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Review

Multisensor for fish quality determination

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The European fish industry is still reluctant to implement methods other than sensory to monitor freshness and quality of fish products, although general concensus exists about the importance of various quality attributes and the need for methods to monitor quality. The objective of the project FAIR CT98-4076 (MUSTEC) was to evaluate several physico-chemical techniques and to integrate their outputs into a more robust estimate of the freshness quality of fish. The techniques used for this multisensor approach were based on visible light spectroscopy, electrical properties, image analysis, colour, electronic noses and texture. Combining the outputs of the instrumental techniques and calibrating them with sensory scores of Quality Index Method (QIM) for attributes like appearance, smell and texture, gives an Artificial Quality Index (AQI) that can be as accurate and precise as the QIM sensory score. The outcome provides a basis for the construction and industrial exploitation of multi-sensor-devices for defining the quality of fish.

Introduction

Quality assurance in the fish sector involves monitoring and documenting defined quality criteria as required by regulations (European Community, 1996), product specifications and consumer demands. These requirements may be of different importance to the various parts of the supply and distribution chains for fish, which vary greatly between countries and for different types of products. With the developments taking place in food law and in the marketing of food, the commercial participants are increasingly demanding a full range of information relating to fish quality and traceability of the products. Selection and supplement of relevant information, including parameters describing quality of fish is thus needed.

Fish quality is a complex concept involving a whole range of factors which for the consumer include for example: safety, nutritional quality, availability, convenience and integrity, freshness, eating quality and the obvious physical attributes of the species, size and product type (Bisogni, Ryan, & Regenstein, 1987; Botta, 1995; Oehlenschläger & Sörensen, 1998; Bremner,

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2000). Information about handling, processing and storage techniques, including time/temperature histories, that can affect the freshness and quality of the products is very important for the partners in the chain. Additionally, seasonal condition, the effects of fishing grounds and capture methods and the occurrence of various quality defects influence the overall quality. One of the most unique characteristics of fish as food is that it is a highly perishable commodity. Consequently, time passed after catch and the temperature 'history' of fish is very often the key factor determining the final quality characteristics of a fish product.

Fish freshness is fundamental to fish quality. The state of freshness can be described by a variety of definite properties of the fish which can be assessed by various indicators (Bremner & Sakaguchi, 2000). These properties, and thus the freshness and quality of the end product, are dependent on different biological and processing factors that influence the degree of various physical, chemical, biochemical and microbiological changes occurring *post mortem* in fish (Huss, 1995; Botta, 1995). Rapid, inexpensive and accurate instrumental and sensory methods have been developed, that can be correlated with time after catch or attributes related to fish freshness (Botta, 1995; Connell, 1995; Olafsdóttir *et al.*, 1997; 1998). An estimate of freshness can be obtained by defining criteria related to changes in sensory attributes like appearance, odour, colour and texture, that can be measured and quantified by sensory or instrumental methods.

The possibility to develop a multi-sensor device to measure and/or estimate fish freshness with a combination of instrumental techniques (electronic noses, spectroscopic methods, texture-meters, image analysers, colour meters and devices measuring electrical properties) was investigated in a European project called "Development of Multi-Sensor Techniques for Monitoring the Quality of Fish" (MUSTEC/FAIR 98 4076) (Nesvadba, 2003; Oehlenschläger *et al.*, 2001).

In this paper some of the results will be highlighted and discussed to give guidelines for further research on appropriate combination of techniques for a multi-sensor instrument for rapid monitoring of fish quality aspects.

Monitoring of the quality of fish in the industry

Sensory assessment has always played a key role in quality and freshness evaluation in the fish industry. The various sensory characteristics, such as outer appearance, odour and colour are still very important in quality control. Parameters related to origin, handling and defects are also considered important in the quality systems in the fish processing industry. Sensory inspection of processed fish is used in the fish industry to find defects that have occurred during handling and processing (Oehlenschläger, 1998).

Evaluation of the quality of whole wet fish

The evaluation of the raw material is done at the moment of landing, at fish auctions or in the reception area in the fish processing plants. Information about species, catching area and catching day has to be provided. Batches are evaluated by looking at handling practices on board: weight of fish and ice, how the fish is aligned in the tub, washing and icing, i.e. fish-ice layers and ice/fish ratio. Evaluation of freshness is done at this stage using sensory assessment. For whole fish the EU quality grading scheme (Howgate, Johnston, & Whittle, 1992), is used as required by EU regulation (European Community, 1996) but some initiatives have been taken to implement a new sensory method called the Quality Index Method (QIM) to standardise sensory assessment for each species (Bremner, 1985; Bremner, Olley, & Vail, 1986; Larsen, Heldbo, Jespersen, & Nielsen, 1992; Luten & Martinsdottir, 1998; Martinsdóttir, Luten, Schelvis, & Hyldig, 2003).

Evaluation of the quality of fillets

For the evaluation of fillets in fish processing, samples are taken randomly after trimming and checked for defects. Defects can be related to the condition of the fish flesh (e.g. gaping, watery), appearance, which includes colour defects (bruises, bloodspots) and dehydration (frozen storage defects). Other defects such as improper packaging and cutting and trimming faults and oversights (remaining bones, parasites, foreign matters, skin and black membrane) are related to workmanship. Evaluation of defects is widely used in control of processes and to grade fish for selling or buying purposes.

For freshness determination of raw fillets, colour and smell are evaluated, but for cooked fish schemes like the Torry scheme (Shewan, MacKintosh, Tucker, & Erhenberg, 1953) are in use. In many companies, however, own sensory schemes tailor made for their special purposes have been developed. Evaluation of raw fillets is also done in secondary processing before further processing and in retail before packaging (e.g. MAP) and labelling for sale.

Sensory evaluation of raw fillets is difficult and therefore, it is likely that the fish industry would welcome a reliable and easy to use multi-sensor device for that evaluation.

Fish sector's view on quality measurements of fish

One of the tasks in the MUSTEC project was to determine possible scenarios for monitoring the quality of fish where a multi-sensor device for evaluation would be useful in the fish industry. A survey was done to gauge the European fish sector's view on the importance of various quality attributes of fish and methods of measuring them. This survey also covered the attitudes of the fish industry towards the need of multi-sensor devices that can be used in quality monitoring and control (Jørgensen *et al.*, 2003).

Sensory attributes influencing the freshness and quality of fish related to appearance, texture, smell, color, defects and handling were all considered very important. However, the views regarding the importance of instrumental techniques to measure these properties were contradictory. Instruments based on a single technique to measure individual properties were not considered important, but there was an agreement on the importance of the needs for rapid instrumental methods to measure the overall concepts freshness and quality (Jørgensen *et al.*, 2003).

The long time tradition in the fish industry to have experienced people with many years of practice in control functions, performing sensory evaluation, is changing. Since personnel in the fish industry is changing and new staff and younger people with little or no experience in evaluating fish quality come into the fish business, advice, guidelines and reliable tools to perform the evaluation are required. Sensory schemes and instrumental methods to evaluate quality are therefore needed for use in the fish industry. However, the implementation of new sensory methods and instrumental methods which measure attributes related to freshness and quality has been very slow in the fish industry. The reason for the reluctance to use monitoring methods for freshness and quality may be that the fish industry is not familiar with the new sensory methods and instruments already commercially available. Perhaps there is no economical incentive for the industry to measure the quality because the demand for fish is greater than supply and therefore all fish is sold at a high price despite different quality. Another reason may be that in many cases the fish processors own the fishing vessels and are well informed about the quality of the catch. All information about origin, catching time and handling are well documented and the traceability of the products is assured giving the confidence that the quality is also known.

The fish sector may have the perception that complex concepts like freshness or quality cannot be quantified by single attribute measurements. One means of overcoming this is by developing an equipment which measures a set of attributes that together can give a better estimation of freshness or quality than with one technique alone (Olafsdóttir *et al.*, 1997). The development of sensors and instrumental techniques, in food, medicine and other areas (Di Natale, D'Amico, & Sberverlieri, 1998) has stimulated advances in statistical and mathematical analyses of the data, especially multivariate analysis and multi-sensor data fusion. Using several different techniques simultaneously (to some extent mimicking the human senses) is a powerful approach for obtaining robust estimates of freshness. An example of this is multivariate analysis developed primarily for monitoring the quality and ripeness of fruit (Steinmetz, Sévila, & Bellon-Maurel, 1999). These ideas apply also to monitoring the freshness of fish. Data fusion of instrumental results and calibration/correlation with the results of sensory evaluations has been pivotal in the MUSTEC project (Di Natale, 2003).

The approach to developing multi-sensor techniques for fish

In the MUSTEC project the multisensor concept was developed by selecting and adapting complementary rapid physical techniques to measure the quality of fish. This involved miniaturising the available instruments to make them portable so that they could be brought together to a single location. Storage experiments of important commercial fish species were done in different countries and fish of different freshness was measured simultaneously with the various instruments.

Physical techniques are generally more rapid than chemical ones, indeed optical and electrical measurements are almost instantaneous. The project involved the following techniques: texture analysis, visible light spectroscopy, image analysis, electronic noses, electrical properties and colour measurements. The sensory method QIM (Quality Index Method) was selected as the reference method. The QIM is a scheme for evaluating the whole fish, but the instrumental measurements were done both on whole fish and fillets. Three storage experiments on cod stored for up to 17 days in ice were done in the project in different countries (Iceland, Norway and Germany), and one storage experiment was done in Spain on hake stored frozen for up to 18 months (Nesvadba, 2003).

Electrical measurements

Three types of fish freshness meters were used in the project, the RTmeter (Iceland), the Torrymeter (UK) and the Intellectron Fischtester VI (Germany) with different electrode systems—two and four electrodes applied to one side of the fish and two electrodes across the fish respectively. The basic principle of all three instruments is similar—measuring the a.c. conductance and capacitance of the fish muscle (Jason & Richards, 1975). These change after death of the fish due to disruption of the cell membranes by autolytic spoilage. The method relies on conduction through skin and therefore works only on whole fish and fillets with skin on. Disruption by mechanical abuse and freezing affects the readings, but apart from this the instruments showed an excellent correlation with QIM, agreeing to within ± 0.5 days of chilled storage (Oehlenschläger, 2003).

Colour measurements

A hand-held spectral colour meter Spectro-pen® was used to measure the whole fish (Schubring, 2003). Spectro-pen® measures the visible spectral range (400–700 nm) at intervals of 10 nm. The CIELab system was used to measure colour of the fish samples. In this system L^* denotes lightness on a 0–100 scale from black to white; a^*, (+) red or (−) green; b, (+) yellow or (−) blue. The colour measurements were performed on both sides of the fish body in ventral as well as dorsal position (below and above the lateral line) from anterior to posterior part in almost equidistant steps.

Fresh cod stored in ice underwent significant changes in the colour values measured ventrally (L^*) or dorsally (a^* and b^*). All sets of colour values show a fairly good linear relationship with both the QIM values and the values for appearance of skin. The prediction error of colour measurement depends on whether the fish is chilled or frozen. In chilled fish the overall error is estimated to be about 2 days.

Image analysis

Kroeger (2003) developed a technique based on image analysis for measuring the appearance of fish on skin and surface of fillets. Images acquired with a CCD camera were analysed to calculate the spatial coherence (essentially the degree of similarity between micro-patterns around each point of the image) and from this the colour and turbidity of the mucus on the skin and the coarseness of muscle fibers on surfaces of fillets. This information correlates with fish freshness. Illumination using monochromatic light of different wavelengths gives the best results. The prediction error of chilled storage time is 2 days (Kroeger, 2003).

VIS spectroscopy

Fish muscle absorbs different components of light differently, depending on the composition and state of the muscle (the presence of different organic molecules and the degree of hydration and coagulation). Thus the spectra change depending on the degree of spoilage during chilled or frozen storage. This is the basis of a very promising technique developed by Fiskeriforskning in Norway (Heia, Esaiassen, & Nilsen, 2003; Nilsen, Esaiassen, Heia, & Sigernes, 2002). Nilsen *et al*. (2002) showed that for lean fish like cod, the estimation of the freshness was more accurate using the visible wavelengths only. Heia *et al*. (2003) gave the details of the technique using transmission spectra measured by a portable spectrometer. This technique is particularly suitable for measuring the quality of fish fillets, a task that is difficult for sensory panels on raw fish in the absence of the head, and therefore of great value to the fish processing industry. The prediction error for storage time of cod fillets is less than 15 h and 1.6 months for frozen storage time of hake.

Texture

The texture of the fish muscle depends on numerous intrinsic biological factors related to the density of the muscle fibres, as fat and collagen content of the fish. After death, autolytic and microbial processes take place and muscle becomes softer and less elastic. During frozen storage, textural changes in fish muscle also occur. These can finally lead to dry and tough products, mainly due to changes occurring in the redistribution of water and deformation of proteins of the muscle fibre.

Instrumental texture measurements are a direct extension of the human sensory assessment (finger press test). Careche *et al*. (2003) described two types of instruments used in the project: a conventional laboratory desk top texture analyser and hand-held devices. The instruments measured the force-deformation curves during indentation of samples of whole fish and fillets. The forces and deformations were sufficiently small for non-destructive measurement and varied with time in a step-wise or sinusoidal manner. This enabled calculation of the firmness and the times of creep/relaxation of the sample when the force/deformation is maintained constant. These properties correlated well with the QIM firmness attribute in chilled fish. The measured firmness and the parameters extracted from the stress relaxation curves also correlated well with the sensory textural attributes such as firmness, dehydration or water loss.

Electronic noses

The composition and concentration of volatile compounds emanating from fish change depending on the freshness of fish. Spoilage odours develop as a result of microbial growth and oxidation leading to the degradation of the tissue. Compounds such as short chain alcohols, carbonyls and esters, trimethylamine, hydrogen sulfide, methylmercaptan, dimethyl disulfide and dimethyl trisulfide are among the most volatile compounds being produced in degrading tissue and are therefore present in the highest amount in the headspace. Electronic noses can monitor the onset of spoilage of fish by detecting some of these volatile degradation compounds. Two types of electronic noses based on different sampling procedures and sensor technologies were employed in the MUSTEC project (Olafsdottir, DiNatale, & Macagnano, 2003). LibraNose is based on an array of eight thickness shear mode resonators coated with metalloporphyrins and a small metal capsule (10 ml) that is put on the surface of the fish for sampling volatiles. FreshSense is based on four electrochemical sensors (CO, H_2S, SO_2, and NH_3) and a larger sampling container (3.2 l) allowing the analysis of the whole fillet. Both systems allow the circulation of air for sampling the volatiles and a closed sampling system is critical to prevent disturbances from other sources of volatile compounds in the environment. The time to reach equilibrium gas concentration after introducing a new sample is 1–5 min depending on the size of the sampling container. The data analysis of the joint noses shows better performance to predict storage days and the sensory quality than the single techniques (Di Natale, Olafsdottir, & Einarsson *et al.*, 2001).

Multi-sensor data fusion/AQI—Artificial Quality Index

The techniques used in the project complemented each other, supplying independent information about the state (quality, freshness) of the fish over the entire duration of chilled or frozen storage experiments. All techniques except the electrical testers and the VIS-spectroscopy have a counterpart in the sensory assessment as defined in the QIM scheme. The outputs of the instruments can therefore be calibrated with the corresponding QIM sensory scores. Moreover, the texture and electronic nose sensors complemented each other by being most sensitive indicators of freshness before and after day four of chilled storage, respectively. This means that combining the data from the various sensors improves the estimate of the freshness of fish. To demonstrate this Di Natale (2003) selected colour, texture and electronic nose measurements and combined their calibrated outputs to construct the Artificial Quality Index (AQI) as illustrated in Fig. 1. It was shown that the AQI can be as accurate and precise as the QIM score. A statistical error analysis shows that the AQI describes the freshness of fish at least as well as the QIM, with the uncertainty of the predicted storage time being less than 0.5 days (Nesvadba, 2003).

This approach can be extended to include more techniques like VIS spectroscopy and image analysis to calibrate against the skin appearance. Measurement techniques as counterparts to all the sensory attributes of the QIM scheme were not included in the project. The aim was to select the techniques that gave the best performance to predict the days of storage. It should be stressed that the instrumental techniques are not necessarily measuring exactly the same changes as the sensory evaluation. For example, the electrical testers and VIS spectroscopy have no clear sensory relation, but showed an excellent correlation to the total QIM score for the iced fish and similarly had very good linear correlation with days in ice.

The results, benefits and limitations of the multi-sensor approach

The unique approach in the MUSTEC project was to perform storage experiments of important commercial fish species in different countries and measure fish of different freshness simultaneously with the various instruments. This enabled and facilitated comparison and evaluation of the techniques, by minimising the problem of biological variation and the effect of different handling of the fish within each storage study.

Comparison of data from storage studies in the different countries was only possible for the techniques that were already developed and therefore maintained the same sampling and measurement settings in all experiments. The QIM showed similar results in all three experiments on cod in different countries. Also some of the methods like the commercial electrical testers showed excellent performance and comparable result when measuring fish from different storage days in the different experiments. However, slight variation was

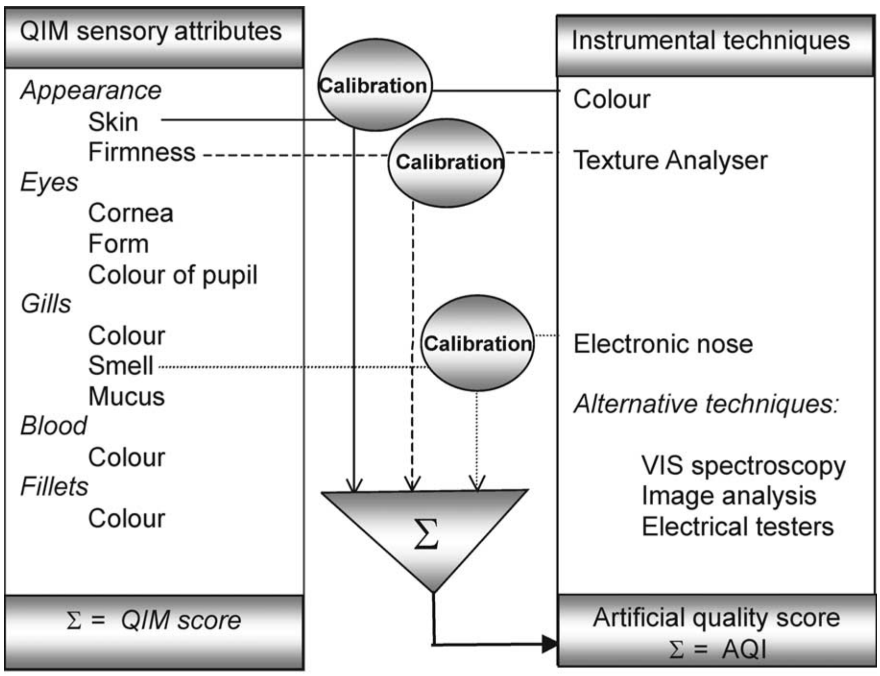

Fig. 1. Construction of the Artificial Quality Index (AQI). After calibration with sensory data (Quality Index Method (QIM)) the instrumental readings are combined into Artificial quality score giving the AQI (adapted from Di Natale, 2003).

noticed for the different batches within the same experiments resulting from variation in initial handling. The small difference in spoilage rate noticed between the experiments can be explained because the experiments were done at different seasons and on different stocks of cod. Data from some of the measurement techniques that were under development in the project like the electronic nose and the handheld texture meter could not be compared between experiments because adjustments were done in measurement set-up to improve the sensitivity of the techniques. However, the comparison of the individual techniques within the same experiments gave good indication of the potential of the single and combined techniques to measure freshness.

The resulting data are useful to give advice, directions and recommendations for further developments of the instrumental techniques and to evaluate the validity of the data to be used in models to predict quality. The benefit of using combined data from different experiments is dependent on that sampling and measurement conditions are the same. The characterisation of samples is improved when more techniques are used for the evaluation. Models based on more than one instrumental technique have been shown to give better performance in predicting quality.

The QIM scheme is developed for the whole fish and spoilage characteristics of the whole fish. The changes on the gills and the eyes are especially more noticeable than the changes occurring in the fillets. Evaluation of raw fillets with sensory evaluation is difficult and QIM has not been developed for fillets yet. The instrumental techniques have a decisive advantage when monitoring the quality of fillets.

Table 1 shows an overview of the methods used in this project and possible scenarios for their usage in the fish industry. The QIM is usable near-line and can measure the freshness of cod with the uncertainty of 0.5 days during chilled storage extending up to 17 days. Both the human assessor and instrumental image analysis can assess visually detectable attributes of quality (such as distortion of the fish shape, bruises, blood spots, pinbones and parasites). The project did not cover these scenarios, however, experience with the image analysis (Kroeger, 2003) indicates that image analysis has a great potential and already far exceeds the capabilities of the human eye.

The instrumental measurements can be as accurate and precise as those of a trained sensory panel and can have the following benefits:

- Transferring the skills of the sensory panel to the physical multi-sensing system
- The measurements of quality are rapid and potentially less costly than a sensory panel

Table 1. Overview of sensory and instrumental methods used in the MUSTEC project for evaluating fish freshness

Methods	Usage for freshness evaluation in the fish industry	Measurement of other aspects than freshness	References
Sensory methods			
Quality Index Method (QIM)	Near-line, non-invasive/ non-destructive, whole fish	Bruises, shape distortion, etc.	Bremner (1985); Bremner *et al.* (1986); Larsen *et al.* (1992); Luten and Martinsdottir (1998), Martinsdottir *et al.* (2003)
Electrical			
RT-Freshmeter Type RT 2E, GR Torrymeter, Intellectron Fischtester VIa	On-line, non-destructive, whole fish/(skin-on)	Frozen and mechanically damaged fish	Oehlenschläger and Nesvadba (1998); Oehlenschläger (2003)
Colour			
Spectro-pen®	Near-line/On-line, non-invasive/ non-destructive, whole fish	Colour of fish	Schubring (1998, 2003)
Image analysis			
CCD camera	On-line, non-invasive/non-destructive, whole fish and fillets	Size, shape, visual defects	Kroeger (2003)
VIS spectroscopy			
FishTube	On-line, non-invasive/ non-destructive, fillets	Smoke particle sizes	Sigernes *et al.* (1998); Nilsen *et al.* (2002); Heia *et al.* (1998, 2003)
Electronic noses			
FreshSense (electrochemical sensors), LibraNose (quartz microbalance sensors)	Near-line, non-invasive/ non-destructive, whole fish and fillets	Contaminants, taints	Di Natale *et al.* (1996; 2001); Olafsdottir, Högnadóttir, Martinsdóttir, and Jónsdóttir, (2000); Olafsdottir *et al.* (2003)
Texture			
Bench top (TA.XT2i SMS) and hand-held (Zwick hardness tester)	Near-line/On-line, non-destructive, whole fish and fillets	Intrinsic variations (for example due to feeding, season), mechanical abuse	Barroso *et al.* (1997, 1998a, 1998b); Schubring, (2002); Careche *et al.* (2003)

- The monitoring is possible online and at locations not accessible to a sensory panel.

For methods to be useful to the industry, they should be

- rapid, preferably non destructive;
- easy to operate;
- widely accepted, so that different companies use the same methods and therefore know what the other side in the buyer-seller relationship has been measuring;
- comparable to and even better than current evaluation methods.

All the techniques used in the project are essentially non-destructive. Whether they will become widely accepted by the fish processing industry remains to be seen. The costs of labour and training of assessors are likely to increase and the cost of instrumentation such as the image analysis is set to decrease dramatically. Consumer and governmental pressures for better description of quality and traceability of fish products will also increase. All of these factors will increase the importance of instrumental techniques of monitoring the quality of fish. The results of the MUSTEC project contribute to achieving these long-term goals by providing a basis for the construction and industrial exploitation of multi-sensor-devices. These outcomes are of a great potential value to the fish processing industry, manufacturers of quality monitoring instruments and for consumers that will benfit from better defined fish quality.

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