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Modeling of rheological behavior of honey using genetic algorithm–artificial neural network and adaptive neuro-fuzzy inference system

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ABSTRACT

Knowledge of rheological properties of honey is of great interest to honey handlers, processors and keepers. In this study, genetic algorithm–artificial neural network (GA–ANN) and adaptive neuro-fuzzy inference system (ANFIS) models were used to predict the viscosity of four types of honey, two poly floral (Mountain, Forest) and two monofloral (Sunflower, Ivy). The GA–ANN and ANFIS were fed with 3 inputs of water content (15.25–19.92%), temperature (10–30 °C) and shear rate (1–42 s^{-1}). The developed GA–ANN, which included 11 hidden neurons, could predict honey viscosity with correlation coefficient of 0.997. The overall agreement between ANFIS predictions and experimental data was also very good ($r=0.999$). Sensitivity analysis results showed that temperature was the most sensitive factor for prediction of honey viscosity. Both GA–ANN and ANFIS models predictions agreed well with testing data sets and could be useful for understanding and controlling factors affecting viscosity of honey.

1. Introduction

Sensory and physical properties and chemical composition of honey depend on the botanical origin and the regional and climatic conditions of the area in which it is produced (Lazaridou, Biliaderis, Bacandritsos, & Sabatini, 2004).

The information on the viscosity is needed for a variety of engineering applications. Viscosity of honey is affected by water content, sugars concentration, pH, temperature and shear rate (Kar & Arslan, 1999). Viscosity increased as water content decreased due to the plasticizing effect of water, which reduces intermolecular friction (Al-Mahasneh, Rababah, & Ma'abreh, 2013). Viscosity was also reported to be inversely proportional to temperature, especially at temperatures below 30 °C. This was attributed to the decrease of molecular friction and hydrodynamic forces associated with temperature increase (Mossel, Bhandari, D'Arcy, & Caffin, 2000).

Honey exhibits Newtonian behavior, where shear stress is proportional to shear rate (Rao, 1999; Mossel et al., 2000; Abu-jdayil, Ghzawi, Al-Malah, & Zaitoun, 2002; Yilmaz et al., 2014). Ahmed, Prabhu, Raghavan, and Ngadi (2007), Chen, Lin, Wu, and Chen (2009), Samanalieva and Senge (2009), Witczak, Juszczak, and Gałkowsk (2011) and Karasu, Toker, Yilmaz, Karaman, and Dertli (2014a), studies cited a non-Newtonian

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behavior attributed to the presence of crystallized sugars and polysaccharides dextran.

Oroian (2012) studied Physicochemical and rheological properties of Romanian honeys. All the investigated honeys displayed Newtonian behaviour at all temperatures. By using the polynomial modeling method, it was possible to develop a mathematical model to describe honey viscosity in the function of temperature and chemical composition.

Researchers explored the potential of artificial neural networks (ANNs) and adaptive neuro-fuzzy inference system (ANFIS) as an analytical alternative to conventional modeling techniques (such as multiple regression analysis and response surface methodology) such as rheological behavior of food, which are often limited by strict assumptions of normality, linearity, homogeneity, and variable independence (Salehi & Razavi, 2012; Yolmeh, Habibi Najafi, & Salehi, 2014a; Karasu, Doğan, Toker, & Canıyılmaz, 2014b).

ANNs have been used to rheological modeling properties of different complex food systems (Ruan, Almaer, & Zhang, 1995; Bouchard & Grandjean, 1995; Rai, Majumdar, & Dasgupta, 2005; Al-Mahasneh et al., 2013; Toker & Dogan, 2013). They found out ANN was able to predict rheological properties with high accuracy. It has been shown that non-linear methods based on artificial intelligence (neural networks), are far better in generalization and prediction in comparison to conventional methods (Yalcin, Toker, Ozturk, Dogan, & Kisi, 2012; Salehi & Razavi, 2012; Toker, Dogan, & Goksel, 2012a; Toker, Yilmaz, Karaman, Dogan, & Kayacier, 2012b; Yolmeh, Habibi Najafi, Farhoosh, & Salehi, 2014b).

Modeling of rheological properties of the mellorine including different oil and gum types by combined design, ANN and ANFIS models was studied by Karasu et al. (2014b). The ANFIS model was also found to be sufficient to predict apparent viscosity values based on the oil type, gum concentrations, and shear rate (R^2=0.9121).

Toker et al. (2012a) investigated the fuzzy modeling of the effect of the swelling power (SP) of starch and water absorption capacity (WAG) of gum on rheological behaviour of model. Fuzzy modeling technique yielded a very satisfactory prediction accuracy of 99% for each parameter.

It is difficult to predict the combined effect of water content, temperature and shear rate on rheological properties of honey using conventional models. Hence, the objectives of this work were to investigate the effect of water content, temperature and shear rate on honey viscosity and study the efficiency of GA–ANN and ANFIS to model non-Newtonian viscosity of Iranian honey.

2. Materials and methods

All honey samples were collected directly from beekeepers in Golestan Province, Iran, in the different seasons of 2012. The samples were two monofloral (Sunflower, Ivy) and two polyfloral (Mountain, Forest) honeys. Moisture content of honey samples were determined by measuring the refractive index at 20 °C using a digital refractometer (ABBE Refractometer, CETi, BELGIUM). The water content was fixed based on a Chataway table (Bogdanov, 2002). All experiments performed in three replicates and the data was presented as a mean ± standard deviation of each experiment.

2.1. Rheological measurements

Since the presence of crystals and air bubbles can influence the viscosity of honey, all honey samples were heated to 55 °C for 1 h in a water bath to dissolve any crystals which might be present in honey. Then to ensure complete removal of air bubbles, the preheated honey samples were stored in an incubator (model BINDER, USA) at 30 °C for 48 h.

The rheological measurements were carried out on the honey samples at 18 rotations, ranging from 5 to 200 rpm and at five temperatures, ranging from 10 to 30 °C, using a rotational viscosimeter Brookfield, model RVDV- II+ pro, manufactured by Brookfield Engineering Laboratories, USA. A water bath (Model ULA-40Y, Brookfield, Inc. USA) connected to viscometer was used to maintain constant temperature in range of 10–30 °C during different experiments. The viscosity and shear stress curves of the honeys were drawn in the shear rate range of 1.048–41.81 s^{-1} at temperatures from 10 to 30 °C (at 5 °C intervals).

2.2. GA–ANN model

ANN is a type of artificial intelligence that mimics the behavior of human brain and is famous for its adaptability due to the use of a generalization technique instead of memorization (Salehi & Razavi, 2012). The most popular ANN is the multi-layer feed-forward neural network, where the neurons are arranged into three layers of input, hidden and output. The number of input neurons corresponds to the number of input variables into the neural network, and the number of output neurons is similar to the number of target output variables. Between the input and the output layers, there is at least one hidden layer that can have any number of neurons and depends on the application of the network. Determination of optimum number of hidden layer neurons is usually performed by trial and error method (Salehi & Razavi, 2012; BahramParvar, Salehi, & Razavi, 2014). Genetic algorithm (GA) optimization technique can be used to overcome this inherent limitation of ANN. GA are search techniques for an optimal value, mimicking the mechanism of biological evolution. They have a high ability to find an optimal value (global optimal value or at least near global one) of a complex objective function, without falling into local optima (Morimoto, 2006; Neurosolution, 2010; Salehi & Razavi, 2011; Shankar, Sokhansanj, Bandyopadhyay, & Bawa, 2010).

In the hidden and output layers, the net input (x_j) to node j is of the form:

$$X_j = \sum_{i=1}^{n} f(W_{ij} y_i + b_j) \quad (1)$$

where y_i are the inputs, w_{ij} are the weights associated with each input/node connection, n is the number of nodes and b_j is the bias associated with node j. Additionally, bias is an extra input added to neurons. The reason for adding the bias term is that it allows a representation of phenomena having thresholds (Delgrange, Cabassud, Cabassud, Durand-Bourlier, & Lain, 1998). In this work, water content, temperature and shear rate were used as inputs and honey viscosity as output.