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An intelligent based decision support system for the detection of meat spoilage

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ABSTRACT

In food industry, safety and quality are considered important issues worldwide that are directly related to health and social progress. Meat spoilage is the result of decomposition and the formation of metabolites, caused by the growth and enzymatic activity of microorganisms, and it presents not only a health hazard but an economic burden to the producer. In this research work, we explore the potential of Fourier transform infrared (FTIR) spectroscopy in combination of principal components analysis and neuro-fuzzy modelling, to determine beef spoilage microorganisms during aerobic storage at chill and abuse temperatures. FTIR spectra were obtained from the surface of beef samples, while culture microbiological analysis determined the total viable count (TVC) for each sample. The dual purpose of the proposed modelling approach is not only to classify beef samples in the respective quality class (*i.e.*, fresh, semi-fresh and spoiled), but also to predict their associated microbiological population directly from FTIR spectra. The proposed neuro-fuzzy network model utilises a prototype defuzzification scheme, whereas the number of input membership functions is directly associated to the number of rules, reducing thus, the "*curse of dimensionality*" problem. Results confirmed the superiority of the adopted methodology compared to other schemes such as multilayer perceptron and the partial least squares techniques and indicated that FTIR spectral information in combination with an efficient choice of a learning-based modelling scheme could be considered as an alternative methodology for the accurate evaluation of meat spoilage.

1. Introduction

In the past few decades, meat industry has enormously thrived, as demands for better food quality continues to grow on both international and domestic markets (Desmond et al., 2000). Interests in meat quality are driven by the need to supply the consumer with a consistent high quality product at an affordable price (ElMasry and Sun, 2010). To realise such need, it is a crucial element within the meat industry to accurately assess meat quality attributes by improving modern techniques for quality evaluation (Herrero et al., 2008). Beef is one of the commercially viable and widely consumed muscle foods throughout the world. Although it is a good food source for proteins and other essential nutrients, it is also an ideal substrate for the growth of both spoilage and pathogenic microorganisms. Spoilage occurs when the formation of off-flavours, off-odours, discoloration, or any other changes in physical appearance or chemical characteristics make the food unacceptable to the consumer. Changes in muscle food characteristics are due to native or microbial enzymatic activity or to other chemical reactions. The current practice to assure the safety of meat still relies on regulatory inspection and sampling regimes. This approach, however, seems inadequate because it cannot sufficiently guarantee consumer protection, since 100% inspection and sampling is technically, financially and logistically impossible. Additionally, although more than 50 chemical, physical and microbiological methods have been proposed for the detection and measurement of bacterial safety or spoilage in meat, most of them are time-consuming and provide retrospective information (Ellis and Goodacre, 2001).

Meat industry however needs rapid analytical methods for quantification of these indicators in order to determine suitable processing procedures for their raw material and to predict the remaining shelf life of their products (Dissing et al., 2013). During previous years, relevant analysis and screening methods had been carried out on meat utilising high-performance liquid chromatography (HPLC) (Vinci and Antonelli, 2002), and gas

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chromatography–mass spectrometry (Ercolini et al., 2010). The development of non-destructive sensing technologies to detect spoilage bacteria as well as pathogenic bacteria with a high degree of dependency in food products is however very desirable. Various rapid, non-invasive methods based on analytical instrumental techniques, such as Fourier transform infrared spectroscopy (FTIR) (Balasubramanian et al., 2009) and Raman spectroscopy (Mouwen et al., 2011) have been researched for their potential in assessing meat quality. The "mechanism" of these approaches is based on the assumption that the metabolic activity of micro-organisms on meat results in biochemical changes, with the simultaneous formation of metabolic by-products, which may contribute to the spoilage phenomenon. The quantification of these metabolic activities represents a unique "signature", providing thus information about the type and rate of spoilage (Nychas et al., 2008).

The huge amount of information provided by spectral data requires an advanced data analysis approach. This has been achieved through the integration of modern analytical platforms with computational and chemometric techniques (Miller and Miller, 2005). Multivariate statistical analyses (*e.g.*, partial least square (PLS) regression, discriminant function analysis (DFA), cluster analysis) have resulted in the development of decision support systems for timely determination of safety/quality of meat products (Guillén et al., 2010). Considering that microbial meat spoilage is a complex process which involves growth of micro-organisms during storage, their spectra contain highly non-linear characteristics. Hence, linear tools might not provide a complete solution to such complex identification/classification problem (Qin et al., 2011). Neural networks (NNs) have gained much interest in predictive engineering and quantitative modelling due to their flexibility and high accuracy as compared to other modelling techniques (*e.g.*, statistical models). In comparison to other NN-based application areas, the field of food science is still in an early development stage. Recently, advanced NN algorithms have shown promising results in applications such as growth parameter estimation of microorganisms (Panagou and Kodogiannis, 2009), whereas hybrid wavelet neural networks have been successfully applied for bacterial survival curves' identification (Amina et al., 2010). NNs usually require a large number of neurons for solving the majority of approximation problems and are prone to dimensionality problems, as each single neuron-node cannot define a multi-dimensional hyper-sphere of the input domain. Although fuzzy logic systems, provide such input space mapping, they do not have learning ability, thus it is difficult to analyse complex systems without prior and accurate knowledge on the system being analysed (Rutkowska, 2002).

To overcome the limitations of NNs and fuzzy systems, neuro-fuzzy approaches have attracted growing interest of researchers in various scientific and engineering areas. The main objective of this paper is to associate FTIR spectral data with beef spoilage, by utilising for the first time a neuro-fuzzy identification model. The proposed "Adaptive Fuzzy Logic System" (AFLS) model includes a prototype defuzzification scheme, and differs from conventional fuzzy rule-table approaches that utilise the "look-up table" concept. In those models, an input space is divided into $K_1 \times K_2 \times .... \times K_n$ fuzzy subspaces, where K_i, $i = 1, 2, .., n$ is the number of fuzzy subsets for the ith input variable (Nelles, 2000). As one fuzzy rule is assigned for each of these subspaces, their main drawback is that the number of fuzzy rules increases exponentially with respect to the number of inputs n. ANFIS is a classical example of such approach, where the number of fuzzy rules is related to the number of input variables as well as the number of membership functions for each input. In the case of AFLS, the number of memberships for each input variable is directly associated to the number of rules, hence, the "curse of dimensionality" problem is significantly reduced.

Datasets related to FTIR spectra and the correlated microbiological analysis (*i.e.* total viable counts - TVC) from beef fillets, were provided to the first author by Agricultural University of Athens, in the framework of the "*Symbiosis-EU*" research project (SYMBIOSIS Project, 2009). Fresh beef fillets were packaged under aerobic conditions and left to spoil at (0, 5, 10, 15, 20 °C), for up to 350 h. FTIR spectra were collected directly from the surface of meat samples, whereas TVCs of bacteria were obtained via standard plating methods. Sensory evaluation was performed during storage and samples were attributed into three quality classes, namely fresh, semi-fresh, and spoiled (Argyri et al., 2010). Due to the nature of FTIR spectral data, it is necessary to utilise a principal components analysis (PCA) to reduce the problem of dimensionality with the minimum information lost. The proposed AFLS model has been utilised to classify beef samples to one of three quality classes, based on their biochemical profile provided by the FTIR spectrometer. The same model simultaneously predicts the microbial load (as total viable counts) on meat surface. Results from AFLS scheme are compared against models based on multilayer neural networks (MLP) and PLS. Such comparison is considered as an essential practice, as we have to emphasise the need of induction to the area of food microbiology, advanced learning-based modelling schemes, which may have a significant potential for the rapid and accurate assessment of meat spoilage. Such an accurate assessment prediction could allow a more efficient management of products in the food chain.

1.1. FTIR spectroscopy in food quality analysis

FTIR spectroscopy has been used extensively by chemists to identify compounds in a wide variety of applied fields. This motivation is justified from the fact that FTIR is a rapid, inexpensive and sensitive technology that rapidly allows real-time measurements at all stages of production without requiring special skills from users. Moreover, it has been recognised as a powerful tool when coupled to chemometric techniques, and is widely utilised for rapid quality control of numerous foodstuffs since it provides information from complex spectra about the composition of food components. In fact, for any individual sample, FTIR spectroscopy provides information on fundamental vibration and stretching of molecules exhibited under infrared light in the spectral region between 4000 and 700 cm^{-1}. It provides a characteristic spectrum that is the result of absorption by various chemical constituents, providing thus a "fingerprint" of each sample (Karoui and De Baerdemaeker, 2007).

Over the last few years, FTIR has been considered as a very important tool in food analysis including authenticity and adulteration. Nutrient determination is time consuming and not appropriate for routine application in the food industries. FTIR was able to determine omega-6 and omega-3 fatty acids in pork adipose tissue (Olsen et al., 2008). It has been used to investigate the influence of heating rates and different heating temperatures on protein denaturation in beef (Kirschner et al., 2004), as well as to study the influence of ageing and salting on uncooked and cooked pork (Wu et al., 2006). In addition, it has been considered as a fast and non-destructive technique for the detection and quantification of pork in beef meatball formulation for Halal verification purposes. The spectral bands associated with pork fat (PF), beef fat (BF), and their mixtures in meatball formulation, were scanned, interpreted, and identified by relating them to those spectroscopically representative to pure PF and BF (Rohman et al., 2011). The quality of oil, an essential ingredient of the food processing industry has also been investigated through the use of FTIR for the accurate quantification of the moisture in edible oils (Vlachos et al., 2006). Although, the vast majority of FTIR-based applications for classification and quantification purposes utilise liquid