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Physicochemical and rheological characterization of honey from Mozambique

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A B S T R A C T

Obtaining information about honey from Mozambique is the first step towards the economic and nutritional exploitation of this natural resource. The aim of this study was to evaluate physicochemical (moisture, hydroxymethylfurfural "HMF", electrical conductivity, Pfund colour, CIE L*a*b* colour and sugars) and rheological parameters elastic modulus G′, loss modulus G″ and complex viscosity η*) obtained at different temperatures (from 10 to 40 °C). All the physicochemical parameters were in agreement with the international regulations. Most of the honey samples were classed as honeydew honey since they were dark and had conductivity values above 0.800 mS/cm. The moduli G′, G″ and η* decreased with increasing temperature. G ′ and G″ were strongly influenced by the applied frequency, whereas η* did not depend on this parameter, demonstrating Newtonian behaviour. An artificial neural network (ANN) was applied to predict the rheological parameters as a function of temperature, frequency and chemical composition. A multilayer perceptron (MLP) was found to be the best model for G″ and η*($r^2 > 0.950$), while probabilistic neural network (PNN) was the best for G′($r^2 = 0.758$). Sensitivity testing showed that in the case of G″ and G′ frequency and moisture were the most important factors whereas for η* they were moisture and temperature.

1. Introduction

Mozambique, located on the east coast of Africa, is a developing country with great potential in terms of the availability of agro-ecological resources. It has a great diversity of climate, vegetation and geographic regions. This results in a variety of melliferous flora that can be exploited throughout the year by transhumance (Alcobia, 1995). Mozambique produces around 600 tonnes of honey a year (FAOSTAT, 2014) increasing by 100 tonnes in the last five years. However, given the availability of agro-ecological resources, Joosten and Smith (2004, pp. 2–3) state that there is a potential to produce 3.600 tonnes a year.

Apicultural development is a valuable human activity that plays an important role in the preservation of biodiversity due to its involvement in the pollination of both wild and cultivated plants. In Mozambique, 78% of the territory is suitable for carrying out this activity; however, the contribution of beekeeping to agricultural is non-existent (Zandamela, 2008). Therefore, it would be of great interest to implement policies to develop beekeeping in this country. This would meet the needs of the domestic market and avoid dependence on imports. All of this would reduce the price of honey and encourage the population to increase the consumption of this nutritious food. Better exploitation of this resource by rural people would mean a significant source of income and therefore a decrease in poverty. For Mozambique, moreover, it would contribute to the improvement of its economy, with the indirect benefit of protecting the environment and biodiversity.

In other developing African countries such as Burkina Faso, beekeeping activities have increased in recent years thanks in part to beekeeping promotion centres installed by beekeeper organizations (Nombré, Schweitzer, Boussim, & Rasolodimby, 2010). These activities are aiding in the production of honey and are playing an important role by creating sustainable livelihoods. Current development in Burkina honey is reflected in the number of scientific papers published in recent years. For example, those focused on the impact of storage conditions on the physicochemical characteristics of Burkina Faso honey (Nombré et al., 2010; Schweitzer, Nombré, Aidoo,& Boussim, 2013a); the impact of

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climatic changes on nectar considering honey production by honeybee colonies (Schweitzer, Nombré, Aidoo, & Boussim, 2013b); the rheological properties of Honey Burkina Faso (Escriche, Oroian, Visquert, Gras, & Vidal, 2016). However, there is an almost total lack of both scientific and non-scientific information concerning the honey from Mozambique. Due to the importance of the rheological properties of honey as a consequence of their implications in organoleptic perception by the consumer and the quality control of raw material and process control, the aim of the present study is to evaluate the physicochemical parameters and the rheological behaviour of Mozambique honey.

2. Materials and methods

2.1. Collection and preparation of samples

Thirty honey samples harvested in 2014 from the three provinces in Mozambique with the highest production of honey were used in this study: 10 from Nampula, 10 from Sofala and 10 from Zambezia. Honey samples were obtained from traditional beehives built with local materials (hollow trunks, bark cylinders, or interwoven twigs) and placed in trees or other places beyond the reach of predators. The honey was extracted by hand from these hives by pressure, hand-pressed or with wooden presses. Approximately 1 kg of each honey sample was purchased directly from the collectors to carry out the present study.

2.2. Physicochemical analyses

The harmonised methods of the international honey commission were followed to analyse the physicochemical parameters (hydroxymethylfurfural “HMF”, moisture and electrical conductivity), and colour Pfund (Bogdanov, 2002). In addition, colour CIE L*a*b* (parameters of the *Commission Internationale de ÍEclairage*) and water activity (a_w) were determined.

Moisture content was analysed by refractrometry (Abbe-type model T1 Atago, Bellevue, Washington, USA) and the Chataway table. HPLC-UV chromatographic methodology using water-methanol (in a proportion of 90 mL of water per 10 mL of methanol) as the mobile phase for this analysis was chosen to quantify the HMF level. The column used was a ZORBAX (Eclipse Plus C18, 4.6 × 150 mm, 5 μm particle size), from Agilent (Agilent Technologies, Santa Clara, California, USA) and the detector was set to 285 nm (Escriche et al., 2016).

Electrical conductivity was determined by conductimetry (Crison Instrument, Barcelona, Spain, model C830). Colour Pfund was obtained with a millimeter Pfund scale C 221 Honey Colour Analyzer (Hanna Instruments, Eibar, Spain).

Colour CIE L*a*b* was obtained using a spectrocolorimeter Minolta CM-3600d (Minolta, Osaka, Japan). The samples were placed in 20-mm-thick holders and measured against a black-and-white background. Translucency was determined by applying the Kubelka–Munk theory for multiple scattering of the reflection spectra. Colour coordinates CIE L* a* b* were obtained from R_∞ between 400 and 700 nm for D65 illuminant and 2° observer (CIE, 1986; Visquert, Vargas, & Escriche, 2014).

Water activity was measured using an electronic dew-point water activity meter (25 °C ± 0.2 °C), Aqualab Series 4 model TE (Decagon Devices, Pullman, Washington, USA), with a temperature-controlled system (Chirife, Zamora, & Motto, 2006). All analyses were performed in triplicate.

Sugar content (glucose, fructose, and sucrose) was analysed in a Compact LC, model 1120 (Agilent Technologies, Ratigen, Germany), coupled to an Evaporative Light Scattering detector (Agilent Technologies model 1200 Series, Ratigen, Germany) and using EZ Chrom Elite software. A Waters Carbohydrate 4.6 × 250 mm, 4 μm chromatographic column was used. The mobile phase was water/acetonitrile (25:75) in isocratic mode at a flow of 0.8 mL/min. Quantification of sugars was realized using external standards constructing the corresponding calibration curves.

All analyses were performed in triplicate.

2.3. Dynamic rheological properties

The dynamic rheological properties of honey samples were obtained with a RheoStress 1 rheometer (Thermo Haake, Karlsruhe, Germany) at different temperatures (10, 15, 20, 25, 30, 35 and 40 °C), using a parallel plate system (Ø 60 mm) with a gap of 500 μm (Oroian, Amariei, Escriche, & Gutt, 2013a,b; Oroian, 2015; Escriche et al., 2016). Measurements were made in triplicate for each sample and condition. After loading the sample, a waiting period of 5 min was used to allow the sample 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*). The complex viscosity η^* represents the total resistance of the material to flow (Marangoni & Wesdorp, 2012) and is defined as the ratio of the maximum resulting stress amplitude (τ^*) over the maximum applied strain amplitude (γ^*) times the angular velocity (ω), as follows:

$$\eta^* = \frac{\tau^*}{\omega \cdot \gamma^*}$$

2.4. Statistical analysis

An analysis of variance (ANOVA) (using Statgraphics Centurion for Windows, Warrenton, Virginia, USA) was carried out to study the influence of the province of origin on the physicochemical and colour parameters (Juan-Borrás, Escriche, Hellebrandova, & Domenech, 2014). The method used for multiple comparisons was the LSD test (least significant difference) with a significance level $\alpha = 0.05$.

The ANNs (artificial neural networks) were developed using the Neurosolutions 6 trial version (NeuroDimension Inc., Gainsville, USA). The system is composed of five inputs (temperature, frequency, moisture content, fructose and glucose content) and three outputs (complex viscosity, loss modulus and elastic modulus). Each model applied to predict the viscoelastic parameters of the samples was checked to discern 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 (33.3% of the data), one group for cross-validation (33.3% of the data) and the last one for testing (33.4 per cent of the data) (Ramzi, Kashaninejad, Salehi, Mahoonak, & Mohamma, 2015; Oroian, 2015).

3. Results

3.1. Physicochemical and colour characterization

Table 1 shows the average (and standard deviation), minimum and maximum values of the moisture, HMF, electrical conductivity, a_w, colour (CIE L*a*b* and Pfund) and sugar content (glucose, fructose and sucrose) of the honey samples from the three