Neural models as a tool for prediction of growth and survival of microorganisms in meat products

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Abstract

The aim of this paper was to check the possibility to utilize neural networks for generating predictive models of growth and survival of microorganisms in meat products. Meatballs were used as a model product for microbial evaluation, inclusive of the total plate count, the number *of Pseudomonas* bacteria, and that of *Pseudomonas fluorescens* bacteria. As a result, twelve databases were generated. Independent factors (the addition of salt, lysozyme, $NaNO_2$ (sodium nitrite), pure culture of *Pseudomonas fluorescens*, storage temperature, and storage time) were included in the bases. The predicted dependent values were: the total number of microorganisms, the number of *Pseudomonas* bacteria, and the number of psychrotrophic bacteria. In this part of the research a basic version of an automatic neural network designer working with STATISTICA Automated Neural Networks Software, version 7 was used. The multilayer perceptron (MLP) was the most suitable neural network for predicting the number of microorganisms in food products. Two algorithms: the error back/forward propagation and coupling gradients were used to study the network. The best way of generating the artificial neural network was to make use of an automatic neural network designer. In conclusion, neural networks represent some of the tools which can be used in food predictive microbiology.

Introduction

Predictive microbiology is a food microbiology sub-discipline concerned with the generation of mathematical models of microbial responses to specific environmental conditions, and verification of the use thereof in predicting the growth, survival rate and inactivation of microorganisms in food. On the grounds of data gathered in controlled conditions, mathematical relationships defining the influence and interactions of specific variables and the generated mathematical models may be further used for predicting microorganism behaviour in a number of food products merely on the basis of physical measurements of original determinants. In the latest studies on predictive microbiology, more and more frequently the necessity is emphasized of conducting research on naturally inoculated food products and establishing models on the basis thereof.

The objective of this paper was an attempt of applying neural networks as a new mathematical modeling tool for the construction of microbiological growth models, survival rate and microorganism inactivation in food products.

Materials and methods

Research material under study was represented by cow haunch meatballs with an addition of breadcrumbs, UHT 2% fat milk, chopped onions (10% of the meat mass), which were a model of a meat product representing the ground meat product group. Besides, the following additives, being independent variables, were included in the product, respectively:
NaCl – 1%, and 2% (z_1); Lysozyme – 25 mg, 248 mg, 622 mg (z_2); $NaNO_2$ – 60 ppm, and 120 ppm (z_3); Pure *Pseudomonas fluorescens* type culture (z_4). The products were stored at the temperature of 5, 10, 15, 20°C (z_5) for 16 days (z_6). Microbiological analyses were conducted towards (predicted dependent variables):
TVC – the total viable count (w_1);
PBC – the count of *Pseudomonas* bacteria (w_2);
TPBC – the total count of psychrotrophic bacteria (w_3).

As a result, twelve databases were generated from the obtained results of microbiological tests. Each database allows for independent variables affecting the growth of microbe groups under study, marked z_1, z_2, z_3, z_4, z_5, z_6, respectively. Predicted dependent variables, i.e. the results of analyses of microbe counts, were marked w_1 and w_2, respectively. STATISTICA Automated Neural Networks Software, version 4.0 integrated with version 7.1 by StatSoft, Inc. was used for the study. Neural models were validated by means of network validation indices.

The total viable count (TVC) in cfu/g was determined on nutrient agar-agar (Noack Polen), pursuant to PN-EN4833:2003. Inoculation was performed by a dipping method incubation temperature - 30^{o} C, and incubation time – 72 hours. The total count of psychrotrophic bacteria (cfu/g) was determined by the flooding method on nutrient agar-agar (Noack Polen), incubation temperature - 7^{o} C, and incubation time – 10 days, in compliance with PN-ISO-17410:2003. The total *Pseudomonas* bacteria count (TC*Ps*, TCPs^{I}) was determined on agar-agar with an addition of selective, lyophilized supplement - 5ml/500 ml of Noack Polen sterile medium. The PN-ISO 13720:1999 standard and Noack Polen medium preparation instruction were complied with. Inoculation was performed by a dipping method; incubation temperature - 30^{o} C, and incubation time – 72 hours. The *Pseudomonas* bacteria total count was determined on agar-agar with an addition of selective CFC (TC$^{P.fluorescens}$) supplement.

Results and discussion

In this paper a basic version of an automatic neural network designer was applied. Due to a random selection of data in learning and testing sets by the automatic designer, it was run ten times for each database. For each database 100 neural networks were obtained.

For the assessment of neural network quality and for the comparison of different networks constructed for the same database, the following measuring instruments were applied: an error measured as discrepancy between actual network output signals and values given in the learning process as a reference standard. A mean square error is usually used, one being a square root of error square sums of specific cases. In the STATISTICA Automated Neural Networks Software, an additional network quality measuring instrument is used, one representing the value of the root of mean squares of regression errors. Another measuring instrument – a deviation ratio – being a ratio of standard deviation of errors, and of a standard deviation determined on the ground of actual values of dependent variables. If the value of that measuring instrument is greater than one, then it is groundless to use the model thus obtained. In all the above mentioned cases, the lower the value of the quality measurement instrument, the higher the quality of the neural network.

A set of 100 networks devised for each database by the automatic designer comprised three types of networks: the MLP – a multilayer perceptron, the RBF – radial basis functions, and the Linear – a linear network. In each set the best network turned out to be the multilayer perceptron. Hajmeer et al. (1997) and Luo and Nakai (2001) also used the MLP network for the modeling of similar dependencies between environmental factors and the microbial survival rate. Jeyamkondan et al. (1999) find this type of network the most universal in solving a variety of problems.

The established networks contained one hidden layer consisting of 2 to 10 neurons. Networks with a greater number of input neurons (i.e. those describing data sets of a greater number of independent variables) consisted of a greater number of neurons in the hidden layer than the networks containing only two neurons in the input layer. The process of learning of the best networks devised by the automatic designer came down to the application of one (backward error propagation) or two (backward error propagation + adjoint gradients) of learning algorithms. Hajmeer et al. (1997) used solely the backward error propagation method for their own network learning.

Table 1. A specification of error values, quality and deviation ratio for the best databases

	Error			**Network Quality**			**Deviation Ratio**		
	U	W	T	U	W	T	U	W	T
Database 5	**0.65**	**0.63**	**0.63**	**0.32**	**0.30**	**0.29**	**0.32**	**0.29**	**0.29**
Database 8	**0.90**	**0.64**	**0.86**	**0.55**	**0.41**	**0.47**	**0.48**	**0.49**	**0.55**

U – the learning set; W- the validating set ; T- the testing set
Source: own research

The specification of quality parameters of the best networks was presented in Table 1. When assessing network quality, it is first of all the validation error that should be taken into account. The learning error gives very little information of the capacity of the network to find correct output values for new input data. The testing error, in turn, is useful for diagnosing problems with network learning. The validation error values obtained ranged from 0.57 to 0.89. The values of the root of mean squares of regression errors (quality) of the network for validating sets ranged from 0.30 to 0.66, and the low values of validation errors did not always coincide with the low values of the quality index. The deviation ratio for validating subsets ranged from 0.29 to 0.88.

Taking into account all the quality measuring instruments, at the same time networks generated for databases No. 5 and 8 by the automatic designer turned out to be the best due to the fact that they were the only ones to be included in the best network groups out of all the measuring instruments under analysis.

By way of enabling visualization of behaviour of the best neural networks generated by the automatic designer, response surfaces of those networks were formed (Fig. 1). With respect to all those networks, output variables were examined as functions of two variables: temperature (x) and time (y).

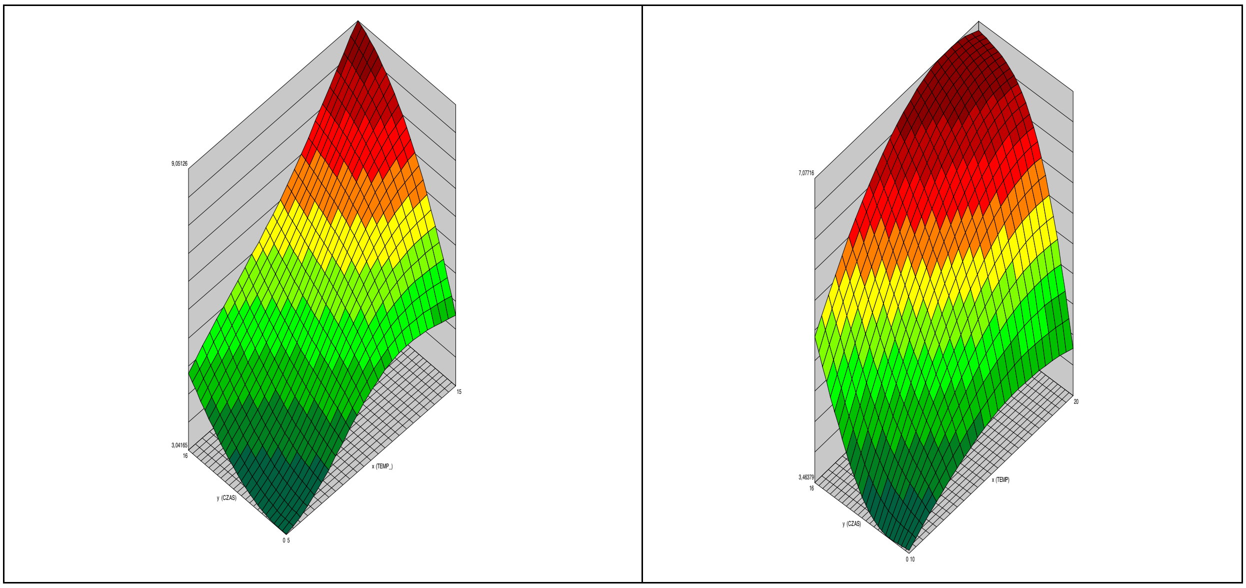

Figure 1. Response surfaces of the best neural network generated by the automatic designer for databases No. 5 and 8.
Source: own research

Conclusions

Neural networks may be used for the generation of neural models which adequately describe the growth of microbes in food products. The multilayer perceptron (MLP) was found to be the most suitable neural network for predicting the microbial count in food products. Two algorithms were used for neural network learning: that of backward error propagation and that of adjoint gradients. The use of the automatic network designer was found to be the best manner of generating neural networks.