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# Neural Network Analysis of Meat Quality: a Comparative Study of Forward-Forward and Backpropagation Learning Methods

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Abstract: This article presents a comparative study of the effectiveness of Forward - Forward and Backpropagation machine learning algorithms for analyzing and predicting the quality of meat raw materials based on pH indicators . The theoretical foundations and practical aspects of applying the new approach and traditional methods in data processing in the meat industry are considered. The developed neural network models are aimed at promptly assessing the quality of raw materials, predicting their technological properties and identifying undesirable changes in the early stages of production. The experimental part of the work includes modeling systems for assessing the quality of meat raw materials and a comparative analysis of the accuracy of sample classification, training time for both algorithms. Particular attention is paid to the issues of interpretability of the resulting models in the context of their practical application in production conditions.

## 1 INTRODUCTION

At present, science as a cluster of disciplines has advanced significantly, seriously updating the methods of qualitative perception of reality. Due to the previously described leap in progress in the plane of methodology and philosophy of the scientific paradigm, discoveries implying the development of the industry and its parts due to the introduction of optimization processes have become central objects for study. This fact takes place due to the heterogeneity and constant updating of input (studied) data coming from outside and requiring detailed analysis.

The process of updating the methodological component of various scientific disciplines is natural for a rapidly flourishing system of knowledge about the objective world.

Raw material analysis has so far been a rather conservative area of veterinary and sanitary science and quality control science. Automation and digitalization were introduced into this area of scientific interest rather late. Such a situation in the presented area has developed, as follows from what has been written earlier, due to the complexity of data processing and its heterogeneity and sometimes sparseness.

In turn, the analysis of meat products, which is vital for maintaining both consumer safety and the country's food security, due to its already mentioned characteristics, requires digital optimization and partial automation of existing research and examination mechanisms within this discipline.

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In the era of rapid development of machine learning systems, both artificial intelligence on a global scale and artificial neural networks in particular, automation and optimization processes are represented mainly by the indicated groups of algorithms.

The choice of these systems as a signature and at the same time promising element for the industry is justified by its adaptability and ease of integration with various devices and systems, including the Internet of Things.

The relevance of using classical architectures of artificial neural networks, such as MLP (multilayer linear perceptron) in quality control and veterinary and sanitary expertise is undeniable. The use of similar and related in mechanics and action lightweight and fast both in training and inference models, can not only simplify the processing of traditional data specific to such an area, but also bring elements of optimization and automation of processes to the group, which require a high concentration from the researcher in carrying out sometimes difficult to implement operations of analysis and the necessary systematization of the obtained data.

Both the MLP architecture and its variations are characterized by a training method called backpropagation .

This algorithm is designed in such a way that the neural network, learning from the data presented to it, minimizes the prediction error by adjusting the weights and biases of the model.

Despite the proven reliability of the backpropagation system, it is currently being rethought, both from the point of view of neurophysiological plausibility and from the point of view of the mathematical concept of action.

One such reinterpretation is the Forward - Forward (double forward propagation) algorithm.

Being more energy efficient than classical BP ( backpropagation ) due to the absence of the need to store activations for the reverse pass and the absence of the need for A- to -D converters, this method can be considered as an alternative to the forward-backward pass.

However, when considering this issue, special attention should be paid not only to the resource consumption of the models, but also to its generalizing ability, as well as stability during training.

The relevance of this article lies in the need to identify the most effective and most stable method of training fully connected networks to solve classification problems inherent in the work of a quality control specialist or veterinary and sanitary expert.

The tasks involved include not only a deep study of the two presented learning methods ( BP and FF ), but also their comparison based on practical simulation of work tasks.

## 2 MATERIALS AND METHODS

The material for this study, which involves a deep multifactorial comparative analysis of not only models but also methods of system training, will be synthetic data artificially generated based on the high-performance computing library NumPy , representing 5 independent sets of numerical values, each containing 1000 measurement lines. The numerical sequences generated by this algorithmic approach represent the so-called hydrogen ion concentration (pH) indicator, a key indicator of acid-base balance in biological systems.

Like the vast majority of quantitative indicators regularly encountered in wildlife and biological systems of various levels of organization, this physicochemical characteristic demonstrates a tendency to approach the Gaussian (normal) probability distribution. However, in order to achieve higher accuracy of calibration of the developed mathematical model and increase its prognostic value, the standard normal distribution of the studied features was purposefully modified and adjusted towards increasing (positive) excess. The resulting leptokurtic distribution, characterized by a sharper peak and elongated "tails" compared to the classical normal distribution, significantly more accurately reflects the real behavior of the studied biochemical characteristic in natural conditions of wildlife, largely due to more adequate modeling of the probability of extreme values appearance in the area of the "heavy tails" of the distribution. A detailed distribution of the studied features by functional categories is clearly shown in Figure 1, illustrating the statistical features of the modeled data.

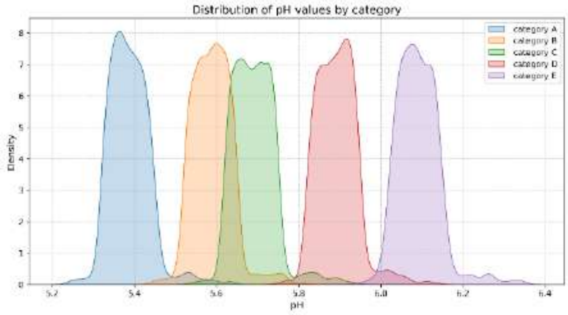

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Figure 1: Distribution of hydrogen ion index features in synthetic data.

As can be seen in the illustration, the tails of the features intersect, which not only reflects a large number of uncertain indicators belonging to different classes, which is similar to the behavior of the characteristic in living nature.

The research method will be a computer simulation reflecting the classification of each of the selected samples in the test sample into classes previously presented in the training sets.

As part of the study, two Dense-layer neural networks with different training methodologies were implemented. The first network was a classic multilayer linear perceptron, trained using the traditional backpropagation method . This approach is standard in the field of deep learning and is characterized by passing the signal in the forward direction with subsequent weight correction based on the calculated error in the reverse direction.

The second system was implemented using an alternative learning method known as forward-forward . A specific forward-forward design was required to implement this model correctly. linear layer , which was a key component of the architecture.

The structural organization of the layer was designed in full compliance with the classical double forward pass methodology described in the literature. In particular, the function " goodness " (measure of compliance), which plays a central role in this method, was calculated as the sum of squares of neuron activations. The threshold value used to separate positive and negative examples was set at 1.0, which corresponds to the recommendations for tuning such systems.

Rprop ( Resilient) was chosen as the optimization algorithm for both models. Backpropagation ). This choice was not random and was justified by a fundamental feature of this optimizer: Rprop allows each weight in the network to have an individual, adaptively changing learning rate depending on the local topology of the error function. This characteristic makes Rprop the most conceptually consistent with the philosophy of the double forward pass method, compared to other available optimizers such as SGD, Adam or RMSprop .

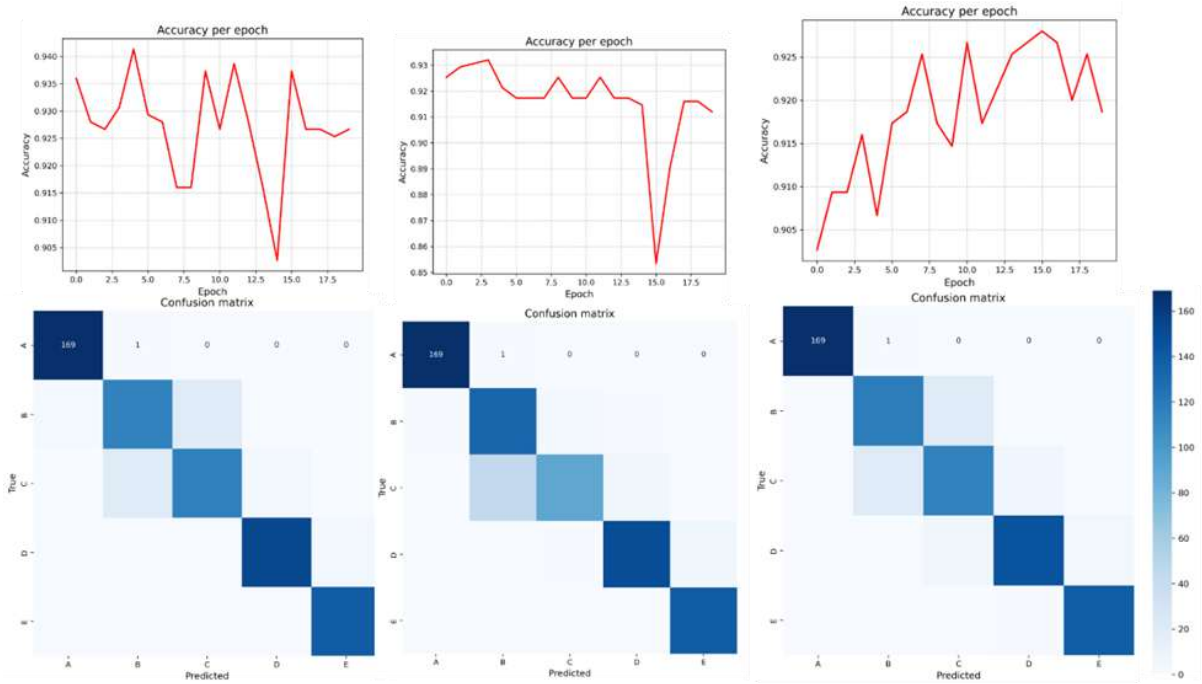
To ensure statistical significance of the results, the training process for each network was repeated 10 times with different initial weight initializations. After each training iteration, the classification quality metrics were measured and subsequently averaged to obtain representative values. Training continued until the networks reached a state of maximum convergence and minimized the loss function ( loss ).

In addition to the standard methods of visualizing the learning process, a specific visualization of the distribution of " goodness " values relative to different classes in the training sample was implemented for the forward-forward - based model , which allowed us to gain additional insight into the functioning of this method. For the multilayer linear perceptron, traditional indicators were visualized: the loss function ( loss ) and the accuracy ( accuracy ) of the model at different stages of learning.

## 3 RESEARCH RESULTS

As a result of the conducted research, a number of significant data were obtained, systematized in tables and graphs.

The following results were obtained from the neural network trained using the double feedforward method.

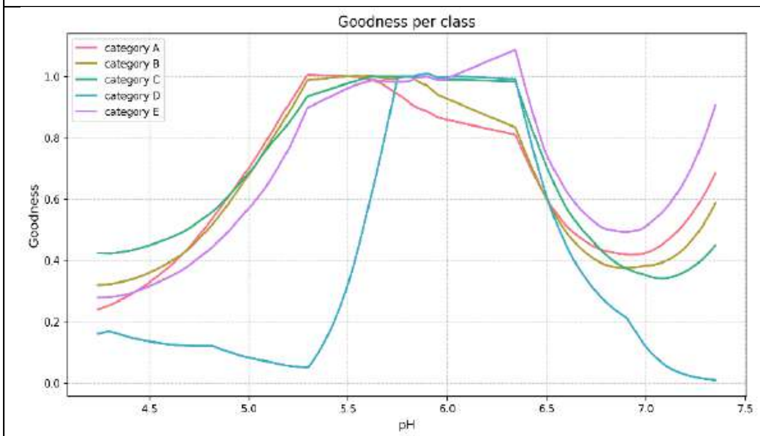



accuracy matrices per epoch .

Firstly : the model trained on 16 epochs, with batch_size=16 and having 2 hidden layers of 90 and 300 neurons, the system showed more often unsatisfactorily unstable behavior of accuracy over epoch, which in turn led to unsatisfactory classification quality. The ratio of predicted and true results for the dynamics of training is shown in Figure 2.

Figure 2 shows the unstable training process of the feedforward model.

Figure 3 shows the correspondence between the goodness ratio for the analyzed classes and the F1 measure, which shows the quality of classification. Thus, the table allows us to understand the correlation between goodness and classification quality.

| Goodness | F1-score | | | | |
|---|---|---|---|---|---|
|  | A | B | C | D | E |
| | 1.00 | 0.85 | 0.81 | 0.94 | 0.98 |

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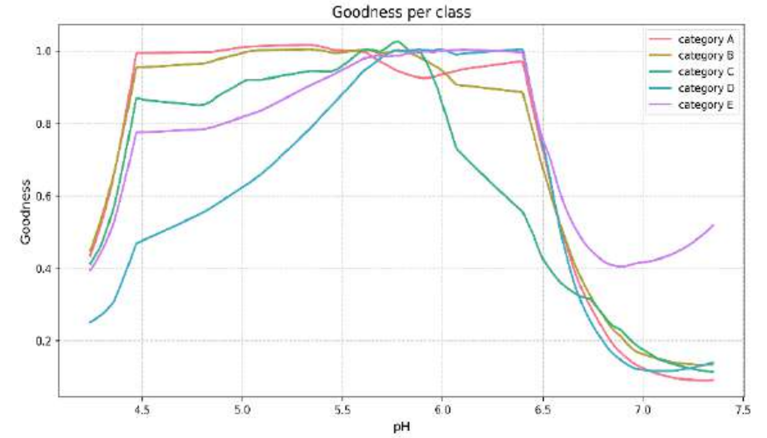
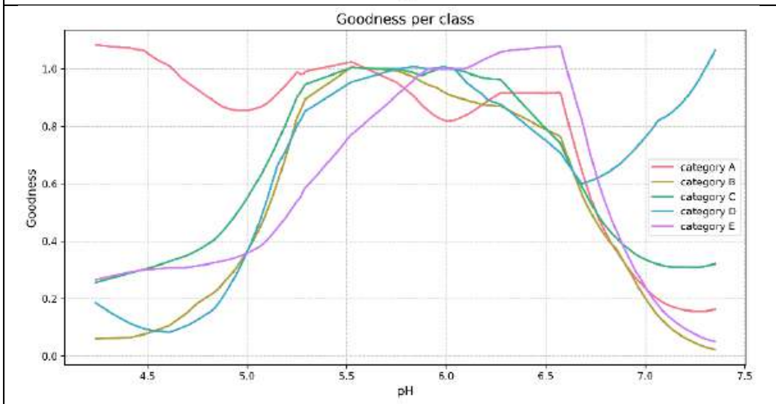
| | | | | | |
|---|---|---|---|---|---|
|  | 0.95 | 0.65 | 0.78 | 0.91 | 0.98 |
|  | 0.82 | 0.00 | 0.79 | 0.92 | 0.93 |

Figure 3: Table of the relationship between goodness and F 1 metrics.

From the table presented and based on the measurements taken, we can conclude that:

The goodness factor shows exceptionally high values over the distance limited by the test parameters, which convincingly demonstrates the overall accuracy of class recognition by the neural network. However, the observed zero F1-measure when identifying some classes can be directly related to the phenomenon of the model getting stuck in local minima of the loss function with a low goodness factor . This phenomenon is a typical optimization problem in training deep neural networks, when the algorithm is unable to overcome the "plateau" and reach a global minimum.

Overall, no more significant correlations between the network architectural characteristics and the experimental results obtained were found during detailed data analysis.

- backward trained model showed significantly more stable results on both the train and validation datasets , indicating superior generalization ability. The classification results are presented as confusion matrices . matrix ) of both studied models were carefully compared with each other and are clearly demonstrated in Figure 4, where the differences in the distribution of classification errors are clearly visible.

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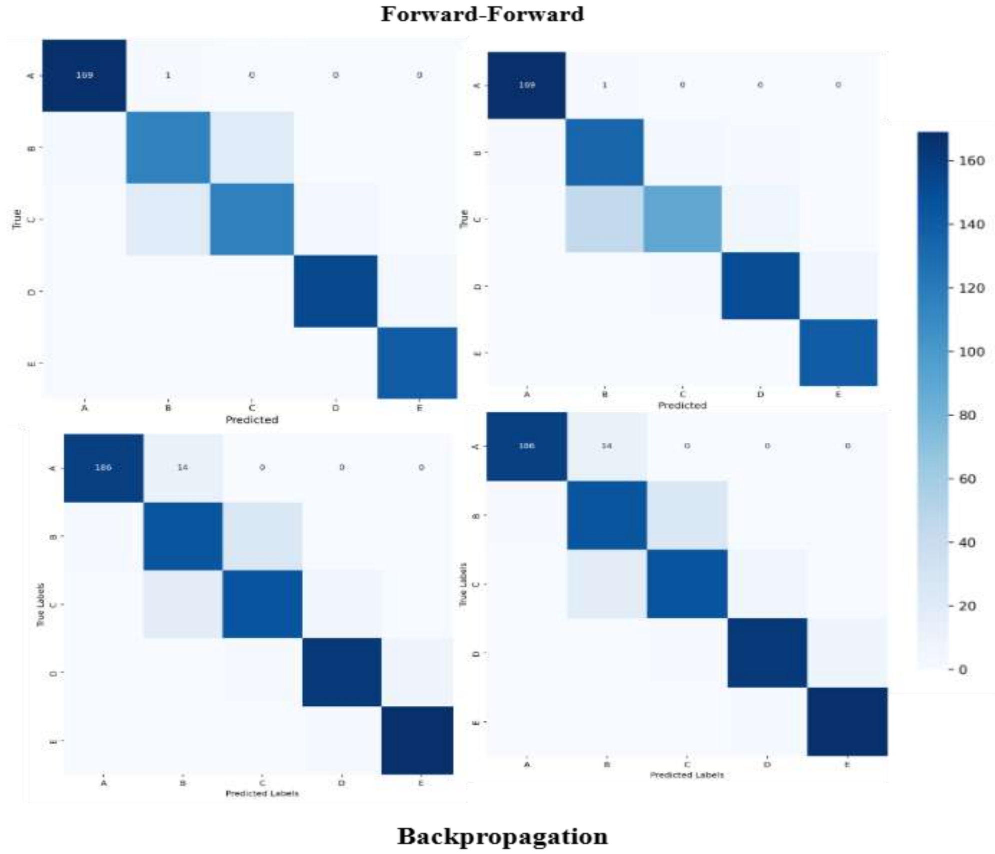


Figure 4: Comparison of classification quality of two models.

Based on the results of the model comparison, it can be concluded that the difference in classification accuracy of most system iterations is insignificant.

Thus, based on the analyzed data array, we can conclude that:

The ability to generalize data is much higher for a classical learning algorithm than for a system trained using the forward-forward method.

Moreover, the traditional multilayer linear perceptron also shows more stable learning than the experimental system.

## 4 CONCLUSIONS

Based on the conducted research, after careful monitoring of the parameters of the models and a comprehensive comparison of the systems based on the results obtained, the following scientifically based conclusions can be formulated:

First, the implemented neural models, despite fundamental differences in training methodologies and the observed instability of the training process in the context of direct double propagation ( forward-forward ), demonstrate only minor divergences in performance, with a moderate advantage in favor of the classical algorithm of backpropagation of errors ( Backpropagation ). This observation is of particular interest in the context of theoretical hypotheses about the potential advantages of alternative methods of training neural architectures . The obtained experimental data convincingly indicate that with identical architectural solutions and comparable hyperparameters , the differentiation in classification accuracy is statistically insignificant, which is not a critical factor for most applied implementations in the considered area.

Secondly, the investigated direct double propagation algorithm does not have a sufficient degree of interpretability, which is determined by its specific learning paradigm, which does not imply explicit connections with the previous layers of the neural network. This feature significantly complicates the analytical decomposition of the internal dynamics of the model and creates significant barriers to understanding the cause-and-effect relationships between the parametric characteristics of various layers of the neural architecture.

Third, a comparative analysis of computational efficiency showed that the convergence rate of the model trained using the backpropagation method demonstrates, on average, higher performance compared to the alternative forward-forward approach , which is a significant factor under resource constraints.

Thus, based on a comprehensive assessment of performance, interpretability and computational efficiency, it can be reasonably concluded that for solving specific problems related to the subject area of veterinary and sanitary examination and product quality control, it is more preferable to use the classical approach of back propagation of errors as a methodologically more mature and practically tested tool.

Overall, the forward - forward method represents a promising alternative to traditional artificial neural network training methodologies, but further in-depth study of its operating mechanisms is required to improve its interpretability and optimize its performance in the context of solving specialized classification problems.

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