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Influence of temperature, frequency and moisture content on honey viscoelastic parameters – Neural networks and adaptive neuro-fuzzy inference system prediction

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ABSTRACT

The aim of this study is to evaluate the influence of temperature, moisture and frequency on nine honeys from viscoelastic (complex viscosity, η^*, loss modulus, G'', and storage modulus, G') point of view using artificial neural networks (ANN) and adaptive neuro-fuzzy inference system (ANFIS). The temperature has ranged between 5 and 40 °C, the moisture content 16.04 and 17.82% and the frequency 0.1 and 10 Hz. Artificial neural networks (Multilayer perceptron – MLP, Probabilistic neural network – PNN, Radial basis function network – RBF and Recurrent network – RN) have been used to evaluate their model of prediction usefulness. Keeping into account the statistical parameters values, it seems that the ANNs methodology predicts better the evolution of viscoelastic parameters of honey in function of temperature, frequency and moisture content than ANFIS.

1. Introduction

Honey is a natural sweetener, being a supersaturated sugar solution which is composed, in its majority, by a carbohydrate mixture (Kabbani, Sepulcre, & Wedekind, 2011). Honey is a hygroscopic material; that is, it has excellent water absorbing properties. Thus, honey changes its moisture content according to the surrounding atmosphere. This characteristic is important for honey storing because it absorbs water when exposed to high relative humidity (RH) (Camara & Laux, 2010).

The rheological parameters of honey are influence by temperature, moisture content and presence of crystals and colloids in the product (Yanniotis, Skaltsi, & Karaburnioti, 2006). Many papers have been published regarding the influence of temperature at specific moisture content (Yanniotis et al., 2006), °Brix concentration (Oroian, Amariei, Escriche, & Gutt, 2013; Oroian et al., 2014), chemical composition (Oroian et al., 2014). Al-Manasneh, Rababah, and Ma'Abreh (2013) applied the neural network approach to evaluate the effect of temperature, shear rate and water content of the viscosity of honey. However, no other study on the influence of frequency, temperature and moisture content on the honey viscoelastic parameters has been reported.

Artificial neural network (ANN) is a system of information processing, which is inspired by the biological nervous system (brain). The objective of a neural network is to compute output values from input values by some internal calculation (Khajeh & Barkhordar, 2013; Sadrzadeh, Mohammadi, Ivakpour, & Kasiri, 2008). Unlike other analytical methods, where prior knowledge of relationships among process parameters is required, ANN draws on previously gathered information and utilizes this when analyzing new data input (Jain, 2010). It is particularly useful in managing uncertainties and non-linear data relationships. In the area of food quality control, ANN has been successfully applied to predict food parameters (Fan et al., 2013; Khajeh & Barkhordar, 2013; Singh, Ruhil, Jain, Patel, & Patil, 2009; Tulbek et al., 2003).

Over the last years, the fuzzy logic and fuzzy inference system have been applied to identify and model complex non-linear systems (Karaman & Kayacier, 2011). To correctly describe the complex and non-linear systems, fuzzy inference systems can be efficiently used with the precise rules for the prediction of certain parameters (Gänzle, Kilimann, Hartmann, Vogel, & Delgado, 2007). The fuzzy inference system can be applied to predict non-linear evolution of food parameters such as physico-chemical or rheological properties (Abu Ghoush, Samhouri, Al Holy, & Herald, 2008). The fuzzy

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inference system has been applied to predict physico-chemical and rheological characteristics of molasses (Karaman & Kayacier, 2011) and mechanical properties of tapioca starch-poly (lactic acid) nanocomposite foams (Lee, Hana, & Jones, 2008).

The aim of this study is to predict the influence of temperature, moisture content and frequency on the viscoelastic parameters of honey (complex viscosity (η^*), loss modulus (G'') and storage modulus (G')), using the artificial neural network and adaptive neuro-fuzzy inference system.

2. Materials and methods

2.1. Materials

Nine different types of honey samples purchased from the local market of Valencia, Spain, have been used for the analysis. The rheological parameters of honeys can be influenced by the presence of crystals and air bubbles (Bhandari, Arcy, & Chow, 1999; Mossel, Bhandari, D'Arcy, & Caffin, 2000). Before being used they were warmed up to 55 °C to dissolve any crystals, and kept in flasks at 30 °C to remove air bubbles that could interfere with rheological studies (Oroian, 2012).

2.2. Moisture content determination

The moisture contents of honey samples were obtained by measuring the refractive index at 20 °C using a digital refractometer (Leica Mark II Plus). The water content and °Brix concentration were determined based on a Chataway Table (Bogdanov, 2002).

2.3. Viscoelastic measurement

The dynamic rheological properties of honey samples were obtained with a RheoStress 1 rheometer (Thermo Haake, Germany) at different temperatures (5, 10, 15, 20, 25, 30 and 40 °C), using a parallel plate system (Ø 60 mm) at a gap of 500 μm. A batch of each composition was prepared and at least two measurements were performed on each batch, using a fresh sample for each measurement. After loading the sample, a waiting period of 5 min was used to allow the sample to recover itself and to reach the desired temperature. In order to determine the linear viscoelastic region, stress sweeps were run at 1 Hz first. Then, the frequency sweeps were performed over the range $f = 0.1$–10 Hz at 1 Pa stress. The 1 Pa stress was in the linear viscoelastic region. Rheowin Job software (v. 2.93, Haake) was used to obtain the experimental data and to calculate storage (or elastic) modulus (G'), loss (viscous) modulus (G''), and complex viscosity (η^*).

2.4. Statistical analysis

The ANNs and ANFIS were developed using the Neurosolutions 6 trial version (NeuroDimension, Inc., USA). The system is composed of three inputs (temperature – T, frequency – f, and moisture content – M) and three outputs (complex viscosity – η^*, loss modulus – G'', and storage modulus – G'). Each model applied for predicting viscoelastic parameters of honeys has been checked to achieve its suitability using the mean squared error (MSE) and mean absolute error (MAE). The viscoelastic data (complex viscosity, loss modulus and storage modulus) were divided into three groups: one group for training (60% of the data), one group for cross-validation (15% of the data) and the last one for testing (25% of the data).

During training, the input and desired data will be repeatedly presented to the network. As the network learns, the error will drop towards zero. Lower error, however, does not always mean a better network. It is possible to overtrain a network.

Cross validationxe "Cross Validation" is a highly recommended criterion to stop the training of a network. Although highly recommended, it is not required. One will often want to try several networks by using only training data in order to see which one works best, and then use cross validationxe "Cross Validation" for the final training. When using cross validationxe "Cross Validation", the next step is to decide how to divide your data into a training set and a validation set, also called the test set. The network is trained with the training set, and the performance checked with the test set. The neural network will find the input–output map by repeatedly analyzing the training set (NeuroDimension 6.0 Trial version).

The cross validation idea is to split the training set into two: a set of examples to train with, and a validation set. The agent trains using the new training set. Prediction on the validation set is used to determine which model to use. The error of the training set gets smaller as the size of the tree grows. The idea of cross validation is to choose the representation in which the error of the validation set is a minimum. In these cases, learning can continue until the error of the validation set starts to increase. The validation set that is used as part of training is not the same as the test set. The test set is used to evaluate how well the learning algorithm works as a whole (Poole & Mackworth, 2010).

2.4.1. Artificial neural networks

The viscoelastic parameters of honeys were modeled using four artificial neural networks such as: Multilayer perceptron – MLP, Probabilistic neural network – PNN, Radial basis function network – RBF and Recurrent network – RN, respectively.

2.4.1.1. Multilayer perceptron – MLP. The MLP can be considered a good method for distinguishing better data that are not linearly separable (Sarle, 1994). As seen in Fig. 1, the input data are transmitted from the input (independent) layers, through the hidden layers, to the output (dependent) layer in a feedforward approach. Different scaling functions could be used to transform the variables at input nodes (Chatterjee & Hadi, 2006). Each neuron of the hidden layer receives input data a computes output data using a transfer (or kernel) function (Leung, Chen, & Daouk, 2000). The transfer function is typically a Gaussian function, defined by

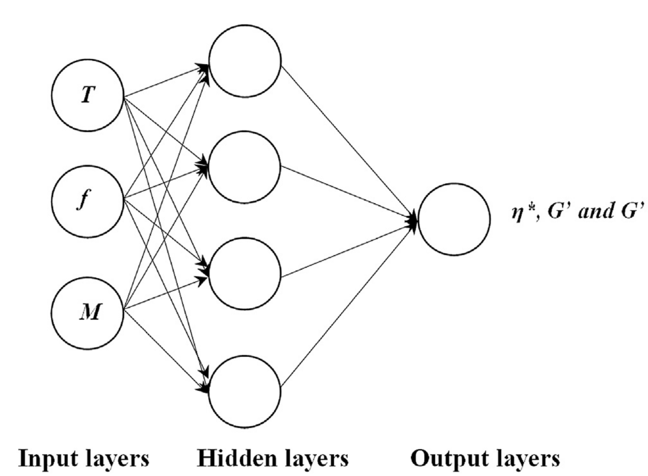

Fig. 1. Schematic diagram of a multilayer perceptron neural network model: T – temperature, f – frequency, M – moisture content, η^* – complex viscosity, G'' – loss modulus, G' – storage modulus.

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