



Deep Learning-based Assessment of Honey Purity using Predictive Modelling

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ABSTRACT

Background: This research paper proposes a new, efficient way of honey quality evaluation through the application of machine learning methods, more specifically on the deep neural network (DNN). Honey is an extremely popular natural sweetener that is not only appreciated for its pleasant taste but also for its numerous health advantages, such as its antioxidant, anti-inflammatory and antimicrobial properties. However, the high popularity of honey has caused its adulteration, particularly through the incorporation of low-cost sugar syrup, to spread rapidly. Such an issue offers critical health hazards to consumers, as honey adulteration cannot be effectively checked through traditional techniques. Therefore, to overcome this challenge, this study aims to present an efficient, smart way to effectively identify honey adulteration.

Methods: This study focuses on predicting the target variable using tabular physicochemical features through a deep learning-based approach. These factors include the colour score, density, water content, pH value, electric conductivity, level of fructose, level of glucose and honey viscosity. All these factors take into consideration the overall description of honey's physical-chemical property. A regression-based model of a Deep Neural Network is trained on a large set of data that comprises more than 200,000 data points.

Result: The performance of the model is excellent and has an R^2 value of 0.99, showing a level of accuracy that is extremely high to predict the purity level of honey. Notably, the discussion brings out clearly that the model performs well without any signs of either overfitting or underfitting and is very reliable and robust to be used in real applications. The discussion clearly brings out the effectiveness and potential role of Machine Learning and deep learning algorithms used in the context of food quality and food safety. The proposed approach is accurate and efficient and has a high potential to be used to check honey adulteration by various organizations and people.

Key words: Adulteration, Deep neural network, Health, Honey quality, Machine learning, Purity.

INTRODUCTION

Honey is a natural sweet, sticky, thick liquid produced by various bee species; honey bees are the most common. The bees prepare honey through the gathering of nectar from flowers and processing this product through their stomachs. In this course, the enzymes break down complex sugars into simpler forms. The nectar produced is stored in honeycombs, which gradually undergo evaporation of the excess water to yield honey. Honey derives its sweet taste primarily from the high percentage of fructose and glucose, two naturally occurring monosaccharides.

Honey has long been used by humans for several purposes, not only for its value as a sweetener but also for its medicinal properties. Honey is mainly used through consumption or through home remedies because of its medicinal values (Samarghandian *et al.*, 2017). Even though honey is a combination of sugar, it also contains proteins, fibers, vitamins and minerals in low quantities (Ranneh *et al.*, 2021). One of the main health benefits associated with taking honey is that it is fat-free, making it a healthy alternative to most sweetness products that are available in stores (Palma-Morales *et al.*, 2023). Moreover, honey is a source of bioactive compounds such as flavonoids and phenolic compounds that work to reduce oxidation processes within the body (Sampath *et al.*, 2010). Several scientific journals have shown that honey has a

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medicinal use when it comes to managing blood sugar and fighting inflammation within the body. Studies indicate that honey can increase adiponectin, a chemical within the body that regulates blood sugar and alleviates any form of inflammation within the body. Certain studies also found that people with type 2 diabetes, if they take honey in moderate amounts on a regular basis, may find that it helps improve their blood sugar levels. In fact, regular

consumption of pure honey also results in a decreased risk of developing any conditions of the heart, as well as an improvement in their cholesterol level (Pasupuleti *et al.*, 2016; Feknous *et al.*, 2022; Amna *et al.*, 2023).

Honey has also been well recognized for its ability to cure cough and throat irritation, particularly in children. Analysis of studies have concluded that honey could be more effective in the reduction of cough compared with popular drugs like diphenhydramine. Honey could also contribute towards halting the time taken to have an episode of coughing. In its practical application, honey can generally be used as a sweetening agent in incorporating it into tea, coffee, milk and yogurt. Honey can also be used in the cooking and preparation of baked foods due to its good taste and health advantages. Despite its health benefits, honey can easily be adulterated. Adulteration is adding foreign substances to honey to increase its volume and profit. Common adulterants include water and many types of sugar syrups, the most popular being cheap syrups. They almost resemble natural honey both in appearance and taste, so it is extremely difficult to identify them even by using advanced chemical and laboratory techniques.

Due to the dietary nature and medicinal values that honey possesses, adulterated honey poses serious health-related threats. Adulterated honey can cause an individual's blood glucose levels and insulin secretion to become high and can lead to an individual contracting type II diabetes. It can also cause the accumulation of visceral and entire bodily fat and an individual to become obese and develop high cholesterol and high blood pressure. Other risks that the adulterants pose include damaging an individual's internal organs by accumulating more fatty substances inside them, leading to fatty liver and renal disorders. The increasing demand for honey in the global market has inspired several producers and vendors to mix the honey with cheap alternatives that fetch higher revenue. One of the biggest problems in detecting the adulteration of honey is that there is no tangible difference between pure and mixed honey. Although several methods have been identified that determine the quality of honey through chemical and lab analyses, these procedures tend to be quite costly and time-consuming. Even though honey is getting highly adulterated, traditional methods of evaluating the purity of honey is dependent on lab based chemical analysis which will be time consuming and not a cost-effective solution. also, it demands expert intervention. There is a need of automated systems capable of checking the quality of honey. No automated system is available that quickly identifies the purity of the honey. This emphasises the need for intelligent and data-driven solutions for honey quality assessment. Purpose of this study is to design an accurate deep learning architecture-based predictive model for honey quality based on physical and chemical properties. This study will enhance the prediction accuracy and also investigate the efficiency of DNN architecture against machine learning techniques.

This serves as an indication of the benefit of incorporating Machine Learning techniques into the evaluation of honey quality. Machine learning techniques have shown great success and effectiveness in addressing difficult and complex issues and challenges across different fields, including the medical, agricultural and food safety fields (Varshitha *et al.*, 2022; AlZubi, 2023 and Al-Awadhi *et al.*, 2024). Data driven AI techniques have proven to be effective solutions in complex agricultural, livestock and wildlife detection problems (Cho *et al.*, 2024); Lee *et al.* (2024); Begum *et al.* (2022); Pakruddin *et al.* (2025). Large datasets have been evaluated and interesting patterns have been discovered, leading to the successful prediction of outcomes. Recent research studies have indicated the successful application of Machine Learning techniques towards the evaluation of honey quality and the detection of its adulteration. The accuracy, predictability and superior performance of the machine learning-based system are the most significant benefits of the evaluation approach.

Related work

Food safety has become one of the major concerns in the world today and in that respect, the adulteration of honey may create serious detriments to public health and weaken consumer trust. Honey is consumed not only as a nutritional sweetener, but also as a pharmaceutical product; therefore, its purity is a matter of the highest importance. However, serious adulteration of honey by using much cheaper substitutes like low-quality honey or artificial sweeteners is a contemporary consequence of increased demand. These methods not only lower the nutritional value of honey consumed but can also result in consumers suffering from adverse health effects for a long time. In this regard, research efforts have focused on developing reliable, accurate and technology-driven methods to detect honey adulteration that ensures food safety. Various studies have indicated the potential benefit of advanced imaging techniques coupled with ML algorithms in addressing this challenge. One such study conducted a comparative analysis of the available honey samples based on hyperspectral imaging data through various ML algorithms such as artificial neural networks (ANN), support vector machines (SVM), k-nearest neighbors (KNN), random forest classification (RF) and decision trees. In hyperspectral imaging, the data obtained is rich in spectral details spread over a broad spectrum of wavelengths; this enables the minute differences present in the make-up of honey to be gauged. The outcome of this study showed that the classification accuracy of identifying adulterated honey was above 98% through the application of ML algorithms to hyperspectral data. Out of various algorithms tested, ANN performed best after hyperparameter tuning, improving its accuracy (Esmael, 2024).

Another prominent work involved the classification of seven various kinds of Spanish uni-floral honeys through the application of Machine Learning algorithms. For effectively

classifying the honey samples, the technique of pollen analysis, together with the application of the human sense of empiricism, also known as the sense of the senses, which takes into consideration the sensory properties such as taste, scent and looks, has been used. For the dataset used in this work, various physicochemical factors such as electric conductivity, pH, water content, carbohydrate content and colour were utilized. Various ML algorithms were tried out in this work, such as C5.0 decision trees, extremely randomized trees (ET), weighted k-nearest neighbours (KNN), penalized discriminant analysis (PDA), shrinkage discriminant analysis (SDA), high-dimensional discriminant analysis (HDDA), nearest shrunken centroids (PAM), support vector machines employing both linear and radial kernels, random forests (RF), artificial neural networks (ANN) and XGB-ExtremeGradient Boosting. For accurate model selection, repeated 10-fold cross-validation was carried out in the training phase itself. The performance of each algorithm was then tested on a test dataset based on various criteria such as accuracy and log loss function. The outcome showed that PDA-based machine learning models reached the highest level of classification accuracy on the test dataset. This work has clearly shown that Machine Learning methods have great potential in accurately categorizing honey varieties and enabling authentication procedures (Fernando *et al.*, 2021).

Apart from classification studies, current research has also shown detailed overviews on modern approaches for honey quality estimation, especially for wild bees honey. These overviews include summaries of both international approaches stated by the International Honey Commission in 2009 and more advanced approaches that have been developed in the past ten years. The present situation in honey quality estimation involves blends of traditional approaches in a lab and advanced approaches. These approaches include nuclear magnetic resonance (NMR), zymography, polymerase chain reaction (PCR), DNA metabarcoding, near-infrared spectroscopy (NIR), potentiometric electronic tongue systems, electronic nose systems and approaches based on chemometrics such as partial least square methods and principal component analysis (PCA). Artificial neural networks (ANN) are usually joined in these approaches for enhanced predictive ability. On the other hand, approaches for efficient estimation of relevant honey attributes such as diastase activity, levels of hydroxymethylfurfural (HMF), sugar and water content, polyphenol content and markers for honey adulteration are also currently under development by researchers (Anna *et al.*, 2020).

Honey ranks among the most adulterated foods globally and it is often mixed with cheap honey or sugar substitutes that have high sweetness. In a bid to handle the problem, yet another researcher suggested an effective technique that incorporated visible near-infrared spectroscopy (Vis-NIRS) and Machine Learning algorithms. The technique allows for fast and non-destructive testing of the samples. Supervised machine learning algorithms

were employed to differentiate the presence of any possible adulterants and the outcomes were highly promising. Models based on random forest (RF) and support vector machine (SVM) were 100% accurate in identifying samples of adulterated honey. Moreover, regression analysis was employed to determine the precise percentage of any adulterants found in each sample (José, 2023).

In summary, these studies have shown the importance of Machine Learning and the use of sensing technologies in the better evaluation of honey quality and the assurance of food safety. Since the methods provide efficient and precise approaches, their potential use in the practical evaluation of honey quality and the assurance of food safety is very high.

MATERIALS AND METHODS

This research work was conducted at the department of CSE (AI and ML), Vidyavardhaka College of Engineering, Mysuru, India for a period of 2 to 3 years.

In the proposed honey quality evaluation model, the honey quality evaluation model requires the honey sample to be assessed to be taken as the input feature for the model. Honey quality can be assessed based on certain significant physicochemical parameters that have a strong correlation with honey quality parameters, mainly honey purity and authenticity. There are two significant approaches in obtaining the input parameter for the proposed modelling and evaluation of honey quality prediction models. These include chemical analysis models, which utilize laboratory parameters to determine the value of the honey quality parameters. The research project was conducted on several physicochemical descriptors of honey which could provide information about its purity and quality. The dataset was used for this research work available at obtained from Kaggle and consists of synthetic data representing physicochemical properties relevant to the prediction task (source : <https://www.kaggle.com/datasets/stealthtechnologies/predict-purity-and-price-of-honey>). The input features used to describe the physicochemical attributes included color score (CS), density, water content (WC), pH, electrical conductivity (EC), fructose (F), glucose (G), pollen analysis as well as the Viscosity of the samples. The color score indicates the variation in the sample's colour from a light shade (1.0) to dark shade (10.0). Density is defined as mass per unit volume, based on the volume of sample taken at 25°C. Water Content indicates how much moisture there is in the sample; pH value shows how acidic the sample is and across all analyses, electrical conductivity provides information on the amount of minerals present in the sample. The sugar composition will include fructose and glucose levels as respective representatives of the composition of honey. Pollen analysis provides information on the floral origin for the sample and will include categories such as clover, wildflower, acacia, manuka, lavender, *etc.* Viscosity, as measured in centipoise (cP), describes how well honey

flows and the viscosity of honey typically will range from 1500 to 10000 cP, with 2500 to 9500 cP representing optimal purity conditions. The target variable being analysed in this study is that of Purity, represented by a numeric value of 0.01 to 1.00 demonstrating how pure/free of impurities and/or adulteration the sample is. Even though the models taken into consideration have significant precision, their utility poses significant challenges with regards to time consumption, cost sensitiveness and expertise. Consequently, their application becomes a challenge.

The second more sophisticated method for feature extraction from honey samples is hyperspectral imaging. Hyperspectral images of honey samples are captured by a hyperspectral camera setup, which captures information from a very large number of wavelengths. Unlike the conventionally applied methods of capturing an image, hyperspectral imaging captures spectral information for every pixel in an image. As a result, subtle variabilities in honey composition can be identified with high precision. In fact, a few features will be distinctly and efficiently segregated that, in turn, makes this method faster and suitable for automated analysis (Anuja *et al.*, 2024 and Shenming *et al.*, 2022).

As shown in the Fig 2, After the extraction of the corresponding features through either chemical analysis or hyperspectral imaging, the features are then used as input to the developed Machine Learning model. The main purpose of the developed model is to determine adulteration in natural honey by estimating the level of purity that is in the honey. Based on the estimated level of purity, the honey is then classified according to its quality, which may be in the form of best quality, better quality, or bad quality depending on the measure of impurity. As indicated in Fig 1, the proposed work will use the DNN model that is designed to handle the problem of regression. Regression is a Machine Learning model that is used in predicting the continuous value. Therefore, in this work, the DNN model will be used to estimate the level of purity in the honey in the form of its continuous value. For high accuracy and

robustness, the model is trained using a dataset with over 200,000 rows of data. The dataset is sufficient for the model to learn the complex interactions between the input variables and the desired purity value.

As shown in Fig 2, a deep neural network (DNN) with the typical feedforward network architecture is widely used to predict the quality of honey by learning complex nonlinear relationships between the input features and the target variable (quality or purity). The suggested neural network model involves an input layer having physicochemical inputs, which will depend on the number of variables, followed by two hidden layers with 128 and 64 neurons each and ReLU activation functions. There will be an output layer with one neuron having a linear activation function for regression. Experimentally obtained features like physicochemical inputs or imaging-based features will serve as inputs to the network. The network will use the Adam optimizer with learning rate set to 0.001, mini-batch size set to 32 and a total of 100 epochs with MSE as the loss function. Backpropagation and gradient descent will be used during the process of training the model, with a view to minimizing errors. As can be seen, this feedforward deep neural network can learn and extract patterns from input data to predict the quality of honey or identify adulteration. After obtaining the output for the purity score from the model, threshold values are set for classifying the honey sample into "Pure" or "Not Pure". The model proposed involves a two-step process that allows both accurate calculation of the purity level and proper categorization based on honey quality. Apart from building a deep neural network model, another comparative study was carried out based on different regression models. This is to know which regression model works best in predicting honey purity and quality.

Thus, the proposed methodology presents a highly efficient, accurate and scalable solution for honey quality evaluation. Through the integration of advanced techniques for feature extraction with regression models based on deep learning, a reliable system for honey adulteration detection to guarantee food safety is obtained.

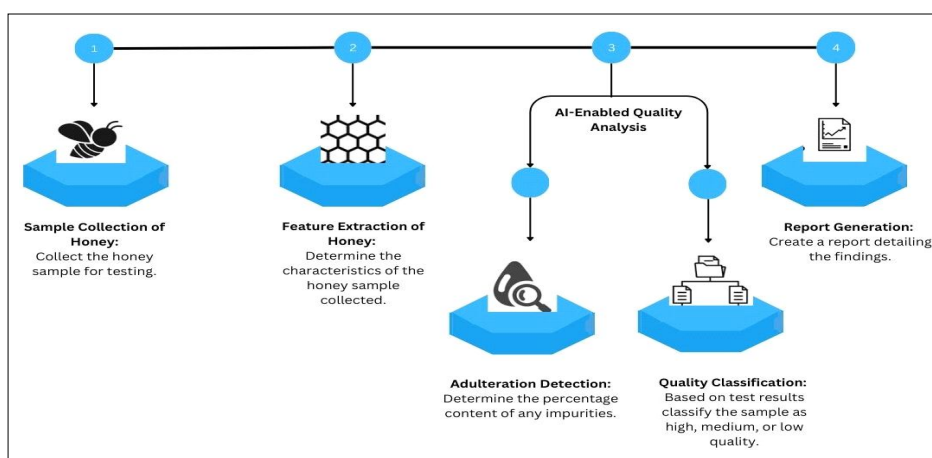


Fig 1: Proposed work of honey quality prediction.

RESULTS AND DISCUSSION

To assess the efficiency of the proposed approach, a comparative experiment is carried out with the use of traditional machine learning algorithms, including linear regression, random forest, adaboost and deep neural network (DNN). As shown in the results, the DNN model outperforms all the baseline models regarding the level of prediction accuracy and error measures. The high efficiency of the DNN algorithm is explained by its capability to detect nonlinear dependencies within the dataset that cannot be addressed by traditional approaches. It should be noted that according to the results of the experiments, the DNN algorithm exhibits the highest R^2 value among all regression models as shown in Fig 3. The R^2 value, also referred to as the coefficient of determination, reflects the degree to which the model can explain the variation in the dependent variable. It measures how close the predicted values generated by the model come to the actual target values (Figueiredo *et al.*, 2011).

R^2 mathematically can be obtained by the following formula:

$$R^2 = 1 - \frac{\text{Sum of squared residuals (SSR)}}{\text{Total sum of squares (SST)}}$$

Where,

SSR= The sum of squares of differences between actual values and predicted ones.

SST= The overall variance in the target data.

R^2 explains the goodness of fit for a regression model and makes a person get an idea of how much variability in the target variable is described by this model.

R^2 ranges between 0 and 1. The closer to 1 an R^2 value is, the better the model performs because its predictions are very close to the actual values. The closer to 0 an R^2 value is, the worse the model is because its predictions show massive variance from the true target values. Therefore, the higher an R^2 value is, the greater predictive accuracy and model reliability the model has.

In this context and in furtherance to the said work, a comparison analysis was conducted by implementing and

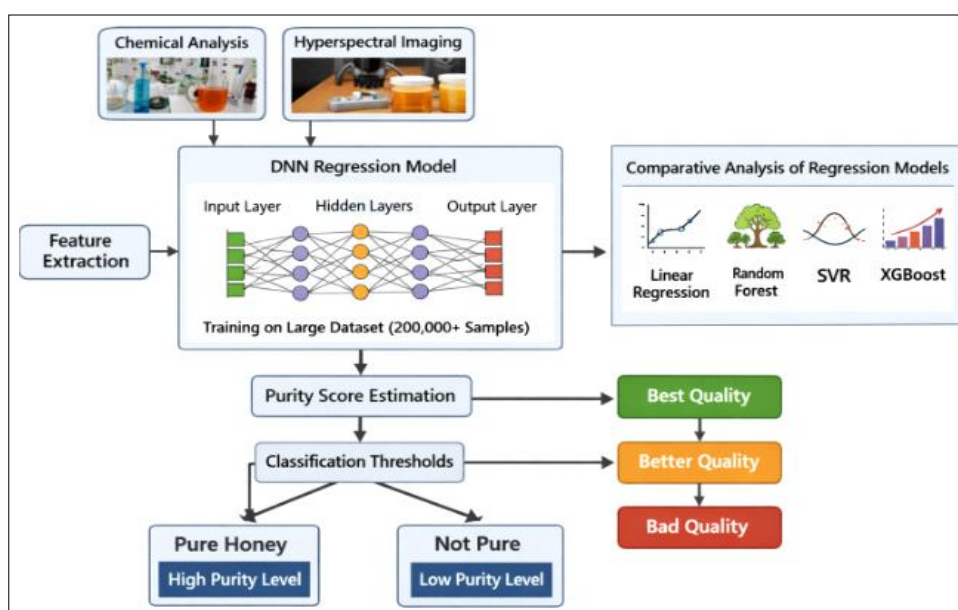


Fig 2: Methodology and architecture of the model.

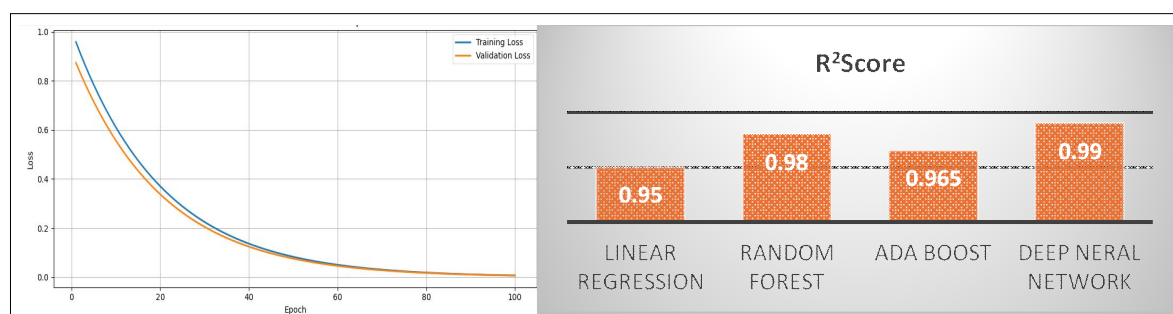


Fig 3: Loss curve of model and comparisons of models using R^2 score.

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Epoch 95/100
9917/9917 — 19s 2ms/step - loss: 6.8537e-04 - mae: 0.0137 - val_loss: 6.8963e-04 - val_mae: 0.0141
Epoch 96/100
9917/9917 — 17s 2ms/step - loss: 6.8123e-04 - mae: 0.0136 - val_loss: 6.3627e-04 - val_mae: 0.0131
Epoch 97/100
9917/9917 — 16s 2ms/step - loss: 6.8106e-04 - mae: 0.0136 - val_loss: 9.9130e-04 - val_mae: 0.0216
Epoch 98/100
9917/9917 — 16s 2ms/step - loss: 6.8537e-04 - mae: 0.0137 - val_loss: 6.3671e-04 - val_mae: 0.0128
Epoch 99/100
9917/9917 — 17s 2ms/step - loss: 6.9324e-04 - mae: 0.0137 - val_loss: 6.2429e-04 - val_mae: 0.0133
Epoch 100/100
9917/9917 — 16s 2ms/step - loss: 6.7374e-04 - mae: 0.0135 - val_loss: 6.2541e-04 - val_mae: 0.0121
1550/1550 — 2s 1ms/step - loss: 6.1899e-04 - mae: 0.0121
Test MAE: 0.01

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Fig 4: Deep neural network model building.

Metric	Equation	Description
Mean Squared Error (MSE)	$MSE = \frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2$	Average of squared errors.
Mean Absolute Error (MAE)	$MAE = \frac{1}{n} \sum_{i=1}^n y_i - \hat{y}_i $	Average of absolute errors.
Root Mean Squared Error (RMSE)	$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2}$	Root of MSE.
R ² (R-Squared)	$R^2 = 1 - \frac{\sum (y_i - \hat{y}_i)^2}{\sum (y_i - \bar{y})^2}$	Model fit quality.

Fig 5: Evaluation metrics of regression.

evaluating four regression models. The performance comparison, as depicted in Fig 4, clearly demonstrates that the proposed Deep Neural Network model outperforms the other models by an R² score of 0.99, which is indicative of a very high value. This high value of R² implies that the model DNN is sufficient in predicting honey purity and deciphering the complicated association between input features and the target variable.

As shown in Fig 5, various metrics can be used for evaluating the performance of regression models. The proposed DNN regression model obtained very low values of error, as the MAE for the training, validation and test datasets were 0.0135, 0.0121 and 0.0121, respectively. The loss values were 6.73×10^{-4} , 6.25×10^{-4} and 6.18×10^{-4} , respectively. The difference between the training and validation datasets is very low, indicating that the model does not overfit and has high accuracy for the prediction of the purity of honey. The suggested neural network structure includes an input layer, whose nodes correspond to the number of attributes used as inputs to the network, followed by two hidden layers, which comprise 128 and 64 neurons with the ReLU activation function, respectively. The output layer has only one node activated by a linear function. To avoid overfitting and improve the stability of the model, a k-fold cross-validation scheme is utilized (k = 5). The presented numerical results are computed by averaging the performance values across all k-folds.

It appears that the developed neural network model can predict target values accurately.

Further clarity on the behaviour of the model can be derived by observing Fig 3 below, where the training and testing loss curves are plotted. The fact that there isn't much variation in the two curves reveals the fact that the model performs very well in terms of generalization. Hence, the model isn't facing any problem of either overfitting or underfitting. In the former case, models tend to perform in a manner where they are very efficient on the training data but go completely wrong on the test data. In the latter case, the model isn't efficient on the training data at all. This can be evidenced by the fact that the model underwent 100 epochs in batch learning. This can be observed in Fig 4. These results, in general, prove the efficiency and validity of the suggested Deep Neural Network model in predicting the quality of the honey.

CONCLUSION

Honey is a widely used natural sweetener valued not only for its taste but also for its health benefits. It contains antioxidants, bioactive compounds and natural sugars that support overall wellness. However, honey is often adulterated with inexpensive sugar syrups and artificial sweeteners, which are difficult to detect due to their similar taste and appearance. Consumption of adulterated honey can lead to serious health issues, including visceral fat

accumulation, fatty liver disease, kidney damage, obesity and high blood sugar levels. Continuous intake may even result in severe long-term complications. The growing demand for honey has encouraged unethical adulteration practices, misleading consumers and violating food quality standards. Traditional methods for detecting honey purity are accurate but time-consuming and costly, limiting large-scale application. To address this, Machine Learning techniques offer an efficient alternative by analysing large datasets to detect adulteration. This study proposes a deep neural network (DNN) regression model to predict honey purity based on physicochemical properties. The model effectively captures nonlinear relationships within the data and outperforms traditional methods. With an R^2 value of 0.99 and low error rates, the model demonstrates high accuracy and strong generalization, making it a reliable solution for honey quality assessment.

Conflict of interest

I would like to confirm you that there is no correction required and I would want to declare that there is no conflict of interest.

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