Artificial neural network prediction of microbiological quality of beef minced meat processed for fast-food meals

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Abstract. In this study, the microbiological quality of 72 minced beef meat samples collected during six months from a local butcher was defined after laboratory analysis and developing advanced mathematical models. This new simultaneous approach provided adequate precision for the prediction of the microbiological profile of minced beef meat as one of the easily spoiled products with a short shelf life. For the first time, an artificial network model was developed to predict the microbiological profile of beef minced meat in a fast-food restaurant according to meat and storage temperatures, butcher identification, and work shift. A concurrent statistical study of practical analysis and the developing mathematical models provided adequate precision for the prediction of the microbiological profile of minced beef meat. The developed ANN provided a good prediction of the microbiological profile of beef minced meat with an overall $R^2$ of 0.867 during the training cycle.

1. Introduction

The artificial neural network model (ANN) is a widely accepted mathematical tool that regularly provides an empirical solution to the problems from a set of experimental data, and is capable of handling complex systems with nonlinearities and interactions between decision variables [1-3]. Predictive ANN modelling is often use in meat science for analysing different characteristics of meat, e.g. temperature and moisture content [4], bacterial growth in modified atmosphere packed cooked meat products [5], rheological features [5], sensory measurements [6], heat capacity prediction [7], slaughter weight in meat-type quails [8], etc.

Meat is the most popular type of food in fast-food restaurants around the world [9], as well as an inseparable part of traditional dishes (e.g., moussaka, sarma), and meat products (e.g., sausages, čevapčići, burgers) [10]. One of the main characteristic of minced meat is water activity of approximately 99%, as well as satisfactorily nutrients which can support microbial growth [11]. Many chemical and physical factors can influence meat quality, such as storage temperature, moisture, oxygen availability, packaging, microbiological contamination, etc. [12]. The microorganisms are commonly present on the meat surface, but also can be distributed throughout comminuted products during the entire production process, especially during the mincing and mixing process used to produce burgers and other minced meat-based products [13].
In order to estimate the microbiological profile of minced beef meat from a local specialist beef butcher shop, the predictive capabilities of the ANN were tested as a function of meat and storage temperatures, butcher identification, and the work shift. This study aims to determine and predict the microbiological profile of minced meat used in a local fast-food restaurant in Novi Sad, Serbia. For this purpose, 72 minced meat samples were purchased during six months from a local butcher after the mincing and mixing process, and the results were used for mathematical modelling and ANN prediction of the microbiological profile of minced-meat products in the mentioned restaurant.

2. Materials and methods

2.1. Sampling

For this study, minced beef originated from a local butcher in Novi Pazar, Serbia. Approximately, one hundred grams of minced meat was obtained from each processed meat batch immediately after transport to the fast food restaurant in Novi Sad, Serbia and placed in a sterilized sampling box. Samples were collected for six months (January-June 2019, every Monday, Wednesday, and Friday) for each batch.

2.2. Microbiological analysis

The microbiological profile of minced meat samples was examined following standard methods, presented in Table 1. The selected microbiological analysis was chosen based on the Guide to Microbiological Criteria for Food [13]. All analyses were done in triplicate and the results were compared to the allowable values for every type of food. Briefly, all results are presented as logarithm-transformed colony count in one gram of sample (log CFU/g), except for *Salmonella* spp., where the absence of the bacterium required. According to the Serbian Rulebook [15], the obtained results can classify meat as satisfactory (result is below m-value), acceptable (result is between m- and M-value), or unsatisfactory (result is above M-value). The m- and M-value define limit values, minimum and maximum for each analysis separately, and depend on the type of food.

| Microorganism/ group of microorganisms | Method | Allowable limit values (m- and M-values) according to the Guide to microbiological criteria for food (log CFU/g) |
|---------------------------------------|--------|-----------------------------------------------------------------------------------|
| Aerobic and mesophilic bacteria        | ISO 4833-1:2013 [16] | m=5  
M=6                                                                 |
| *Escherichia coli*                    | ISO 16649-2:2018 [17] | m=2  
M=3                                                                 |
| *Salmonella* spp.                     | ISO 6579-1:2017 [18] | nd*                                                                 |
| *Listeria monocytogenes*              | ISO 11290-1:2017 [19] | nd                                                                 |
| *Staphylococcus aureus*               | ISO 6888-1:2018 [20] | m=2  
M=3                                                                 |
| Lactic acid bacteria (LAB)            | ISO 7889:2003 [21] | **                                                                 |

*nd- not detected in 25 grams of samples; ** the Guide to Microbiological Criteria for Food [13] does not indicate value for this parameter

2.3. Artificial neural network (ANN) predictive modelling

A multi-layer perceptron model (MLP) with three layers (input, hidden, and output) was used as a concept for ANN modelling, while input and output data were normalized before calculation, to enable improvement of the ANN model’s performance. Furthermore, the experimentally obtained data were
randomly separated into training, cross-validation, and testing data (with 70%, 15%, and 15% of experimental data, respectively), and a series of different topologies were used, in which the number of hidden neurons varied from 5 to 20. The training process was run 100,000 times with random initial values of weights and biases. The Broyden-Fletcher-Goldfarb-Shanno (BFGS) algorithm was used for the solution of the unconstrained nonlinear optimization in the ANN modelling. Successful ANN training was achieved when learning and cross-validation curves approached zero [22].

3. Results and discussion

The developed optimal ANN model showed a good generalization capability for the experimental data obtained, and it can be used to predict the accurate output for a broad range of the input parameters. According to ANN performance, the optimal number of neurons in the hidden layer for aerobic and mesophilic bacteria, *Escherichia coli*, lactic acid bacteria (LAB), and *Staphylococcus aureus* prediction was equal to 10 (network MLP 9-10-4), whereby high values of $R^2$ (overall $R^2$ was 0.867 during training period) and low values of SOS were obtained (Table 2). When striving to implement mathematical modelling in the field of predictive microbiology, the artificial neural network (ANN) model is considered the most suitable predictive tool [23].

### Table 2. ANN summary of observed results

| Network name | Performance | Error |
|--------------|-------------|-------|
|              | Train. | Test. | Valid. | Train. | Test. | Valid. |
| MLP 9-10-4   | 0.867 | 0.832 | 0.854 | 0.484 | 0.490 | 0.897 |
| Training algorithm | Error function | Hidden activation | Output activation |
| BFGS 6447 | SOS | Logistic | Identity |

The predicted values were very close to the desired values in most cases, in terms of $R^2$ value, for ANN models. The ANN model predicted experimental aerobic and mesophilic bacteria, *E. coli*, LAB, and *S. aureus* reasonably well for a broad range of the process variables as seen in Figure 3, where the experimentally measured and ANN model predicted values are presented. The accuracy of the ANN model could be visually assessed by the dispersion of points from the diagonal line in the graphics presented in Figure 1.

Table 3 presents the elements of matrix $W_1$ and vector $B_1$ (presented in the bias row), as well as the elements of matrix $W_2$ and vector $B_2$ (bias) for the hidden layer.
Figure 1. Experimentally gained and the ANN predicted values of the microbiological profile of minced meat

Table 3. Elements of matrix W1 and vector B1 (presented in the bias row) as well as W2 and vector B2 (presented in the bias column)

| Independent variables | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   |
|-----------------------|------|------|------|------|------|------|------|------|------|------|
| Store temperature     | 3.70 | 0.37 | -147.96 | -17.66 | -82.56 | -15.34 | 231.07 | 29.54 | 28.94 | -14.48 |
| Meat temperature      | 99.23 | 142.56 | 58.25 | 20.10 | 65.60 | 27.46 | -94.96 | 105.16 | 151.15 | 25.96 |
| Butcher (A)           | -65.60 | -105.46 | -37.80 | -7.51 | -20.39 | -14.53 | 35.69 | -78.06 | 61.40 | -121.10 |
| Butcher (B)           | 107.49 | 303.75 | 29.99 | 2.40 | 20.45 | 2.62 | -94.96 | 105.16 | 151.15 | 25.96 |
| Butcher (C)           | 41.19 | -63.16 | 59.55 | 3.81 | 19.07 | 4.05 | 34.42 | -64.03 | -101.17 | 53.46 |
| Butcher (D)           | -65.26 | -103.04 | 1.93 | 2.01 | 14.19 | 7.24 | -114.51 | 98.64 | -34.24 | 56.38 |
| Day (Friday)          | 6.55 | 6.67 | 52.01 | 7.05 | 73.63 | 7.72 | 44.36 | 78.00 | 93.39 | 73.42 |
| Day (Monday)          | 4.87 | 10.37 | 25.22 | -1.54 | -2.84 | 0.28 | -37.29 | 58.36 | -73.23 | 66.34 |
| Day (Wednesday)       | 6.45 | 15.05 | -23.48 | -4.91 | -37.44 | -8.57 | -131.65 | -64.04 | -52.44 | -98.96 |
| Bias                  | 17.80 | 32.05 | 53.77 | 0.68 | 33.38 | -0.58 | -124.66 | 72.23 | -32.28 | 40.75 |

| Output variables      | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   |
|-----------------------|------|------|------|------|------|------|------|------|------|------|
| Aerobic and mesophilic bacteria | 65.57 | -65.39 | -5.27 | -0.52 | 5.61 | 5.91 | -3.40 | -0.25 | 0.08 | -5.50 | 0.30 |
| LAB*                  | 3.41 | -3.35 | -38.85 | 0.96 | 38.44 | 15.05 | -27.28 | 0.49 | -0.15 | -16.01 | 0.56 |
| E. coli               | 55.53 | -55.56 | 71.22 | 0.43 | -71.60 | 2.03 | 50.36 | 0.16 | -0.10 | -2.21 | 0.09 |
| S. aureus             | 20.40 | -20.35 | -13.56 | -0.59 | 13.24 | -33.94 | -9.39 | 0.40 | 0.04 | 34.45 | -0.06 |

*LAB - lactic acid bacteria
The goodness of fit between experimental measurements and calculated results is presented in Table 4. The mathematical model had an insignificant lack of fit tests, which means that all the models represented the data adequately. A high $R^2$ is indicative that the variation was accounted for and that the data fitted adequately to the proposed model.

**Table 4.** The goodness of fit tests for the microbiological profile prediction of beef minced meat

|                      | $\chi^2$ | RMSE | MBE | MPE | $r^2$ | Skew | Kurt | SD | Var. |
|----------------------|----------|------|-----|-----|-------|------|------|----|------|
| Aerobic and mesophilic bacteria | 1.612    | 1.176| 0.000| 26.823| 0.592| -0.125| -0.274| 0.738| 0.545 |
| LAB                  | 1.047    | 0.947| 0.000| 31.823| 0.731| 0.144| 0.085| 0.595| 0.354 |
| E. coli             | 0.087    | 0.2737| 0.000| 36.413| 0.819| 4.195| 27.617| 0.171| 0.029 |
| S. aureus           | 0.153    | 0.362| 0.000| 67.756| 0.880| 0.933| 3.896| 0.228| 0.052 |

*LAB - lactic acid bacteria

4. Conclusions

A simultaneous statistical study comparing practical analyses with the developing mathematical models showed the models provided adequate precision for the prediction of the microbiological profile of minced beef meat as one of the easily spoiled products with a short shelf life due to a fast decrease of quality parameters and microbial growth. Furthermore, the developed ANN provided good prediction of the microbiological profile of beef minced meat with an overall $R^2$ of 0.867 during the training cycle.

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