Scientific quarterly journal ISNN 1429-7264

Agricultural Engineering

2014:1(149):165-173

Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2014.149.018

INVESTIGATION OF THE IMPACT OF WATER CONTENT AND ACTIVITY ON ELECTRIC PROPERTIES OF HONEY WITH THE USE OF NEURAL NETWORKS

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ARTICLE INFO

Article history:
Received: April 2013
Received in the revised form: December 2013
Accepted: January 2014

Keywords:
honey
electrical properties
artificial neural networks
water activity
water content

ABSTRACT

The objective of this research was to determine how water content and water activity impact on the selected electrical honey parameters. Experimental data obtained for fifty samples of honey collected on the territory of Poland were used for research. These were nectar honeys, nectar-honeydew as well as honeydew honeys. Chemical and electrical parameters were determined for each sample: conductivity of 20 percentage water and honey solution, conductivity and impedance of liquid honey. Then, with the use of artificial neural networks, multi-dimensional mathematical models, describing relationships between electrical and chemical properties were constructed. Based on these models, with the use of knowledge on networks structure and values of synaptic weights, degree of the impact of particular input parameters on output parameters of the model was determined. The tests which were carried out proved that water activity and content influence impedance more than conductivity of liquid honey and solution.

Introduction and objective of the research

Water content and water activity are of great importance for food quality and food storage. There is a connection between these two parameters and their values have a great impact on preservation of food products of biological origin. Honey is that type of food therefore water as well as monosaccharides content determine its physical properties. Water content influences the honey fermentation phenomenon, which deteriorates the product quality (Lazaridou et al., 2004). There is a correlation between water content and water activity, however water activity provides more information on the product. During honey storage, crystallization process is observed, what influences the water-binding characteristics in honey and causes increase in water activity (Iurlina and Fritz, 2005; Wojtacki, 1989).

Measurement of honey water activity requires specialised equipment therefore it can be performed only in specialized laboratories. Electrical features of biological materials are seldom used for food quality assessment, however one can find some publications on this subject (Skierucha et al., 2012; Łuczycka et al., 2011). Electrical properties such as conductivity and impedance can be used for assessment of honey quality. Therefore it is appropriate to establish the effect of water content and water activity on certain electrical features of honey.

The determination of relations between chemical and electrical honey properties based on the measurement data is difficult with the use of analytical methods. In publications on the agricultural engineering subject one can find many reports describing the use of artificial neural networks for modeling of complex nonlinear relationships (Langman, 1999; Hebda and Francik, 2006; Górski et al., 2008; Łapczyńska-Kordon et al., 2008). A multilayer perceptron with quite a simple structure can be used for these tasks (Pentoś et al., 2008; Łuczycka and Pentoś, 2010).

When sufficiently extensive measurement data set is used for network training, the network can be used as a mathematical model of complex, multidimensional and nonlinear relationships (Rutkowska et al., 1999; Osowski, 2006; Rutkowski, 2011). The network structure is empirically selected as to obtain a model with high accuracy for both, training and testing data set.

The aim of the research was to use neural models obtained from simulation tests for determination of the influence level of water content and water activity on certain honey electrical properties.

Methodology

Chemical and electrical parameters were determined for fifty honey samples. Among these fifty samples were nectar honeys (39 samples), nectar-honeydew honeys (4 samples) and honeydew honeys (7 samples). All honey samples were harvested in year 2011 directly from producers located on the area of Poland. The following honey parameters were measured: water content, water activity, the content of glucose, fructose and proline, pH, diastase, strained honey conductivity, conductivity of aqueous solution of honey at 20%, strained honey impedance.

Water activity measurement was conducted at the Department of Agriculture and Food Technology at Bialystok University of Technology. For water activity determination liquid honey was used. Samples were heated up to the temperature of 55ºC and afterwards cooled down to the temperature of 25ºC. The measurements were taken in the temperature of 25ºC by the use of AQUA LAB CX-2 device with a climate chamber. The measurements were taken by five repeated tests (using five different samples) and afterwards average value was calculated. Water content determination was conducted with the use of refractometric method by refractive index measurement (with Abbe-type refractometer). Other chemical parameters were measured in Bee Product Quality Testing Laboratory, the Research Institute of Horticulture, Apicultural Division in Pulawy. For glucose and fructose content measurement, HPLC method was used, for proline content – a calorimetric (A) method, for diastase – Phadebas (A) method.

Electrical parameters measurement was conducted in the Institute of Agricultural Engineering, Wroclaw University of Environmental and Life Sciences. All parameters were measured in the temperature of 25ºC. Impedance was measured by means of ATLAS 0441 apparatus. The impedance analyzer enabled the complex impedance measurement. The real part of impedance and imaginary part of impedance were used separately in neural models. For the conductivity determination by direct method, aqueous solution of honey at 20% was used. The measurement was taken by means of AZ 8361 Cond./TDS apparatus. Before measurement, a liquid form of honey was obtained by samples heating up to the temperature of 40ºC. Electrical honey features measurements were taken four times.

The values of experimental data were of the wide range (e.g. conductivity of aqueous solution of honey at 20% – from 165 to 1222, water activity from 0.52 to 0.65). This kind of values high spread can cause difficulties during neural network training process and can lead to mistakes in determination of the influence level of certain input parameters on output parameters. Therefore, training data were normalized into a new range of <0.1–1> using the equation (Eq. 1):

$$ZN = \frac{ZN_{max} - ZN_{min}}{Z_{max} - Z_{min}} \cdot (Z - Z_{min}) + ZN_{min} \quad (1)$$

where:

ZN – normalized value of z variable,
ZN_{min} – minimum value of a normalized range,
ZN_{max} – maximum value of a normalized range,
Z – experimental value of z variable,
Z_{min} – minimum experimental value of z variable,
Z_{max} – maximum experimental value of z variable.

Based on the data obtained during the experiment, a neural model was performed. The following honey features were suggested as input model parameters:

– water content, (%)
– water activity, (-)
– glucose content ($g \cdot 100g^{-1}$)/fructose content ($g \cdot 100g^{-1}$) ratio
– proline content, ($mg \cdot 100g^{-1}$)
– pH, (-)
– diastase, (-).

As output model parameters the following honey electrical features were suggested:

– strained honey conductivity, ($S \cdot m^{-1}$)
– conductivity of aqueous solution of honey at 20%, ($S \cdot m^{-1}$)
– impedance, (Ω) .

Input as well as output model parameters were proposed on the basis of authors experience.

Two independent network models were used for the determination of water content and water activity influence on honey electrical parameters. In the first model the input parameters were as follows: water content, glucose content /fructose content ratio, proline content, pH and diastase. In the second model water activity was used instead of water content.

The aim of neural models development was to determine the influence of water content and water activity on certain honey electrical parameters. Therefore neural networks containing five input nodes and four neurons in the output layer were used. The scientific reports of other authors (Ślipek et al., 2003) show that the experimental data set should be divided into a training and testing set in appropriate proportions e.g. 70% patterns for the training set and 30% patterns for the testing set. During the training process, the training set of 150 patterns and the testing set of 50 patterns were used. Simulations were executed using *Matlab* environment. The feed-forward neural networks (a multilayer perceptron) with one hidden layer were used. The initial weights values were selected randomly. The training process was executed using some different training algorithms (selected backpropagation algorithm modifications). Several dozen network configurations were tested. The number of neurons in the hidden layer was changed from 3 to 50. The best network architecture was chosen on the basis of the error value for the training set (the error value for the testing set was also calculated in order to avoid the overfitting effect). The mean relative error calculated as follows was used:

$$\varepsilon = \frac{\sum_{i=1}^{n} \frac{|(x_i^{\exp} - x_i^{calc})|}{x_i^{calc}} \cdot 100\%}{n} \qquad (2)$$

where:

$x_i^{\exp}$ – the output expected value for *i*th pattern from training or testing set,

x_i^{calc} – the output value for *i*th pattern from training or testing set calculated by neural model,

n – the number of patterns in the training or testing set.

On the basis of the network structure and connection weights values after learning process, the algebraic expression describing relations between output and input parameters can be developed (Pentoś, 2009). Each connection between two neurons is described by the connection weight value *w*. For each neuron the activation function *f* is defined (in this work the sigmoid activation function for neurons in the hidden layer and linear activation function for neurons in the output layer were defined). The general expression describing the output signal of *i*th neuron in the output layer is as follows:

$$y_i = f_{wi}(\sum_{j=1}^{n} w_{ij}^{(2)} v_j)\,, \qquad (3)$$

where:

$$v_j = f_{uj}(\sum_{k=1}^{m} x_k w_{kj}^{(1)})\,. \qquad (4)$$

In the expressions 3 and 4 x_k is the *k*th element of the input vector, y_i is the *i*th element of the output vector, f_{wi} is the activation function of *i*th neuron in the output layer, f_{ui} is the activation function of *j*th neuron in the hidden layer, $w_{kj}^{(1)}$ is the connection weight between *k*th input node and *j*th neuron in the hidden layer, $w_{ji}^{(2)}$ is the connection weight between *j*th neuron in the hidden layer and *i*th neuron in the output layer, v_j is the output signal of *j*th neuron in the hidden layer, n is the number of neurons in the hidden layer, m – is the number of input nodes.

On the basis of connection weights values in the neural network built of neurons with a sigmoid activation function in the hidden layer and a linear activation function in the output layer, for each network output the expression describing relationship between input and output model parameters can be developed. The expression is the sum of components as follows:

$$\frac{a}{1+\exp(b_1 x_1 + b_2 x_2 + ... + b_n x_n)} \tag{5}$$

where the value of component a depends on the connection weights of neurons in the output layer values and values of components $b_1, b_2, ..., b_n$ depend on the connection weights of neurons in the hidden layer. The expression describing the output signal of *i*th neuron in the output layer can be approximated by the following expression:

$$y_i = \chi_{i1} x_1 + \chi_{i2} x_2 + ... + \chi_{in} x_n \tag{6}$$

where values of components χ can be calculated or estimated using numerical methods. In this case, the multiple regression method was used. The data set representing the relationship between y_i and input parameters was generated (points must be located evenly in the parameters hyperspace across the parameters variability range). Based on the generated data set, the multiple regression was conducted (with the control of correlation coefficient R and determination coefficient R^2).

Test results

In order to verify the neural model accuracy, the preliminary tests were conducted. The aim of preliminary tests was to determine if all input model variables influence significantly on output model parameters. The four independent neural models were developed using *Statistica* environment. In each neural model six input nodes were used for six input variables mentioned above. Each neural model contained one output neuron for output variable (for four consecutive output parameters mentioned above). For each model, 150 feed-forward networks with different architecture were investigated using *Automated Neural Networks* in order to find the best network architecture. For the best networks found during this investigation, the sensitivity analysis was conducted. The results of the sensitivity analysis proved that all input variables influence significantly all output variables (the errors ratio value ≥1). The most significant influence on strained honey conductivity was observed for diastase and the least for the glucose content /fructose content ratio. In case of conductivity of aqueous solution of honey at 20%, the most important input variable is diastase and the least – proline content. In case of real part of impedance – proline content and pH respectively, in case of imaginary part of impedance – diastase (the most important) and water content (the least important).

Afterwards, two independent neural models were developed and used for determination of the influence of water content and water activity on honey electrical parameters. As a model used for determination of water content on honey electrical parameters, the network with the architecture 5-9-4 (nine neurons in the hidden layer) was used. The mean relative error calculated for training data set was equal to 2% (for the testing data set it was 5%).

On the basis of the connection weights values the expression describing relationship between each output variable and input variable was determined. Afterwards, each expression was approximated by polynomial and the following algebraic expressions were obtained:

$$y_1 = -27x_1 + 4{,}24x_2 + 0{,}79x_3 - 6{,}17x_4 + 32{,}77x_5 \quad (7)$$

$$y_2 = -9{,}28x_1 + 15{,}25x_2 + 0{,}49x_3 - 15{,}54x_4 + 11{,}16x_5 \quad (8)$$

$$y_3 = 58{,}45x_1 + 11{,}96x_2 - 21{,}93x_3 + 20x_4 - 108x_5 \quad (9)$$

$$y_4 = 41x_1 - 7{,}6x_2 - 14{,}77x_3 + 8{,}7x_4 - 89x_5 \quad (10)$$

where the follow-up y_i mean strained honey conductivity, conductivity of aqueous solution of honey at 20%, real part of impedance and imaginary part of impedance respectively and the follow-up x_i mean water content, glucose content /fructose content ratio, proline content, pH and diastase respectively.

In the fig.1. the absolute values of polynomial components describing the influence of water content on honey electrical parameters (output model variables) are shown.

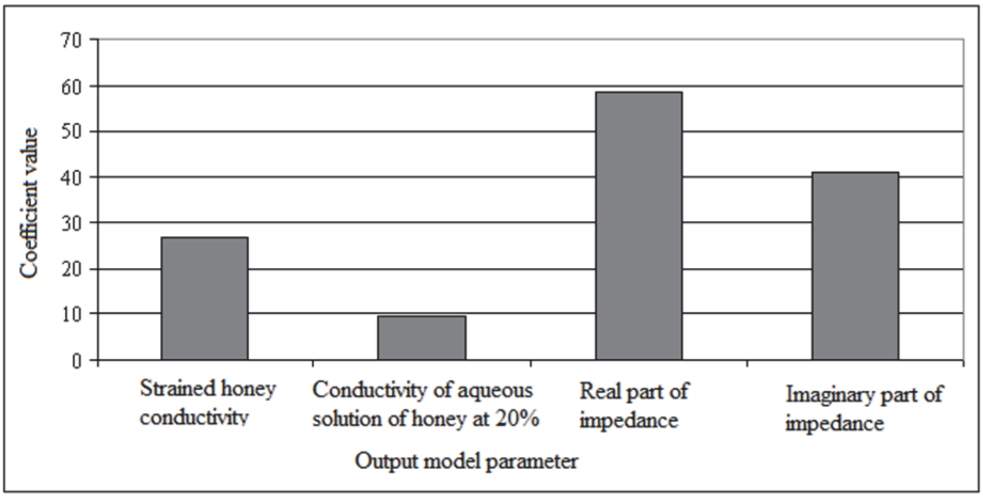

Figure 1. Absolute values of coefficients which picture the impact of water content on input parameters of the model

As a model used for determination of water activity on honey electrical parameters, the network with ten neurons in the hidden layer (the architecture 5-10-4) was used. The mean relative error calculated for training data set was equal to 2.5% (for testing data set 5.1%). On the basis of a neural model, the following polynomial expressions were obtained.

$$y_1 = 10{,}5x_1 + 14{,}5x_2 - 6x_3 + 11{,}6x_4 - 12{,}6x_5 \quad (11)$$

$$y_2 = -8{,}7x_1 - 9{,}6x_2 - 28{,}5x_3 + 24x_4 - 27x_5 \quad (12)$$

$$y_3 = 31{,}45x_1 - 17{,}3x_2 + 59x_3 + 15{,}3x_4 + 50x_5 \quad (13)$$

$$y_4 = 36{,}23x_1 - 44x_2 + 50x_3 - 12x_4 + 51{,}5x_5 \quad (14)$$

where the follow-up y_i mean strained honey conductivity, conductivity of aqueous solution of honey at 20%, real part of impedance and imaginary part of impedance respectively and the follow-up x_i mean glucose content /fructose content ratio, proline content, pH, diastase and water activity respectively.

In the fig.2. the absolute values of polynomial components describing the influence of water activity on honey electrical parameters (output model variables) are shown.

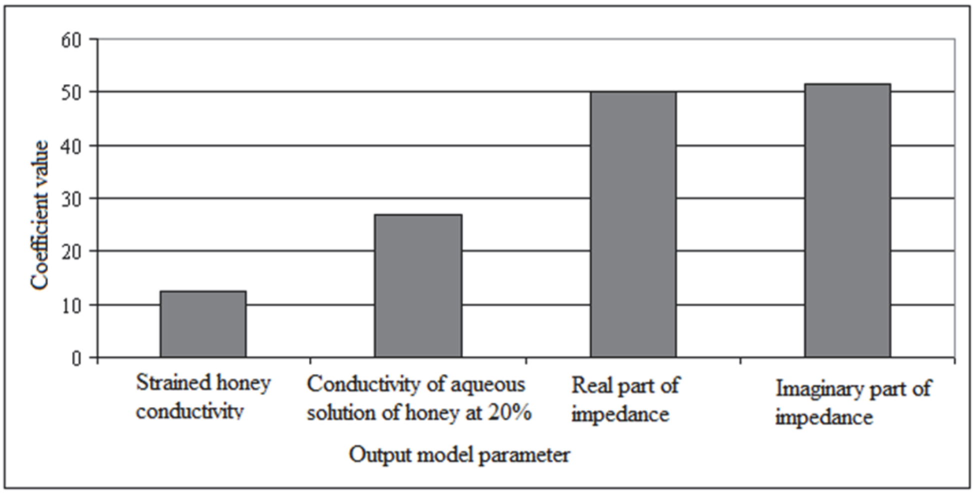

Figure 2. Absolute values of coefficients which picture the impact of water content on output parameters of the model

The polynomial expressions presented in this work are the approximation of relationships represented by a neural model obtained by the use of numerical methods. Therefore they mustn't be used as a model of relationships between chemical and electrical honey parameters. However, the contribution of input variables is not distorted. The differences between coefficients presented in Fig. 1 and Fig. 2 can not be properly interpreted because the coefficients calculation was performed using two independent neural models. Only differences of coefficients values calculated for one model can be properly interpreted.

Conclusion

Neural networks are a useful tool for the analysis of the influence of input variables on output model parameters. Particularly, when the number of parameters is high, relationships between parameters are nonlinear and the nature of relationships is difficult to describe using analytical methods. On the basis of the research results the following conclusions can be reached:

1. The water content influences the most the real and imaginary part of impedance and the least - strained honey conductivity.
2. The water activity has a significantly greater influence on the impedance (real and imaginary part) than on strained honey conductivity and conductivity of aqueous solution of honey at 20%.

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BADANIE WPŁYWU ZAWARTOŚCI WODY I AKTYWNOŚCI WODY NA CECHY ELEKTRYCZNE MIODU Z WYKORZYSTANIEM SIECI NEURONOWYCH

Streszczenie. Celem badań było ustalenie stopnia wpływu zawartości wody oraz aktywności wody na wybrane cechy elektryczne miodu. W badaniach wykorzystano dane doświadczalne uzyskane dla pięćdziesięciu próbek miodów zebranych na terenie całej Polski. Były to miody nektarowe, nektarowo-spadziowe oraz spadziowe. Dla próbek oznaczono parametry chemiczne oraz elektryczne: przewodność dwudziestoprocentowego roztworu wodnego miodu oraz przewodność i impedancję patoki. Następnie wykorzystując sztuczne sieci neuronowe, skonstruowano wielowymiarowe modele matematyczne, opisujące zależność cech elektrycznych od parametrów chemicznych. Na podstawie tych modeli, wykorzystując znajomość struktury sieci oraz wartości wag synaptycznych, określono stopień wpływu poszczególnych parametrów wejściowych na parametry wyjściowe modelu. Przeprowadzone badania wykazały, że aktywność i zawartość wody w znacznie większym stopniu wpływają na impedancję niż na przewodność patoki oraz roztworu.

Słowa kluczowe: miód, właściwości elektryczne, sztuczne sieci neuronowe, aktywność wody, zawartość wody