposure increased the redness and preserved it during 12 days of storage at refrigerated temperatures. This is explained by the strong binding ability of CO to the haem in myglobin and haemoglobin to make it highly resistant to autoxidation and discolouration [33].

The diets used for fish feeding have an effect on the muscle colour. The impact of commercial diets on the muscle colour of cultured Gulf of Mexico sturgeon (*Ancipenser oxyrinchus desotoi*) has been investigated [34]. The L*, a*, and b* values of uncooked fillets stored for up to 15 days on ice have been measured using MVS. A colour difference in the fillets of sturgeon, which were fed with catfish, hybrid bass, and trout diets, was found. A comparison of colour measurements of these fillets using a hand-held Minolta colorimeter versus MVS has also been reported [35]. Overall colour change is defined as ΔE (Eqn. 6.1):

$$\Delta E = \sqrt{\left(L^* - L^*_{ref}\right)^2 + \left(a^* - a^*_{ref}\right)^2 + \left(b^* - b^*_{ref}\right)^2} \tag{6.1}$$

Colour change during storage is calculated by taking time zero colour values as reference (subscript $_{\text{ref}}$ in Eqn. 6.1). ΔE values were calculated using L*, a*, and b* values obtained from both devices. The respective ΔE values were significantly different between hand-held Minolta colorimeter and MVS at days 5, 10, and 15. Little colour change was observed over storage time using MVS and this was also observed visually in the images of the centre slices of the sturgeon fillets. The MVS could easily determine the variability in colour within a fillet surface. It was concluded that MVS provided valuable information regarding colour uniformity of a food product without increasing the number of readings required for each sample. MVS images could be kept in picture format and could be useful in automation and in-line quality control of food products' colour [35].

MVS could be used for automated quality control and grading of salmon fillets based on colour. The changes in skin and fillet colour of anesthetized and exhausted Atlantic salmon after killing, during rigor mortis, and after seven days of ice storage have been investigated [36]. Atlantic salmon (*S. salar*) fillets have been sorted based on their colour obtained by CVS [37]. Human inspectors also evaluated the colours of fillets visually according to the Roche *Salmo*Fan™ lineal standard. No significant differences were observed between the CVS and inspections made by humans ($P < 0.05$). It was concluded that CVS could replace manual labour in fish processing companies.

Blood residues have a negative effect on the shelf-life, meat quality, and sensory attributes of fish. Their impact on the quality of exsanguinated and unbled farmed trout (*Scophthalmus maximus*) was investigated [38]. Exsanguination improved the visual quality and CVS was able to quantify blood residues in the farmed trout. Other applications of the MVS to seafood quality evaluation have already been discussed [39].

6.3 Smell-related quality

Volatile compounds contributing to the characteristic odour of aquatic foods can be measured to determine their freshness [40]. Qualitative and quantitative analyses of volatiles of seafood products can be performed by using gas chromatography (GC) or gas chromatography/mass spectrometry (GC/MS). Individual components could also be correlated to sensorial perception using GC-olfactometry (GC-O) [41].

Fresh fish has no fishy odour, but smell develops with time after the fish is dead. Fish degradation after harvest is generally attributed to microbial spoilage, enzymatic degradation, and lipid oxidation. The composition of fish headspace, which is a result of microbiological and chemical degradation, gives information about its freshness [42,43]. Long-chain alcohols and carbonyl compounds, bromophenols, and *N*-cyclic compounds could be considered

as the major chemicals involved in the fresh fish odour. Short-chain carbonyl compounds, amines, sulphur compounds, aromatics, *N*-cyclic products, and acid compounds are produced upon microbial spoilage [40]. Defining fish freshness is a major problem, since the methods are time consuming, destructive, and labour-intensive [44]. Recent developments in sensor technologies and data analysis techniques have resulted in the development of rapid methods to detect post-mortem quality changes in foods [1,2,45]. Sensors for specific gases have also been developed to detect trimethylamine (TMA) and dimethylamine (DMA), which are assumed to be the fish degradation products [46–50]. In fact, no single index can cover all the complex changes occurring during fish spoilage [51], thus multiple sensors could be used to perform simultaneous analysis of various sensory related attributes [2]. In this respect, e-noses based on selective detection of the important volatile compounds, which are contributing to the spoilage odour (i.e. amines, sulphur compounds, alcohols, aldehydes, and esters) could be used to rapidly determine quality changes in fish [52].

The concept of the artificial nose system was proposed in 1982 [53] and was called an "electronic nose" at the beginning of 1990s, defined as "an instrument, which comprises an array of electronic chemical sensors with partial specificity, and an appropriate pattern-recognition system capable of recognizing simple or complex odours" [54]. The e-nose is composed of a sampling system, an array of gas sensors with different selectivities, a signal processing and conditioning system, and an appropriate pattern recognition algorithm to recognize simple or complex odours [54]. The most important part of an e-nose is the sensors. There are various types of sensors, and they need to be selected carefully to meet a particular application's requirements for precision, reproducibility, sensitivity, and stability, and to improve the discrimination characteristics of the aroma profiles. In general, sensor types used in e-noses are metal oxide semiconductor (MOS), conducting polymer, surface acoustic wave (SAW), bulk acoustic wave (BAW) devices, metal oxide field effect transistors (MOSFET), electrochemical, smell-seeing, and GC/MS-based sensors [55,56].

The signals collected from the e-nose sensors are evaluated with appropriate pattern recognition techniques. Two basic approaches, multivariate data analysis and artificial neural networks, are commonly used. Principal component analysis (PCA), discriminant function analysis (DFA), cluster analysis (CA), partial least squares regression (PLSR), canonical correlation analysis (CCA), and fuzzy logic or artificial neural networks (ANN) are most frequently used as pattern recognition techniques [57–60].

Various gas sensors were used to detect fish freshness in the 1990s [2,46,61–63] and by the end of that decade, e-noses started to be used in assessing seafood quality [64,65]. Most of the studies on the use of e-noses to assess seafood quality during the last decade [44,66–96] are listed in Table 6.1.

6.4 Taste-related quality

One of the factors positively related to the consumption of seafood products is a liking for the taste of the product [97,98]. The sense of taste in mammalians is perceived by non-specific taste buds, present on the papillae of the tongue. Overall, taste is correlated with a combination of basic tastes and taste sensations (bitterness, saltiness, sourness, sweetness, umami, metallic, astringency, spicy, and cooling effects). Interaction between different tastes may cause a desensitizing effect or threshold increase when two substances eliciting different tastes are present simultaneously. In addition to this, the decrease in sensitivity threshold

Table 6.1 Electronic nose applications to aquatic foods, with species, sensor types, and data analyses in the last decade

Product	Electronic nose used	Sensors	Data analysis techniques	Reference
European sea bass (*Dicentrarchus labrax*)	PEN2 model-Win Muster Airsense Analytic Inc. (Germany)	MOS	PCA and CA	[44]
Octopus (*Octopus vulgaris*)	Custom-made portable electronic nose (China)	TGS	PCA and DFA	[66]
Moroccan sardines (*Sardinia pilchardus*)	Custom-made portable electronic nose (Morocco)	TGS	PCA	[67]
Blue crab (*Callinectes sapidus*)	Cyranose 320^{TM}, Cyrano Sciences Inc. (USA)	CP	PCA, CDA, and SDA	[68]
Smoked salmon (*Salmo salar*)	FishNose (Iceland)	MOS	PCA and PLSR	[69]
Sardines (*Sardinia pilchardus*)	Custom-made portable electronic nose (Morocco)	MOS (TGS)	PCA, DFA, and FANN	[70]
Pink shrimp (*Pandalus jordani*)	e-NOSE 4000, EEV Inc. (UK)	CP sensors	DFA	[71]
Cod (*Gadus morhua*)	FreshSense, Maritech (Iceland)	ECS (CO, H_2S, SO_2, and NH_3)	PCA and PLSR	[52]
Smoked Atlantic salmon (*Salmo salar*)	FishNose, Optotek Engineering (Slovenia) (adapted from GEMINI e nose-Alpha MOS, France)	MOS	PCA and PLSR	[72]
Alaska pink salmon (*Oncorhynchus gorbuscha*)	Cyranose 320^{TM}, Cyrano Sciences Inc. (USA)	CP sensors	PCA and FSGDA	[73]
Haddock (*Melanogrammus aeglefinus*)	FreshSense, Icelandic Fisheries Laboratories and Maritech (Iceland)	ECS (CO, H_2S, SO_2, and NH_3)	PLSR	[74]
Sardines (*Sardina pilchardus*)	EnQbe, Tor Vergata (University of Rome and CNR (Italy)	TSM resonators	PLSR	[75]
Alaska pink salmon (*Oncorhynchus gorbuscha*)	Cyranose 320^{TM}, Cyrano Sciences Inc. (USA)	CP sensors	PCA and FSGDA	[76]
Smoked Atlantic salmon (*Salmo salar*)	Gemini, Alpha MOS (France) FishNose, Optotek (Slovenia)	MOS	PCA and PLSR	[77]
Shrimp (*Pandalus borealis*)	FreshSense, Maritech (Iceland)	ECS (CO, H_2S, SO_2, and NH_3)	PCA	[78]
Cod (*Gadus morhua*)	FreshSense, Bodvaki-Maritech (Iceland)	ECS (CO, H_2S, SO_2, and NH_3)	ANOVA	[79]
Baltic cod (*Gadus morhua*)	NST 3320, Applied Sensor (Sweden)	FE, MOS	PCA and regression	[80]

(*Continued*)

Table 6.1 (*Continued*)

Product	Electronic nose used	Sensors	Data analysis techniques	Reference
Anchovy (*Engraulis japonica*) sauce	e-NOSE 4000, Neotronics (UK)	CP sensors	PCA	[81]
Capelin (*Mallotus villosus*)	FreshSense, IFL, Element Sensor Systems (Iceland)	ECS (CO, H_2S, SO_2, and NH_3)	ANOVA	[82]
Cod (*Gadus morhua*) roe	FreshSense, IFL, Bodvaki-Maritech (Iceland)	ECS (CO, H_2S, SO_2, and NH_3)	PCA	[83]
Herring (*Clupea harengus*)	Custom-made system (Norway)	MOSFET, TGS	PLSR	[84]
Anchovy (*Engraulis encrasicholus* L.)	AromaScan, AromaScan Inc. (UK)	CP sensors	PCA and ANN	[85]
Atlantic salmon (*Salmo salar*)	AromaScanTM, AromaScan Inc. (USA)	CP sensors	DFA	[86]
Atlantic salmon (*Salmo salar*) Haddock (*Melanogrammus aeglefinus*) Atlantic cod (*Gadus morhua*)	Custom-made system (USA)	MOS	NN	[50]
Redfish (*Sebastes marinus*)	FreshSense, Bodvaki Company (Iceland)	ECS (CO, H_2S, SO_2, and NH_3)	PCA	[87]
Tilapia (*Oreochromis niloticus*)	e-NOSE 4000, EEV Inc. (UK)	CP sensors	DFA	[88]
Catfish (*Ictalurus punctatus*)	e-NOSE 4000, EEV Inc. (UK)	CP sensors	DFA	[89]
Argentinean hake (*Merluccius hubbsi*)	Custom-made system (Argentina)	Polycrystalline tin dioxide sensors	PCA	[90]
Atlantic cod (*Gadus morhua*)	FreshSense, Element Bodvaki Company (Iceland)	ECS (CO, H_2S, NO, SO_2, and NH_3)	PLS-DA	[91]
	LibraNose, Tor Vergata University of Rome with Technobiochip Company (Italy)	TSM resonators		
Mahi-mahi (*Coryphaena hippurus*)	AromaScan, AromaScan Inc. (USA)	CP sensors	DFA	[92]
Capelin (*Mallotus japonica*)	FreshSense, IFL, Element Sensor System (Iceland)	ECS (CO, H_2S, NO, SO_2, NH_3A7AM, and NH_3)	PCA and PLSR	[93]
Shrimp (*Penaeus aztecus*, *Litopenaeus vannamei*, *and Penaeus monodon*)	e-NOSE 4000, EEV Inc. (UK)	CP sensors	DFA	[94]
Atlantic salmon (*Salmo salar*)	e-NOSE 4000, EEV Inc. (UK)	CP sensors	DFA	[95]
Yellowfin Tuna (*Thunnus albacares*)	e-NOSE 4000, EEV Inc. (UK)	CP sensors	DFA	[96]

Abbreviations: ANN, Artificial neural network; CA, Cluster analysis; CDA, Canonical discriminant analysis; CP, Conducting polymer; DFA, Discriminant function analysis; ECS Electrochemical sensors; FANN, Fuzzy ARTMAP neural networks; FE, Field effect sensor; FSGDA, forward stepwise general discriminant analysis; IFL, Icelandic Fisheries Laboratories. MOS, Metal oxide semiconductor sensor; NN, Neural network; PCA, Principle component analysis; PLS-DA, partial least significant discriminant analysis; PLSR, Partial least squares regression; SDA, Stepwise discriminant analysis; TGS, Taguchi gas sensor.

may occur when substances are present at non-perceptible concentrations. In fact, perception thresholds of the human tongue to most tastes are much higher compared to those for olfaction [99].

In the last decade, a novel instrument, the e-tongue, has been developed to detect the tastes of food samples, especially liquid samples. This instrument is composed of a sensor array in combination with pattern recognition tools [100,101]. Most of the e-tongues reported so far consist of a combination of electrochemical methods based on potentiometric [102] or amperometric sensors [103]. These instruments have been widely used in quantitative analyses of liquids such as milk [104], alcoholic drinks (beer and wines) [102,105–107], vegetable and olive oils [108–109], natural and mineral waters [104,110,111], and various fruit juices [112,113], etc. The e-tongue has been applied to determine fish freshness [114, 115]. Simple Au and Ag wires have been used for the analysis of minced gilthead sea bream (*S. aurata*) and it has been found that this method could be used for the evaluation of fish freshness [114]. However, the e-tongue has limited application in the seafood area since the sample needs to be minced for e-tongue application. The e-tongues are more for use in determining the taste properties of liquid food products.

6.5 Combination of machine vision system and electronic nose

The MVS and e-nose combinations offer possibilities for the development of accurate and rapid measurement of quality of seafood in "orthogonal" dimensions. Therefore, their combination offers increased resolution of the discrimination capacity compared to the methods considered individually. The ability of e-nose and MVS to classify tilapia fillets based on their odours and colour has been investigated [88]. When e-nose data together with machine vision data were used to analyze the quality of tilapia fillets, the classification rates were higher than analyses using either data alone. Similar results were found when e-nose data alone were used for analyzing the quality of raw and cooked catfish fillets. The correct classification rates were lower than the ones obtained by using MVS together with e-nose [89]. These results point towards the advantages of the discriminating ability based on two independent quality parameters (colour and odour) considered together.

6.6 Conclusions

Rapid, objective, and non-destructive determination of smell and visual attributes of foods is possible with MVS and e-noses. Their combination increases the resolution of the discrimination capability of the analyses. MVS can be calibrated to assure comparability of images and results from different laboratories. E-noses have slightly different sensors between instruments, and their calibration is more challenging for seamless exchange of data between laboratories. For their widespread application certified data bases need to be developed, possibly with information regarding the important odour-active components of the sample atmospheres. Battery-operated portable e-noses can make field and on-line plant applications possible. The digital and discrete nature of the data from MVS and e-noses allow new possibilities for traceability and documentation of the quality of aquatic products.

References

1. Ólafsdóttir, G., Martinsdóttir, E., Oehlenschläger, J. *et al.* (1997). Methods to evaluate fish freshness in research and industry. *Trends in Food Science and Technology*, **8**, 258–265.
2. Olafsdottir, G., Nesvadba, P., Di Natale, C. *et al*. (2004). Multisensor for fish quality determination. *Trends in Food Science and Technology*, **15**, 86–93.
3. Huss, H.H. (1994). Assurance of seafood quality. *Technical Paper No. 334.* FAO Fisheries, Rome, Italy.
4. Luten, J.B. & Martinsdóttir, E. (1997). QIM: a European tool for fish freshness evaluation in the fishery chain. In: *Methods to Determine the Freshness of Fish in Research and Industry. Proceedings of the Final Meeting of the Concerted Action "Evaluation of Fish Freshness" AIR3CT94 2283*, *Nantes Conference*. Ólafsdóttir, G., Luten, J.B., Dalgaard, P. *et al*. (eds), International Institute of Refrigeration, Paris, France, pp. 287–296.
5. Hyldig, G. & Green-Peterson, D.M.B. (2004). Quality index method – an objective tool for determination of sensory quality. *Journal of Aquatic Food Product Technology*, **13**, 71–80.
6. Costell, E. (2002). A comparison of sensory methods in quality control. *Food Quality and Preference*, **13**, 341–353.
7. Hyldig, G. & Nielsen, J. (2004). QIM – a tool for determination of fish freshness. In: *Seafood Quality and Safety: Advances in the New Millennium*. Shahidi, F. & Simpson, B.K. (eds), ScienceTech Publishing Company, St. John's, NL, Canada, pp. 81–89.
8. Larsen, E.P., Heldbo, J., Jespersen, C.M. & Nielsen, J. (1992). Development of a method for quality assessment of fish for human consumption based on sensory evaluation. In: *Quality Assurance in the Fish Industry: Proceedings of an International Conference,* Copenhagen, Denmark, August 1991, Huss, H.H., Jakobsen, M, & Liston, J. (eds), Elsevier Science, Amsterdam, The Netherlands, pp. 351–358.
9. Andrade, A., Nunes, M.L. & Batista, I. (1997). Freshness quality grading of small pelagic species by sensory analysis. In: *Methods to Determine the Freshness of Fish in Research and Industry. Proceedings of the Final Meeting of the Concerted Action "Evaluation of Fish Freshness" AIR3CT94 2283, Nantes Conference*. Ólafsdóttir, G., Luten, J.B., Dalgaard, *et al*. (eds), International Institute of Refrigeration, Paris, France, pp. 333–338.
10. Huidobro, A., Pastor, A. & Tejada, M. (2000). Quality index method developed for raw gilthead seabream (*Sparus aurata*). *Journal of Food Science*, **65**, 1202–1205.
11. Sveinsdottir, K., Martinsdottir, E., Hyldig, G., Jørgensen, B. & Kristbergsson, K. (2002). Application of quality index method (QIM) scheme in shelf-life study of farmed Atlantic salmon (*Salmo salar*). *Journal of Food Science*, **67**, 1570–1579.
12. Sveinsdottir, K., Hyldig, G., Martinsdottir, E., Jørgensen, B. & Kristbergsson, K. (2003). Quality index method (QIM) scheme developed for farmed Atlantic salmon (*Salmo salar). Food Quality and Preference*, **14**, 237–245.
13. Bonilla, A.C., Sveinsdottir, K. & Martinsdottir, E. (2007). Development of quality index method (QIM) scheme for fresh cod (*Gadus morhua*) fillets and application in shelf-life study. *Food Control*, **18**, 352–358.
14. Balaban, M.O., Kristinsson, H.G. & Otwell, W.S. (2005). Evaluation of color parameters in a machine vision analysis of carbon monoxide-treated fish-part 1: Fresh tuna. *Journal of Aquatic Food Product Technology*, **14**, 5–24.
15. Balaban, M.O. & Odabasi, A.Z. (2006). Measuring color with machine vision. *Food Technology*, **60**, 32–36.
16. Zion, B., Shklyar, A. & Karplus, I. (2000). *In-vivo* fish sorting by computer vision. *Aquacultural Engineering*, **22**, 165–179.
17. Misimi, E., Erikson, U., Digre, H., Skavhaug, A. & Mathiassen, J.R. (2008). Computer vision-based evaluation of pre-and post-rigor changes in size and shape of Atlantic cod (*Gadus morhua*) and Atlantic salmon (*Salmo salar*) fillets during rigor mortis and ice storage: Effects of peri-mortem handling stress. *Journal of Food Science*, **73**, E57–E68.
18. Misimi, E., Erikson, U. & Skavhaug, A. (2008). Quality grading of Atlantic salmon (*Salmo salar*) by computer vision. *Journal of Food Science*, **73**, E211–E217.
19. Balaban, M.O., Yeralan, S. & Bergmann, Y. (1994). Determination of count and uniformity ratio of shrimp by machine vision. *Journal of Aquatic Food Product Technology*, **3**, 43–58.

20. Luzuriaga, D., Balaban, M.O. & Yeralan, S. (1997). Analysis of visual quality attributes of white shrimp by machine vision. *Journal of Food Science*, **62**, 113–118, 130.
21. Parr, M.B., Byler, R.K., Diehl, K.C. & Hackney, C.R. (1994). Machine vision based oyster meat grading and sorting machine. *Journal of Aquatic Food Product Technology*, **3**, 5–24.
22. Lee, D.J., Lane, R.M. & Chang, G.H. (2001). Three-dimensional reconstruction for high speed volume measurement. In: *Proceedings of the International Society for Optical Engineering (SPIE)*, Vol. 4189. Harding, K.G., Miller, J.W.V. & Batchelor. B.G. (eds), Boston, MA, pp. 258–267.
23. Damar, S., Yagiz, Y., Balaban, M.O., Ural, S., Oliveira, A.C.M. & Crapo, C.A. (2006). Prediction of oyster volume and weight using machine vision. *Journal of Aquatic Food Product Technology*, **15**, 3–15.
24. Balaban, M.O. (2008). Quantifying nonhomogeneous colors in agricultural materials. Part I: Method development. *Journal of Food Science*, **73**, S431–S437.
25. Balaban, M.O., Aparicio, J., Zotarelli, M. & Sims, C. (2008). Quantifying nonhomogeneous colors in agricultural materials. Part II: Comparison of machine vision and sensory panel evaluations. *Journal of Food Science*, **73**, S438–S442.
26. Yagiz, Y., Balaban, M.O., Kristinsson, H.G., Welt, B.A. & Marshall, M.R. (2009). Comparison of Minolta colorimeter and machine vision system in measuring colour of irradiated Atlantic salmon. *Journal of the Science of Food and Agriculture*, **89**, 728–730.
27. Jeremiah, L.E., Carpenter, Z.I. & Smith, G.C. (1972). Beef color as related to consumer acceptance and palatability. *Journal of Food Science*, **37**, 476–479.
28. Gormley, T.R. (1992). A note on consumer preference of smoked salmon color. *Irish Journal of Agricultural and Food Research*, **31**, 199–202.
29. Yagiz, Y., Kristinsson, H.G., Balaban, M.O. & Marshall, M.R. (2007). Effect of high pressure treatment on the quality of rainbow trout (*Oncorhynchus mykiss*) and mahi mahi (*Coryphaena hippurus*). *Journal of Food Science*, **72**, C509–C515.
30. Yagiz, Y., Kristinsson, H.G., Balaban, M.O., Welt, B.A., Ralat, M. & Marshall, M.R. (2009). Effect of high pressure processing and cooking treatment on the quality of Atlantic salmon. *Food Chemistry*, **116**, 828–835.
31. Kong, F., Tang, J., Rasco, B., Crapo, C. & Smiley, S. (2007). Quality changes of salmon (*Oncorhynchus gorbuscha*) muscle during thermal processing. *Journal of Food Science*, **72**, S103–S111.
32. Haard, N.F. (1992). Biochemistry and chemistry of color and color changes in seafoods. In: *Advances in Seafood Biochemistry – Composition and Quality*. Flick, G.J. & Martin, R.E. (eds), Technomic Publishing Company Inc., Lancester, PA, pp. 305–360.
33. Sorheim, O., Aune, T. & Nesbakken, T. (1997). Technological, hygienic and toxicological aspects of carbon monoxide used in modified-atmosphere packaging of meat. *Trends in Food Science and Technology*, **8**, 307–312.
34. Oliveira, A.C.M., O'Keefe, S.F., Balaban, M., Sims, C.A. & Portier, K.M. (2004). Influence of commercial diets on quality aspects of cultured Gulf of Mexico surgeon (*Ancipenser oxyrinchus desotoi*). *Journal of Food Science*, **69**, S278–S284.
35. Oliveira, A.C.M. & Balaban, M.O. (2006). Comparison of a colorimeter with a machine vision system in measuring color of Gulf of Mexico sturgeon fillets. *Applied Engineering in Agriculture*, **22**, 583–587.
36. Erikson, U. & Misimi, E. (2008). Atlantic salmon skin and fillet color changes effected by peri-mortem handling stress, rigor mortis, and ice storage. *Journal of Food Science*, **73**, C50–C59.
37. Misimi, E., Mathiassen, J.R. & Erikson, U. (2007). Computer vision-based sorting of Atlantic salmon (*Salmo salar*) fillets according to their color level. *Journal of Food Science*, **72**, S30–S35.
38. Roth, B., Schelvis-Smit, R., Stien, L.H., Foss, A., Nortvedt, R. & Imsland, A. (2007). Exsanguination of trout and the effect of fillet quality measured mechanically, by sensory evaluation, and with computer vision. *Journal of Food Science*, **72**, E525–E531.
39. Balaban, M.O., Odabaşı, A.Z., Damar, S. & Oliveira, A.C.M. (2008). Quality evaluation of seafood. In: *Computer Vision Technology for Food Quality Evaluation*. Sun, D.-W. (ed.), pp. Academic Press, Burlington, MA, 189–209.
40. Ólafsdóttir, G. & Fleurence, J. (1997). Evaluation of fish freshness using volatile compounds – classification of volatile compounds in fish. In: *Methods to Determine the Freshness of Fish in Research and Industry. Proceedings of the Final Meeting of the Concerted Action "Evaluation of Fish Freshness" AIR3CT94 2283, Nantes Conference*. Ólafsdóttir, G., Luten, J.B., Dalgaard, P. *et al*. (eds), International Institute of Refrigeration, Paris, France, pp. 51–69.

41. Triqui, R. & Bouchriti, N. (2003). Freshness assessments of Moroccan sardines (*Sardina pilchardus*): Comparison of overall sensory changes to instrumentally determined volatiles. *Journal of Agricultural and Food Chemistry*, **51**, 7540–7546.
42. Josephson, D.B., Lindsay, R.C. & Ólafsdóttir, G. (1986). Measurement of volatile aroma constituents as a means for following sensory deterioration of fresh fish and fishery products. In: *Proceedings of an International Symposium, University of Alaska Sea Grant Program*, Anchorage, AK. Kramer, D.E. & Liston, J. (eds), Elsevier Science, Amsterdam, The Netherlands, pp. 27–47.
43. Lindsay, R.C., Josephson, D.B. & Ólafsdóttir, G. (1986). Chemical and biochemical indices for assessing the quality of fish packaged in controlled atmosphere. In: *Proceedings of an International Symposium, University of Alaska Sea Grant Program*. Anchorage, AK. Kramer, D.E & Liston, J. (eds), Elsevier Science, Amstherdam, The Netherlands, pp. 221–234.
44. Limbo, S., Sinelli, N., Torri, L. & Riva, M. (2009). Freshness decay and shelf-life predictive modelling of European sea bass (*Dicentrarchus labrax*) applying chemical methods and electronic nose. *LWT – Food Science and Technology*, **42**, 977–984.
45. Ellis, D.I. & Goodacre, R. (2001). Rapid and quantitative detection of the microbial spoilage of muscle foods: Current status and future trends. *Trends in Food Science and Technology*, **12**, 414–424.
46. Egashira, M., Shimizu, Y. & Takao, Y. (1990). Trimethylamine sensor based on semiconducting metal oxides for detection of fish freshness. *Sensors and Actuators B*, **1**, 108–112.
47. Wei, P.H., Li, G.B., Zhao, S.Y. & Chen, L.R. (1999). Gas-sensing properties of Th/SnO_2 thin-film gas sensor to trimethylamine. *Journal of the Electrochemical Society*, **146**, 3536–3537.
48. Shiyong, Z., Peihai, W. & Shenhao, C. (2000). Enhancement of trimethylamine sensitivity of MOCVD-SnO_2 thin film gas sensor by thorium. *Sensors and Actuators B*, **62**, 117–120.
49. Kwon, T.-H., Park, S.-H., Ryu, J.-Y. & Choi, H.-H. (1998). Zinc oxide thin film doped with Al_2O_3, TiO_2 and V_2O_5 as sensitive sensor for trimethylamine gas. *Sensors and Actuators B*, **46**, 75–79.
50. Hammond, J., Marquis, B., Michaels, R. *et al*. (2002). A semiconducting metal-oxide array for monitoring fish freshness. *Sensors and Actuators B*, **84**, 113–122.
51. Martin, R.E., Gray, R.J.H. & Pierson, M.D. (1978). Quality assessment of fresh fish and the role of the occurring microflora. *Food Technology*, **5**, 188–192.
52. Ólafsdóttir, G., Lauzon, H.L., Martinsdottir, E., Oehlenschläger, J. & Krisbergsson, K. (2006). Evaluation of shelf-life of superchilled cod (*Gadus morhua*) fillets and the influence of temperature fluctuations during storage on microbial and chemical quality indicators. *Journal of Food Science*, **71**, S97–S109.
53. Persaud, K. & Dodd, G.H. (1982). Analysis of discrimination mechanisms in the mammalian olfactory system using a model nose. *Nature*, **299**, 352–355.
54. Gardner, J.W. & Bartlett, P.N. (1994). A brief history of electronic noses. *Sensors and Actuators B*, **18**, 211–220.
55. Korel, F. & Balaban, M.Ö. (2009). Electronic nose technology in food analysis. In: *Handbook of Food Analysis Instruments*. Ötleş, S. (ed.), CRC Press Taylor and Francis Group, Boca Raton, FL, pp. 365–378.
56. Deisingh, A.K., Stone, D.C. & Thompson, M. (2004). Applications of electronic noses and tongues in food analysis. *International Journal of Food Science and Technology*, **39**, 587–604.
57. Haugen, J.E. & Kvaal, K. (1998). Electronic nose and artificial neural network. *Meat Science*, **49**, S273–S286.
58. Egashira, M. & Shimizu, Y. (1993). Odour sensing by semiconductor metal oxides. *Sensors and Actuators B*, **13**, 443–446.
59. Hong, H.K., Shin, H.W., Yun, D.Y. *et al.* (1996). Electronic nose system with micro gas sensor array. *Sensors and Actuators B*, **36**, 338–341.
60. Ólafsdóttir, G. (2003). Rapid olfaction arrays for determining fish quality. In: *Rapid and On-line Instrumentation for Food Quality Assurance*. Tothill, I.E. (ed.), CRC Press, Boca Raton, FL, pp. 339–360.
61. Ólafsson, R., Martinsdóttir, E., Ólafsdóttir, G., Sigfússon, T.I. & Gardner, J.W. (1992). Monitoring of fish freshness using tin oxide sensors. In: *Sensors and Sensory Systems for an Electronic Nose*. Gardner, J.W. & Bartlett, P.N. (eds), Kluwer, Dordrecht, The Netherlands, pp. 257–272.
62. Nanto, H., Sokooshi, H. & Kawai, T. (1993). Aluminium-doped ZnO thin film gas sensor capable of detecting freshness of sea foods. *Sensors and Actuators B*, **14**, 715–717.
63. Schweizer-Berberich, P.-M., Vaihinger, S. & Göpel, W. (1994). Characterization of food freshness with sensor arrays. *Sensors and Actuators B*, **18**, 282–290.

64. Winquist, F., Sundgren, H. & Lundström, I. (1995). A practical use of electronic noses: Quality estimation of cod fillet bought over the counter. In: *Proceedings of the 8th International Conference on Solid-State Sensors and Actuators and Eurosensors IX (Transducers' 95)*. Stockholm, Sweden, pp. 695–698.
65. Di Natale, C., Macagnano, A., Davide, F. *et al.* (1997). An electronic nose for food analysis. *Sensors and Actuators B*, **44**, 521–526.
66. Zhang, S., Xie, C., Bai, Z., Hu, M., Li, H. & Zeng, D. (2009). Spoiling and formaldehyde-containing detections in octopus with an e-nose. *Food Chemistry*, **113**, 1346–1350.
67. Barbri, N.E., Llobet, E., Bari, N.E., Correig, X. & Bouchikhi, B. (2008). Application of a portable electronic nose system to assess the freshness of Moroccan sardines. *Materials Science and Engineering C*, **28**, 666–670.
68. Sarnoski, P.J., Jahncke, M.L., O'Keefe, S.F., Mallikarjunan, P. & Flick, G.J. (2008). Determination of quality attributes of blue crab (*Callinectes sapidus*) meat by electronic nose and Draeger-tube analysis. *Journal of Aquatic Food Product Technology*, **17**, 234–252.
69. Jónsdóttir, R., Ólafsdóttir, G., Chanie, E. & Haugen, J.-E. (2008). Volatile compounds suitable for rapid detection as quality indicators of cold smoked salmon (*Salmo salar*). *Food Chemistry*, **109**, 184–195.
70. Barbri, N.E., Amari, A., Vinaixa, M., Bouchikhi, B., Correig, X. & Llobet, E. (2007). Building of a metal oxide gas sensor-based electronic nose to assess the freshness of sardines under cold storage. *Sensors and Actuators B*, **128**, 235–244.
71. Luzuriaga, D.A., Korel, F. & Balaban, M.Ö. (2007). Odor evaluation of shrimp treated with different chemicals using an electronic nose and a sensory panel. *Journal of Aquatic Food Product Technology*, **16**, 57–75.
72. Haugen J.E., Chanie, E., Westad, F. *et al.* (2006). Rapid control of smoked Atlantic salmon (*Salmo salar*) quality by electronic nose: Correlation with classical evaluation methods. *Sensors and Actuators B*, **116**, 72–77.
73. Chantarachoti, J., Oliveira, A.C.M., Himelbloom, B.H., Crapo, C.A. & McLachlan, D.G. (2006). Portable electronic nose for detection of spoiling Alaska pink salmon (*Oncorhynchus gorbuscha*). *Journal of Food Science*, **71**, S414–S421.
74. Olafsdottir, G., Lauzon, H.L., Martinsdottir, E. & Kristbergsson, K. (2006). Influence of storage temperature on microbial spoilage characteristics of haddock fillets (*Melanogrammus aeglefinus*) evaluated by multivariate quality prediction. *International Journal of Food Microbiology*, **111**, 112–125.
75. Macagnano, A., Careche, M., Herrero, A. *et al.* (2005). A model to predict fish quality from instrumental features. *Sensors and Actuators B*, **111–112**, 293–298.
76. Oliveira, A.C.M., Crapo, C.A., Himelbloom, B., Vorholt, C. & Hoffert, J. (2005). Headspace gas chromatography-mass spectrometry and electronic nose analysis of volatile compounds in canned Alaska pink salmon having various grades of watermarking. *Journal of Food Science*, **70**, S419–S426.
77. Olafsdottir, G., Chanie, E., Westad, F. *et al.* (2005). Prediction of microbial and sensory quality of cold smoked Atlantic salmon (*Salmo salar*) by electronic nose. *Journal of Food Science*, **70**, S563–S574.
78. Zeng, Q.Z., Thorarinsdottir, K.A. & Olafsdottir, G. (2005). Quality changes of shrimp (*Pandalus borealis*) stored under different cooling conditions. *Journal of Food Science*, **70**, S459–S466.
79. Olafsdottir, G., Jonsdottir, R., Lauzon, H.L., Luten, J. & Kristbergsson, K. (2005). Characterization of volatile compounds in chilled cod (*Gadus morhua*) fillets by gas chromatography and detection of quality indicators by an electronic nose. *Journal of Agricultural and Food Chemistry*, **53**, 10140–10147.
80. Kent, M., Oehlenschlager, J., Mierke-Klemeyer, S. *et al.* (2004). A new multivariate approach to the problem of fish quality estimation. *Food Chemistry*, **87**, 531–535.
81. Kim, J.H., Ahn, H.J., Yook, H.S. *et al.* (2004). Color, flavor, and sensory characteristics of gamma-irradiated salted and fermented anchovy sauce. *Radiation Physics and Chemistry*, **69**, 179–187.
82. Bragadóttir, M., Pálmadóttir, H. & Kristbergsson, K. (2004). Composition and chemical changes during storage of fish meal from capelin (*Mallotus villosus*). *Journal of Agricultural and Food Chemistry*, **52**, 1572–1580.
83. Jonsdottir, R., Olafsdottir, G., Martinsdottir, E. & Stefansson, G. (2004). Flavor characterization of ripened cod roe by gas chromatography, sensory analysis, and electronic nose. *Journal of Agricultural and Food Chemistry*, **52**, 6250–6256.
84. Haugen, J.-E. & Undeland, I. (2003). Lipid oxidation in herring fillets (*Clupea harengus*) during ice storage measured by a commercial hybrid gas-sensor array system. *Journal of Agricultural and Food Chemistry*, **51**, 752–759.

85. Vázquez, M.J., Lorenzo, R.A. & Cela, R. (2003). The use of an "electronic nose" device to monitor the ripening process of anchovies. *International Journal of Food Science and Technology*, **38**, 273–284.
86. Du, W.-X., Lin, C.-M., Huang, T., Kim, J., Marshall, M. & Wei, C.-I. (2002). Potential application of the electronic nose for quality assessment of salmon fillets under various storage conditions. *Journal of Food Science*, **67**, 307–313.
87. Ólafsdóttir, G., Li, X., Lauzon, H.L. & Jónsdóttir, R. (2002). Precision and application of electronic nose for freshness monitoring of whole redfish (*Sebastes marinus*) stored in ice and modified atmosphere bulk storage. *Journal of Aquatic Food Product Technology*, **11**, 229–249.
88. Korel, F., Luzuriaga, D.A. & Balaban, M.Ö. (2001). Objective quality assessment of raw tilapia (*Oreochromis niloticus*) fillets using electronic nose and machine vision. *Journal of Food Science*, **66**, 1018–1024.
89. Korel, F., Luzuriaga, D.A. & Balaban, M.Ö. (2001). Quality evaluation of raw and cooked catfish (*Ictalurus punctatus*) using electronic nose and machine vision. *Journal of Aquatic Food Product Technology*, **10**, 3–18.
90. O'Connell, M., Valdora, G., Peltzer, G. & Negri, R.M. (2001). A practical approach for fish freshness determinations using a portable electronic nose. *Sensors and Actuators B*, **80**, 149–154.
91. Di Natale, C., Olafsdottir, G., Einarsson, S., Martinelli, E., Paolesse, R. & D'Amico, A. (2001). Comparison and integration of different electronic noses for freshness evaluation of cod-fish fillets. *Sensors and Actuators B*, **77**, 572–578.
92. Du, W.-X., Huang, T.-S., Kim, J., Marshall, M.R. & Wei, C.-I. (2001). Chemical, microbiological, and AromaScan evaluation of mahi mahi fillets under various storage conditions. *Journal of Agricultural and Food Chemistry*, **49**, 527–534.
93. Ólafsdóttir, G., Högnadóttir, Á., Martinsdóttir, E. & Jónsdóttir, H. (2000). Application of an electronic nose to predict total volatile bases in capelin (*Mallotus villosus*) for fishmeal production. *Journal of Agricultural and Food Chemistry*, **48**, 2353–2359.
94. Luzuriaga, D.A. & Balaban, M.O. (1999). Evaluation of the odor of decomposition in raw and cooked shrimp: Correlation of electronic nose readings, odor sensory evaluation and ammonia levels. In: *Electronic Noses & Sensor Array Based Systems-Design and Applications*. Hurst, W.J. (ed.), Technomic Publishing Company, Lancaster, PA, pp. 177–184.
95. Luzuriaga, D.A. & Balaban, M.O. (1999). Electronic nose odor evaluation of salmon fillets stored at different temperatures. In: *Electronic Noses & Sensor Array Based Systems-Design and Applications*. Hurst, W.J. (ed.), Technomic Publishing Company, Lancaster, PA, pp. 162–169.
96. Newman, D.J., Luzuriaga, D.A. & Balaban, M.O. (1999). Odor and microbiological evaluation of raw tuna: Correlation of sensory and electronic nose data. In: *Electronic Noses & Sensor Array Based Systems-Design and Applications*. Hurst, W.J. (ed.), Technomic Publishing Company, Lancaster, PA, pp. 170–176.
97. Gall, K. & O'Dierno, L. (1994). Aquaculture marketing survey: Consumers, retail stores, and food service operations in New York and New Jersey. New Jersey Department of Agriculture, New York Sea Grant, Northeast Regional Aquaculture Center, and the USDA, Stony Brook, NY, p. 109.
98. Gempesaw, C.M., Bacon, J.R., Wessells, C.R. & Manalo, A. (1995). Consumer perceptions of aquaculture products. *American Journal of Agricultural Economics*, **77**, 1306–1312.
99. Di Natale, C. & Ólafsdóttir, G. (2009). Electronic nose and electronic tongue. In: *Fishery Products Quality, Safety and Authenticity*. Rehbein, H. & Oehlenschläger, J. (eds), Wiley-Blackwell, Oxford, UK, pp. 105–126.
100. Legin, A., Rudnitskaya, A., Vlasov, Y., Di Natale, C., Mazzone, E. & D'Amico, A. (2000). Application of electronic tongue for qualitative and quantitative analysis of complex liquid media. *Sensors and Actuators B*, **65**, 232–234.
101. Tian, S.Y., Deng, S.P. & Chen, Z.X. (2007). Multifrequency large amplitude pulse voltammetry: a novel electrochemical method for electronic tongue. *Sensors and Actuators B*, **123**, 1049–1056.
102. Legin, A., Rudnitskaya, A., Vlasov, Y., Di Natale, C., Mazzone, E. & D'Amico, A. (1999). Application of electronic tongue for quantitative analysis of mineral water and wine. *Electroanalysis*, **11**, 814–820.
103. Winquist, F., Wide, P. & Lundström, I. (1997). An electronic tongue based on voltammetry. *Analytica Chimica Acta*, **357**, 21–31.
104. Dias, L.A., Peres, A.M., Veloso, A.C.A., Reis, F.S., Vilas-Boas, M. & Machado, A.A.S.C. (2009). An electronic tongue taste evaluation: Identification of goat milk adulteration with bovine milk. *Sensors and Actuators B*, **136**, 209–217.

105. Rudnitskaya, A., Polshin, E., Kirsanov, D. *et al.* (2009). Instrumental measurement of beer taste attributes using an electronic tongue. *Analytica Chimica Acta*, **646**, 111–118.
106. Pigani, L., Foca, G., Ulrici, A. *et al.* (2009). Classification of red wines by chemometric analysis of voltammetric signals from PEDOT-modified electrodes. *Analytica Chimica Acta*, **643**, 67–73.
107. Rudnitskaya, A., Schmidtke, L.M., Delgadillo, I., Legin, A. & Scollary, G. (2009). Study of the influence of micro-oxygenation and oak chip maceration on wine composition using an electronic tongue and chemical analysis. *Analytica Chimica Acta*, **642**, 235–245.
108. Apetrei, C., Rodríguez-Méndez, M.L. & Saja, J.A. de. (2005). Modified carbon paste electrodes for discrimination of vegetable oils. *Sensors and Actuators B*, **111–112**, 403–409.
109. Cosio, M.S., Ballabio, D., Benedetti, S. & Gigliotti, C. (2007). Evaluation of different storage conditions of extra virgin olive oils with an innovative recognition tool built by means of electronic nose and electronic tongue. *Food Chemistry*, **101**, 485–491.
110. Moreno, L., Merlos, A., Abramova, N., Jiménez, C. & Bratov, A. (2006). Multi-sensor array used as an "electronic tongue" for mineral water analysis. *Sensors and Actuators B*, **116**, 130–134.
111. Martínez-Máñez, R., Soto, J., Garcia-Breijo, E., Gil, L., Ibáñez, J. & Llobet, E. (2005). An "electronic tongue" design for the qualitative analysis of natural waters. *Sensors and Actuators B*, **104**, 302–307.
112. Lvova, L., Kim, S.S., Legin, A. *et al.* (2002). All-solid-state electronic tongue and its application for beverage analysis. *Analytica Chimica Acta*, **468**, 303–314.
113. Bleibaum, R., Stone, H., Tan, T., Labreche, S., Saint-Martin, E. & Isz, S. (2002). Comparison of sensory and consumer results with electronic nose and tongue sensors for apple juices. *Food Quality and Preference*, **13**, 409–422.
114. Gil, L., Barat, J.M., Garcia-Breijo, E., Ibañez, J. *et al.* (2008). Fish freshness analysis using metallic potentiometric electrodes. *Sensors and Actuators B*, **131**, 362–370.
115. Barat, J.M., Gil, L., García-Breijo, E. *et al.* (2008). Freshness monitoring of sea bream (*Sparus aurata*) with a potentiometric sensor. *Food Chemistry*, **108**, 681–688.