Chemical composition and temperature influence on honey texture properties

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Abstract The aim of this study is to evaluate the chemical composition and temperatures (20, 30, 40, 50 and 60 °C) influence on the honey texture parameters (hardness, viscosity, adhesion, cohesiveness, springiness, gumminess and chewiness). The honeys analyzed respect the European regulation in terms of moisture content and inverted sugar concentration. The texture parameters are influenced negatively by the moisture content, and positively by the °Brix concentration. The texture parameters modelling have been made using the artificial neural network and the polynomial model. The polynomial model predicted better the texture parameters than the artificial neural network.

Keywords Honey · Texture · Water · Sugar composition · HMF · Modelling

Introduction

Texture is primarily the response of the tactile sense to physical stimuli that result from contact between some part of the body and the food. The tactile sense (touch) is the primary method for sensing texture but kinesthetics (sense of movement and position) and sometimes sight (degree of slump, rate of flow) and sound (associated with crisp, crunchy and crackly texture) are also evaluate texture (Bourne 2002).

Texture is a key quality attribute used in the fresh and processed food industry to assess product quality and acceptability.

Among the texture characteristics, hardness (firmness) is one of the most important parameters of fruit and vegetables (Konopacka and Plochanski 2004). Crispness is the key trait of cellular, brittle and crunchy food (Taniwaki and Kohyama 2012). Given gelled products such as muscle food, springiness, cohesiveness, adhesiveness and gumminess are significant properties for the texture evaluation (Akwetey and Knipe 2012; Stejskal et al. 2011, Chen and Opara 2013).

Texture and food structure are inextricably linked; the micro- and macro- structural composition of foods will determine the sensory perception, and any change in structure carries the risk of changing perceived texture and violating consumer expectations (McKenna and Kilcast 1999).

Texture profiles are curves which monitor and record the spatial or temporal characteristic events of samples during food texture measurements. Analysis of the profiles of mechanical and acoustic measurements is an important aspect of food texture research. Texture profile analysis (TPA) sets up a 'bridge' from objective measurement to subjective sensation and makes food texture characteristics more predictable (Chen and Opara 2013). The TPA profile has been used for achieving the textural properties of: commercial cooked meat products (de Avila et al. 2014), fresh cut pineapple (Montero-Calderon et al. 2008), date flesh (Rahman and Al-Farsi 2005), salmon fillet (Wu et al. 2014), mushroom (Jaworska and Bernas 2010) and sausages (Herrero et al. 2007).

The honey rheological properties have been the purpose of many papers. The rheological properties of honey revealed a Newtonian behaviour in the great part of the articles published (Oroian 2012; Oroian 2013, Kayacier & Karaman 2008; Ramzi et al. 2015), but in some case have been reported as a non-Newtonian fluid (Witczak et al. 2011, Yanniotis et al. 2006; Ahmed et al. 2007). In the last decade, the influences of different factors on honey rheological parameters have been investigated, as: temperature (Yanniotis et al. 2006), chemical

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composition (Oroian et al. 2014), shear rate and water content (Al-Mahasneh et al. 2013).

To the author knowledge no other study related to the honey texture has been reported.

The aim of this study is to evaluate the influence of chemical composition and temperature on the honey texture parameters (hardness, viscosity, adhesion, cohesiveness, springiness, gumminess, chewiness) using the statistical methods (Pearson correlation, Principal component analysis) and to model the honey texture parameters in function of chemical composition and temperature using the response surface methodology and artificial neural network.

Materials and methods

Materials

6 samples of honeys (H1, H2, H3, H4, H5 and H6) have been purchased from the local producers from Romania. The texture parameters of honeys, like the rheological parameters, can be influenced by the presence of crystals and air bubbles (Bhandari et al. 1999; Mossel et al. 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 rheological/textural studies (Oroian 2012).

Carrez solution I (15 g of potassium hexacyanoferrate in water and make up to 100 ml), Carrez solution II (30 g of zinc acetate and make up to 100 ml), sodium bisulphite solution 0.20 %, glucose, fructose, sucrose, acetonitrile and methanol were purchased from Sigma Aldrich (Germany).

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 sample has been homogenised. The distilled water has been used as reference material (n_D) at 20 °C is 1.3330. In order to determine the moisture content, the prism of the refractometer should be clean and dry. The honey is placed on the refractometer prism in order to cover the surface. After 2 min the refractive index has been read. The water content was determined based on a Chataway Table reading the corresponding moisture content of the refractive index determined (Bogdanov 2002).

Chemical composition determination

The hydroxymethylfurfural (HMF) content was determined using White method which is based on the determination of UV absorbance of HMF at 284 nm. 5 g of honey are placed into a 50 ml beaker. Dissolve the sample in approximately 25 ml of water and transfer quantitatively into a 50 ml

volumetric flask. Add 0.5 ml of Carrez solution I and mix. Add 0.5 ml of Carrez solution II, mix and make up to the mark with water. Filter through paper; rejecting the first 10 ml of the filtrate. Pipette 5.0 ml in each of two test tubes. Add 5.0 ml of water to one of the test tubes and mix well (the sample solution). Add 5.0 ml of sodium bisulphite solution 0.2 % to the second test tube and mix well (reference solution). Determine the absorbance of the sample solution against the reference solution at 284 and 336 nm.

$$\text{HMF (mg/kg)} = (A_{284} - A_{336}) \cdot 149.7 \cdot 5 \cdot D/W$$

where A_{284} – absorbance at 284 nm, A_{336} – absorbance at 336 nm, 149.7 – constant, 5 – theoretical nominal sample weight, D – dilution factor, W – weight in g of the honey sample (Bogdanov 2002).

Glucose, fructose and sucrose were determined using an HPLC 10 AD VP Shimadzu, with RI detector, according to the Harmonised methods (Bogdanov 2002). The compounds were separated on an amino column 250 × 4.6 mm i.d. and particle size 5 µm. The samples were prepared as: 5 g of honey were dissolved in water (40 ml) and transferred quantitatively into a 100 ml volumetric flask, containing 25 ml methanol and filled up to the volume with water. The solution was filtered through a 0.45 µm membrane filter and collect in sample vials. Flow rate 1.3 ml/min, mobile phase: acetonitrile/water (80:20, v/v), column and detector temperature 30 °C, sample volume 10 µl. A calibration curve was made for each sugar using standard solutions of different concentrations (0.5–80 mg/ml). The linear regression factor of the calibration curves was higher than 0.9982 for all sugars. Sugars were quantified by comparison of the peak area obtained with those of standard sugars. The results for each sugar were expressed as g/100 g honey.

Texture profile analysis (TPA)

The TPA was carried out at 20, 30, 40, 50 and 60 °C with Mark 10 Texture Analyzer (Mark 10 Corporation, USA) equipped with a 50 mm disc probe, the flask diameter was 70 mm. The TPA was operated at a constant speed of 150 mm/min, until a depth of 12.5 mm (the honey column had 25 mm). The TPA can offer a great number of texture parameters, as: hardness (H), viscosity (V), adhesion (A), cohesiveness (Co), springiness (S), gumminess (G) and chewiness (Ch) (Chen and Opara 2013).

Artificial neural network (ANN)

The data used for ANN modelling were used and for polynomial model too. The ANN modelling was made up using the Neuro Solutions trial version (NeuroDimension Inc., Gainesville, FL, USA). The software for ANN has an

advanced neural networks wizard known as the Neural Builder where it is packed with more powerful nonlinear analysis methods to build the network “architecture”. Network “architecture” is a representation by a graph where the input variables are organized in layers, while the weights that modulate the combination of the non-linear functions are represented as lines connecting units in different layers. The non-linear analysis method chosen in this software is known as the multilayer perceptron (MLP) where it belongs to the supervised learning neural network and is very important in engineering applications. It also provides flexibility and complexity to approximate nonlinear functions to any desired accuracy by changing the number of layers and the number of neurons in each layer (Fathi et al. 2009; Madadlou et al. 2009; Rai et al. 2005). The performance of the network is explicitly measured based on the mean squared error (MSE), defined as the difference of the output of ANN and a pre specified external desired signal.

The exact MLP network architecture of this study has an input layer of three neurons, one hidden layer of five neurons and an output layer of two neurons. The input layer comprised of three neurons because of the seven input variables of fructose, glucose, sucrose, sugars (the difference between °Brix concentration –reported as dry matter – and the sum of fructose, glucose and sucrose), non-sugars components (the difference, reported to 100 g, between 100 g and the sum of moisture content and °Brix concentration), moisture content and temperature. The output layer of one neuron represents the honey hardness, viscosity, adhesion, cohesiveness, springiness, gumminess and chewiness. The lines connecting the

input neurons and hidden neurons represent the weights. Each hidden neurons passes its weighted sum through a hyperbolic tangent function as the hidden layer transfer function. In this study, 8 neurons in the hidden layer were determined from the lowest value of mean squared errors (MSE) of 0.020. The choice of one hidden layer is usually sufficient for the purpose of approximation of continuous nonlinear function as more hidden layers may cause over-fitting (Madadlou et al. 2009; Rai et al. 2005; Torrecilla et al. 2004; Cheok et al. 2012). Besides the number of neurons in hidden layers, the momentum and learning rate are two important settings for this MLP network. The recommended momentum and learning rate values of 0.7 and 0.1 were used in this study to calculate the weights (Samarasinghe 2007).

Polynomial modelling of textural properties

The data model regarding the prediction of honey hardness, viscosity, adhesion, cohesiveness, springiness, gumminess or chewiness according to its chemical composition (fructose, glucose, sucrose, sugars (the difference between °Brix concentration –reported as dry matter – and the sum of fructose, glucose and sucrose), non-sugars components (the difference, reported to 100 g, between 100 g and the sum of moisture content and °Brix concentration), moisture content and temperature was made using a 3rd grade polynomial equation with seven variables. The measured and predicted values have been compared to see the suitability of the model. The equation of the model is as given (eq. 10):

$$\text{Texture} = b_0 + \sum_{i=1}^n b_i x_i + \sum_{i=1}^n b_{ii} x_i^2 + \sum_{i=1}^n b_{iii} x_i^3 + \sum_{i < j < k} b_{ijk} x_i x_j x_k + \sum_{i < j} b_{ij} x_i x_j + \sum_{i < j} b_{ij} x_i^2 x_j + \sum_{i < j} b_{ij} x_i x_j^2 \quad (1)$$

where *Texture* is the honey hardness, viscosity, adhesion, cohesiveness, springiness, gumminess or chewiness predicted, b_0 is a constant that fixes the response at the central point of the experiments, b_i – regression coefficient for the linear effect terms, b_{ij} – interaction effect terms, b_{ii} – quadratic effect terms and b_{iii} – cubic effect terms.

The coded values (Table 1) were applied for statistical calculations, according to the following equation (Poroach-Seritan et al. 2011; Myers and Montgonery 2002):

$$x_i = \frac{z_i - z_i^0}{\Delta z_i}, i = 1, n \quad (2)$$

where: x_i denotes the coded level of the variable (dimensionless value, z_i is the actual value of the variable); z_i^0 is the center point of the variable and Δz_i is the interval variation. Central composite design (CCD), used extensively in polynomial

experimental design, was employed to evaluate the individual and interactive effects of four main controllable variables on the dye removal efficiency (output response). CCD with four input variables consists of 30 experiments with 30 orthogonal two levels full factorial design points (coded as ± 1).

The response of predicted honey hardness, viscosity, adhesion, cohesiveness, springiness, gumminess or chewiness obtained from polynomial modelling and ANN was then compared using the absolute average deviation (ADD) given in Eq. (1) (Bas and Boyaci 2007):

$$\text{ADD} = \frac{\sum_{i=1}^P (|Y_{i,\text{exp}} - Y_{i,\text{cal}}|) / Y_{i,\text{exp}}}{P} \times 100 \quad (3)$$

where $Y_{i,\text{exp}}$ and $Y_{i,\text{cal}}$ are the experimental and calculated responses, and P is the number of the experimental run. Absolute average deviation (AAD) in this study is a measure

Table 1 Correspondence between actual and coded values of design variables

Design variables	Symbol	Actual values of coded levels	
		−1	+1
Moisture content (g/100 g)	X ₁	17.12	18.52
Fructose (g/100 g)	X ₂	35.20	44.80
Glucose (g/100 g)	X ₃	28.20	36.20
Sucrose (g/100 g)	X ₄	0.00	19.60
Sugars (g/100 g)	X ₅	0.80	11.60
Non-sugar substances (g/100 g)	X ₆	1.18	1.28
Temperature (°C)	X ₇	20	60

of how much the predicated data from models deviates from the experimental data (Cheok et al. 2012).

Statistical analysis

Statistical analysis was performed using the Statgraphics Plus software system – trial version. The data corresponding to each variable were analyzed by one-factor analysis of variance (ANOVA). Multiple comparisons were performed using the least significant difference test (LSD) and Fisher ratio (F), and statistical significance was set at $\alpha = 0.05$. Pearson correlation was made using SPSS trial version (USA).

Results and discussions

In the Table 2 are presented the moisture content, °Brix concentration, HMF content, fructose, glucose and sucrose concentration of the six honeys analysed.

The moisture content of the six honeys ranged between 17.12–18.52 g/100 g. Product moisture content of honey is widely related to the harvest season and the level of its maturity released in the hive. The parameter is highly important for the shelf life of honey during storage. Honey is hygroscopic and will pick up moisture from the environment (Karabagias et al.

2014). The moisture content met the threshold requirements of the Codex Alimentarius (20 % maximum) (Codex Standard Codex standard 2001). The moisture content is in the same range with those reported by Karabagias et al. (2014); Kucuk et al. (2007); Escuredo et al. (2012); Rybak-Chmielewska et al. 2013; Szczesna et al. 2011, Waś et al. Codex standard 2001a and Waś et al. 2011. The °Brix concentration ranged between 80.3 and 81.6°.

The HMF content, which is an indicator of honey freshness, ranged between 2.1–19.8 mg/kg. This parameter in honey is related to its quality and extent of heat processing, but it has not been related to the origin of sample (Anklam 1998). These low values demonstrate that honey was indeed fresh and had not been subjected to excessive heat treatments. The HMF was in the same ranged with the content observed in other studies (Terrab et al. 2003; Zappala et al. 2005; Escriche et al. 2009; Oroian 2012; Szczesna and Rybak-Chmielewska 1999; Rybak-Chmielewska et al. 2013; Szczesna et al. 2011, Waś et al. Codex standard 2001a and Waś et al. 2011).

All the six honeys had a total content of glucose and fructose greater than 60 g/100 g honey (Table 2). These values respect the requirements of the EU Directive Codex standard (2001).

Texture profile of honeys

In the Fig. 1 is presented a typical TPA of a honey at different temperatures (20, 30, 40, 50 and 60 °C). It can be observed that the honey response to the stress is decreasing with the increasing of the temperature, so we can conclude that the texture profile (and the texture parameters too) are influenced negatively by the temperature. As the temperature increases, the average speed of the molecules in honey increases and the amount of the time they spend “in contact” with their nearest neighbours decreases; thus, as temperature increases, the average intermolecular forces decrease and in conclusion the textural properties are decreasing (Recondo et al. 2006). The honey texture properties studied were: hardness (H), viscosity (V), adhesion (A), cohesiveness (Co), springiness (Sp), gumminess (Gu) and chewiness (Ch).

The highest hardness, viscosity, cohesiveness, springiness, gumminess and chewiness were observed in the case of honey H6, while the highest adhesion was observed in the case of honey H1.

In the Table 3 are presented the Pearson correlation between the textural properties and physicochemical properties. It seems that all textural properties are strongly positively influenced one by the other ($P < 0.001$). The moisture content has a highly negatively influence on the magnitude of the textural parameters ($P < 0.001$) while the °Brix concentration has a highly positively influence on the same parameters ($P < 0.001$). With respect to the chemical compounds, the other substances presented in the honey (non-sugar defined

Table 2 Physicochemical parameters of the honeys

Honey	H1	H2	H3	H4	H5	H6
Moisture content (g/100 g)	17.16	17.48	18.52	17.92	18.12	17.12
°Brix concentration (%)	81.5	81.3	80.3	80.9	80.7	81.6
HMF (mg/kg)	19.8	10.2	9.5	2.1	9.7	7.9
Fructose (F) (g/100 g)	37.1	41.8	38.1	44.8	41.8	35.2
Glucose (G) (g/100 g)	33.8	32.7	33.5	28.2	36.2	33.1
Sucrose (S) (g/100 g)	0	1.4	1	1.6	1.9	1.7
F + G (g/100 g)	70.9	74.5	71.6	73.0	78.0	68.3
F/G	1.09	1.28	1.14	1.58	1.15	1.06

Fig. 1 Texture profile analysis (TPA) of H3 sample

as the difference between 100 g of honey and the sum of °Brix concentration and moisture content) have an important positive influence on all the textural parameters ($P < 0.001$). Fructose content is influencing negatively the hardness (H), viscosity (V), adhesion (A), cohesiveness (Co), gumminess (Gu) and chewiness (Ch) and positively the springiness. The influence of glucose and sucrose on textural parameters is a negligible one. A positive influence has the other sugars presented in the honey (defined as the difference between the °Brix concentration and the sum of glucose, sucrose and fructose) on the textural parameters. The sum of fructose and glucose and the ratio of these two compounds are influencing negatively the textural parameters.

Textural properties modelling

In order to achieve the evolution of the textural properties (hardness (H), viscosity (V), adhesion (A), cohesiveness (Co), springiness (Sp), gumminess (Gu) and chewiness (Ch)) in function of the honey composition and the temperature have been used two models: polynomial models and artificial networks modelling.

Artificial neural network (ANN)

The texture parameters prediction using the ANN was limited to the selection of a suitable number of neurons in the hidden

Table 3 Pearson correlation of textural and physicochemical parameters of honeys

	H	V	A	Co	Sp	Gu	Ch	B	M	F	G	S	F + G	F/G	Su	Non
H	1	0.961**	0.952**	0.923**	0.970**	0.999**	0.999**	0.930**	-0.943**	-0.675	0.138	-0.256	-0.619	-0.487	0.695	0.987**
V		1	0.851*	0.973**	0.938**	0.970**	0.970**	0.887*	-0.901*	-0.623	-0.07	-0.063	-0.678	-0.370	0.704	0.980**
A			1	0.815*	0.944**	0.943**	0.943**	0.958**	-0.962**	-0.565	0.109	-0.462	-0.524	-0.428	0.654	0.896*
Co				1	0.866*	0.937**	0.933**	0.841*	-0.856*	-0.683	-0.053	-0.172	-0.779	-0.377	0.804	0.952**
Sp					1	0.967**	0.973**	0.959**	-0.966**	0.497	-0.016	-0.181	-0.550	-0.296	0.636	0.943**
Gu						1	0.998**	0.925**	-0.938**	-0.682	0.113	-0.247	-0.646	-0.477	0.716	0.992**
Ch							1	0.926**	-0.939**	-0.672	0.097	-0.241	-0.649	-0.463	0.717	0.991**
B								1	-0.999*	-0.393	-0.051	-0.274	-0.464	-0.208	0.575	0.874*
M									1	0.421	0.039	0.270	0.485	0.232	-0.592	-0.891*
F										1	-0.462	0.409	0.716	0.867*	-0.732	-0.731
G											1	-0.079	0.289	-0.841*	-0.238	0.116
S												1	0.380	0.30	-0.535	-0.191
F + G													1	0.273	-0.977**	-0.698
F/g														1	-0.313	-0.509
Su															1	0.743
Non																1

H hardness, V viscosity, A adhesion, Co cohesiveness, Sp springiness, Gu gumminess, Ch chewiness, B Brix concentration, M moisture content, F fructose content, G glucose content, S sucrose content, F + G fructose + glucose content, F/G fructose glucose ratio, Su - (the difference between °Brix concentration – reported as dry matter – and the sum of fructose, glucose and sucrose), Non - non-sugars components (the difference, reported to 100 g, between 100 g and the sum of moisture content and °Brix concentration)

layer as the number of neurons for input and output layers were already defined from the experimental design. The ANN design, for hardness (H), viscosity (V), adhesion (A), cohesiveness (Co), springiness (Sp), gumminess (Gu) and chewiness (Ch), was made using 7 input layers (fructose, glucose, sucrose, sugars (the difference between °Brix concentration –reported as dry matter – and the sum of fructose, glucose and sucrose), non-sugars components (the difference, reported to 100 g, between 100 g and the sum of moisture content and °Brix concentration), moisture content and temperature), the number of neurons in the hidden layer was determined after running several networks iteratively and observing the minimum value in the mean squared errors (MSE) and regression coefficients.

In the Figs. 2 are presented the evolution of experimental data versus predicted values for ANN prediction of honey hardness (H), viscosity (V), adhesion (A), cohesiveness (Co), springiness (Sp), gumminess (Gu) and chewiness (Ch). In the Table 4 are presented the regression coefficients and ADD values for each parameter.

The ADD values for the ANN prediction of honey hardness (H), viscosity (V), adhesion (A), cohesiveness (Co), springiness (Sp), gumminess (Gu) and chewiness (Ch) ranged between 0.95 and 17.86, while the R^2 ranged between 0.9240 and 0.9960.

The independent variables importance for the ANN prediction of honey hardness (H), viscosity (V), adhesion (A), cohesiveness (Co), springiness (Sp), gumminess (Gu) and chewiness (Ch) are presented in Fig. 3. It seems that temperature have the highest influence on the ANN prediction of the textural parameters.

Polynomial modelling

The textural parameters (hardness (H), viscosity (V), adhesion (A), cohesiveness (Co), springiness (Sp), gumminess (Gu) and chewiness (Ch)) in function of seven parameters (fructose, glucose, sucrose, sugars (the difference between °Brix concentration –reported as dry matter – and the sum of fructose, glucose and sucrose), non-sugars components (the difference, reported to 100 g, between 100 g and the sum of moisture content and °Brix concentration), moisture content and temperature) were fitted to cubic model using polynomial models. The equations for each parameter are presented in the equations presented below:

$$\begin{aligned} H = & -1.57 + 0.77 X_1 + 5.56 X_2 + 4.64 X_3 \\ & + 1.11 X_4 + 6.28 X_5 - 3.33 X_7 + 8.55 X_7^2 \\ & + 1.46 X_1 X_7 + 9.80 X_2 X_7 + 8.17 X_3 X_7 \\ & + 1.96 X_4 X_7 + 11.05 X_5 X_7 - 0.20 X_7^3 \\ & - 3.53 X_1 X_7^2 - 24.61 X_2 X_7^2 - 20.55 X_3 X_7^2 \\ & - 4.92 X_4 X_7^2 - 27.79 X_5 X_7^2 \end{aligned} \quad (4)$$

$$\begin{aligned} V = & -0.04 + 0.09 X_1 + 0.78 X_2 + 0.65 X_3 \\ & + 0.14 X_4 + 0.88 X_5 - 0.62 X_7 - 0.88 X_7^2 \\ & + 0.26 X_1 X_7 + 1.69 X_2 X_7 + 1.41 X_3 X_7 \\ & + 0.32 X_4 X_7 + 1.90 X_5 X_7 - 0.04 X_7^3 \\ & + 0.34 X_1 X_7^2 + 2.65 X_2 X_7^2 + 2.23 X_3 X_7^2 \\ & + 0.56 X_4 X_7^2 + 3.03 X_5 X_7^2 \end{aligned} \quad (5)$$

$$\begin{aligned} A = & -40.37 + 17.00 X_1 + 123.31 X_2 + 103.15 X_3 \\ & + 24.67 X_4 + 139.53 X_5 - 70.47 X_7 - 81.09 X_7^2 \\ & + 29.27 X_1 X_7 + 204.25 X_2 X_7 \\ & + 170.78 X_3 X_7 + 41.34 X_4 X_7 \\ & + 231.18 X_5 X_7 - 1.08 X_7^3 - 33.51 X_1 X_7^2 \\ & - 234.27 X_2 X_7^2 - 195.96 X_3 X_7^2 \\ & - 47.37 X_4 X_7^2 - 265.16 X_5 X_7^2 \end{aligned} \quad (6)$$

$$\begin{aligned} Co = & 7.19 - 2.63 X_1 - 18.87 X_2 - 15.81 X_3 \\ & - 3.80 X_4 - 21.37 X_5 + 1.41 X_7 - 4.61 X_7^2 \\ & - 0.57 X_1 X_7 - 4.24 X_2 X_7 - 3.55 X_3 X_7 \\ & - 0.83 X_4 X_7 - 4.79 X_5 X_7 - 0.03 X_7^3 \\ & + 1.89 X_1 X_7^2 + 13.51 X_2 X_7^2 + 11.32 X_3 X_7^2 \\ & + 2.75 X_4 X_7^2 + 15.33 X_5 X_7^2 \end{aligned} \quad (7)$$

$$\begin{aligned} Sp = & 5.77 - 2.04 X_1 - 14.51 X_2 - 12.18 X_3 \\ & - 2.93 X_4 - 16.45 X_5 - 4.20 X_7 - 3.98 X_7^2 \\ & + 1.69 X_1 X_7 + 12.10 X_2 X_7 + 10.13 X_3 X_7 \\ & + 2.44 X_4 X_7 + 13.70 X_5 X_7 - 0.05 X_7^3 \\ & + 1.58 X_1 X_7^2 + 11.43 X_2 X_7^2 + 9.59 X_3 X_7^2 \\ & + 2.31 X_4 X_7^2 + 12.96 X_5 X_7^2 \end{aligned} \quad (8)$$

◀ **Fig. 2** Textural properties modeling – experimental vs. predicted data: **a** hardness, **b** viscosity, **c** adhesion, **d** cohesiveness, **e** springiness, **f** gumminess, **g** chewiness – rhombus - ANN, square – cubic model

Table 4 Artificial neural networks (ANN) methodology statistical parameters

	R ²	P-value	ADD
Hardness	0.9620	0.001	10.37
Viscosity	0.982	0.001	4.96
Adhesion	0.985	0.001	8.82
Cohesiveness	0.970	0.001	1.04
Springiness	0.996	0.001	0.95
Gumminess	0.924	0.001	15.08
Chewiness	0.945	0.001	17.86

$$\begin{aligned}
 Gu = & 1.09 - 0.35 X_1 - 2.49 X_2 - 2.10 X_3 - 0.51 X_4 \\
 & - 2.83 X_5 - 2.31 X_7 + 4.81 X_7^2 + 1.03 X_1 X_7 \\
 & + 6.79 X_2 X_7 + 5.65 X_3 X_7 + 1.35 X_4 X_7 \\
 & + 7.64 X_5 X_7 - 0.18 X_7^3 - 2.00 X_1 X_7^2 \\
 & - 13.72 X_2 X_7^2 - 11.43 X_3 X_7^2 - 2.72 X_4 X_7^2 \\
 & - 15.45 X_5 X_7^2
 \end{aligned} \quad (9)$$

$$\begin{aligned}
 Ch = & 2.23 - 0.84 X_1 - 5.96 X_2 - 5.01 X_3 \\
 & - 1.21 X_4 - 6.77 X_5 - 3.90 X_7 + 3.44 X_7^2 \\
 & + 1.67 X_1 X_7 + 11.39 X_2 X_7 + 9.51 X_3 X_7 \\
 & + 2.28 X_4 X_7 + 12.85 X_5 X_7 - 0.17 X_7^3 \\
 & - 1.45 X_1 X_7^2 - 9.80 X_2 X_7^2 - 8.15 X_3 X_7^2 \\
 & - 1.93 X_4 X_7^2 - 11.02 X_5 X_7^2
 \end{aligned} \quad (10)$$

Table 5 Polynomial model statistical parameters

	R ²	P-value	ADD
Hardness	0.9845	0.003	5.22
Viscosity	0.9814	0.001	3.34
Adhesion	0.9854	0.003	10.34
Cohesiveness	0.9940	0.003	0.38
Springiness	0.9699	0.001	1.85
Gumminess	0.9841	0.004	6.21
Chewiness	0.9870	0.002	6.62

In the Table 5 are presented the regression coefficients, *P*-values, ADD values for each equation. All proposed model are significant ($P < 0.05$). The coefficients of regressions (R^2) obtained for the above cubic equation indicated that the variation of hardness (H), viscosity (V), adhesion (A), cohesiveness (Co), springiness (Sp), gumminess (Gu) and chewiness (Ch) can be explained by independent variables of 6 of the 7 parameters used (fructose, glucose, sucrose, sugars (the difference between °Brix concentration – reported as dry matter – and the sum of fructose, glucose and sucrose)). The ADD values ranged between 0.38–10.34, while the R^2 ranged between 0.9814–0.9940. It seems that the cubic model has better ADD values for hardness, viscosity, cohesiveness, gumminess and chewiness are smaller than in the case of ANN modelling, in the case of adhesion and springiness the ADD values of ANN modelling are lower. Keeping into account the regression coefficients and ADD values it seems that the cubic model is a better predictor compared to the ANN modelling.

Fig. 3 Parameters importance for Artificial neural network (ANN)

The regression analysis allowed us to observe that X_7 and X_5 had significant negatively linear effects on texture parameters modelling. Just in the case of hardness, viscosity, adhesion and cohesiveness have been observed a positively linear effect on the texture parameters modelling (X_7 and X_5 too). The interaction between one with another one parameter are in general no significant ($P > 0.05$). In Fig. 2 is presented the evolution of experimental data versus predicted data of textural parameters using the cubic model.

Conclusions

The honeys analyzed displayed a textural profile influenced by the temperature and °Brix concentration. From all the seven textural parameters analysed, the adhesion had the highest magnitude and the viscosity the smallest magnitude. Keeping into account the ADD values, the cubic polynomial model predicted better the texture parameters than the ANN methodology. In the case of ANN methodology, the temperature has been the parameters with the highest importance in the prediction.

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