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Full Length Research Paper

Examination of rheological and physicochemical characteristics in Lithuanian honey

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The aim of the study was to determine the effect of the biological origin and temperature on rheological and physicochemical characteristics of honey. The honey of the selected varieties differed in color, scent, microstructure, total acidity, moisture, and pH. The level of moisture statistically significantly correlated with the rheological characteristics. The highest total acidity was a characteristic of forest and buckwheat honey, and the lowest of acacia honey. The lowest pH value (3.76) was found in forest and rape honey, and the highest in eucalyptus honey. Moisture levels significantly correlated with the rheological characteristics. All varieties of honey at all the studied temperatures were characterized by properties of non-Newtonian substances. The study showed that the effect of temperature on rheological characteristics of different types of honey varied and was more pronounced in honey with a crystalline structure, and less pronounced in non-crystalline honey.

Key words: Honey, rheological characteristics, physicochemical properties.

INTRODUCTION

Honey is known as a viscous and aromatic product produced by bees, mainly from the nectar of flowers or honeydew (Lazaridou et al., 2004). This natural product is widely appreciated as the only concentrated form of sugar available worldwide and is also used as a food preservative (Cherbuliez and Domerago, 2003; Ferreira et al., 2009). Honey contains readily available sugars, organic acids and some amino acids, as well as certain macro and microelements, and also is a rich source of many biologically active compounds (Juszcak and Fortuna, 2006; Kayacier and Karaman, 2008). The composition and properties of honey vary with the floral and honeydew sources utilized by honeybees, as well as regional and climatic conditions (Lazaridou et al., 2004). The color of honey, beside flavor and aroma, is one of the characteristics that serve to indicate the plant source. It ranges from very pale yellow through amber and dark reddish amber to nearly black (Bertoncelj et al., 2007; Mateo Castro et al., 1992; Terrab et al., 2004).

About 80,000 bee colonies are grown in Lithuania (The Lithuanian Department of Statistics under the Government of the Republic of Lithuania 2008), and ca. 1.8 thousand tons of honey is harvested in the country. One colony of bees produces ca. 20 to 22 kg of honey. Lithuania is exporting honey (about 100 to 200 tons) to the USA, Germany, and the Nordic countries (The Lithuanian Department of Statistics under the Government of the Republic of Lithuania 2010). The predominant variety of honey in Lithuania is polyfloral honey (from meadows and forests), and also rape and buckwheat honey; linden honey is less common, and acacia honey is very rare.

The Greeks, Egyptians, and other cultures made use of honey as a medicine throughout history. It is one of the oldest known medicines and has continued being used up to present times. Honey is a viscous texture, in addition features anti-bacterial, anti-inflammatory, promotes wound healing, and is used as the active ingredient in creams and ointments compositions. Honey's hygroscopic property also makes it an ideal ingredient as it helps keep skin hydrated and fresh and prevents drying. Many authors demonstrated that honey serves as a source of natural antioxidants, which are effective in reducing the risk of heart disease, cancer, immune-systemdecline, cataracts, different inflammatory processes etc.(The National Honey Board, 2003). Antioxidant

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activity was the lowest in the brightest acacia and lime honeys and the highest in darker honeys, namely fir, spruce and forest (Bertoncelj et al., 2007).

Honey is described in the pharmacopoeias of many countries, including the European Pharmacopoeia (Supplement 5.1 to the 5th). The quality of honey is determined by testing the water content, purity, diastase number. The rheological characteristics are not analyzed by honey quality standard. Rheology is a key physical property in understanding the flow and deformation of raw materials, processing intermediates, and final products (Race, 1991; Martin, 1998; Sopade et al., 2004). The rheological data are used in engineering calculations involving a wide range of equipments such as pipelines, pumps, mixers, extruders, homogenizers, coaters, heat exchangers, calenderes; in the determination of ingredient functionality in the product development and shelf life testing (Sopade et al., 2004; Steffe, 1996).

Rheological properties of honey are very important in terms of applications related to handling, processing, storage, and quality control (Yoo, 2004). The rheological behavior of honey depends on the floral sources, moisture, and temperature (Rao, 1977). Consequently, rheology can be used to characterize changes in the composition of honey which can occur naturally over time, such as moisture absorption, or sugar crystallization (Cohen and Weihs, 2010). In most of the published papers, honey is reported to be a Newtonian fluid (Lazaridou et al., 2004; Juszcak and Fortuna, 2006; Bhandari et al., 1999; Mossel et al., 2000), pseudoplastic (Pereira et al., 2003; Smanalieva and Senge, 2008), and dilatant (Steffe, 1996). Australian honeys (bloodwood, blue top iron bark, gum top, heath, narrow leafed iron bark, stringy bark, tea tree, yapunyah, and yellow box) were analyzed over a range of temperatures (1 to 40°C) and exhibited Newtonian behavior (Mossel et al., 2000).

Queiroz et al. (2005) showed that the honey from *Piptadenia moniliformis* flowers has a non-Newtonian fluid behavior with characteristics of a pseudoplastic fluid. Thixotropy is quite pronounced in honey from heather (*Calluna vulgaris*), buckwheat (*Fagopyrum esculentum*), white clover (*Trifolium repens*), New Zealand manuka (*Leptospermum scoparium*), and Indian karvi (*Carvia callosa*) (Munro, 1943). Dilatancy is reported in Nigerian honey (*Opuntia engelmanni*) and several *Eucalyptus* honeys such as that from *Eucalyptus ficifolia* (White, 1978). The thixotropic behavior is thought to be due to proteins in the honey, while the presence of a high-molecular weight (1,250,000) dextran is responsible for the dilatancy (White, 1978).

Viscosity of honey depends on several factors: such as temperature, moisture and crystal structure, it is important to evaluate these factors before using honey as active substance or excipient in pharmaceutical products. Viscosity, one of the most important rheological parameters of honey, largely affects product quality and processing conditions related to the design of honey-processing equipment (Yanniotis et al., 2006). It is known that knowledge of the effects of temperature on the rheological properties of honey is necessary for its production, processing, and storage (Oh and Yoo, 2011). The rheological properties of honey are important qualities that influence the sensory quality of the product and also affect a number of technological opera-tions,such as honey heating, mixing, filtering, hydraulic transport and bottling (Yanniotis et al., 2006).

Considering that the rheological properties of honeys are strongly influenced by temperature, it is necessary to study the effect of temperature on the relationship between moisture content, microstructure and rheological properties of honeys to provide some information for estimating the quality of honey. Therefore, many researchers have studied the rheological properties of honey at different temperatures (Sopade et al., 2004; Kang and Yoo, 2008; Bhandari et al., 1999; Al-Malah et al., 2001; Abu-Jdayil et al., 2002; Yoo, 2004). However, the rheological properties of different honey varieties produced in the Baltic region at diffirent temperatures has not been studied. The aim of the study is to determine the effect of the biological origin and temperature on rheological and physicochemical characteristics of honey.

MATERIALS AND METHODS

The objective of the study was buckwheat, eucalyptus, acacia, rape, and forest honey. Honey samples were obtained in a Lithuanian supermarket. Eucalyptus honey was selected for comparative studies, as it is popular among Lithuanian consumers. Honey samples were kept in a sealed glass container at room temperature.

Rheological flow examination

The examination was performed using a rheometer Carri-med CSL^2 500 (TA Instruments, Germany), by applying the cone-plate geometry system (cone diameter (40 mm), angle (2°) and sample thickness (850 μm) at the designated temperatures 20, 30, 40, and 50°C. In the previous research, many researches heated at 50 or 55°C honey samples before rheological measurement (Mossel et al., 2000; Abu-Jdayil et al., 2002; Lazaridou et al., 2004; Yoo, 2004; Sopade et al., 2004). In the present study, however, the measuring of honey samples has been done in a natural state without a heating process applied to the samples. The temperature range from 40 to 50°C was selected, due to honey crystals melting temperature and peculiarities of the production of liquid and semi-solid preparations (Xu, 2003; Rowe et al., 2003; Bakier, 2004, Smanalieva and Senge, 2008). The shear rate was increased for 2 min from 0 to 500 s^{-1}, and then for 2 min decreased from 500 to 0 s^{-1}. The rheological characteristics were calculated by applying Ostwald de Waele's mathematical model (Bourne, 2002).

Determination of the pH value

Determination of the pH value was performed with a pH/mV meter Delta OHM HD 2105.1 (Delta OHM, Italy).

Determination of the microstructure

The microstructure of the samples was determined by using the

Motic® (Motic China Group Co., Ltd., China) microscope, Reaetifs Ral (France) immersion oil, and 100x magnification lenses. The microstructure of the samples was photographed with a Moticcam 1000 1.3 Pixel camera (Motic China Group Co., Ltd., China).

Determination of moisture levels

Moisture levels were determined with a refractometer (ИРФ-22, N. 550251), by applying the Chatway method. The refraction index was determined with a refractometer at the temperature of 20°C. Depending on the refraction index, the moisture level (%) was determined according to the presented tables (Decree of the Minister of Agriculture of the Republic of Lithuania, 2000, Codex standard for honey. Codex STAN 12-1981 Codex Alimentarius Commission Adopted in 1981. Revisions 1987 and 2001)

Determination of total acidity

The total acidity of honey is a total amount of free and linked organic and inorganic acids in honey.

10 g of honey was weighed with 0.01 g accuracy, and subsequently dissolved in 75 ml of distilled water. The sample was then titrated with 0.1 M potassium (sodium) alkali, adding 4 to 5 drops of phenolphthalein into the titration flask. The altered color of the solution should remain stable for 10 seconds (Decree of the Minister of Agriculture of the Republic of Lithuania, 2000, Codex standard for honey. Codex STAN 12-1981 Codex Alimentarius Commission Adopted in 1981, Revisions 1987 and 2001). All measurements were performed in triplicate. The results were obtained by calculating the arithmetic mean ± standard error (SE)

Statistical analysis

Statistical analysis was performed using SPSS 17.0 software, by applying the univariate dispersion analysis (ANOVA). Multiple comparisons were performed by applying Tukey's HSD criterion. Correlations were determined by applying Spearman's criterion. The significance level was set at α = 0.05.

RESULTS AND DISCUSSION

Physicochemical characteristics of honey

Data presented in Table 1 show that buckwheat and rape honey had specific sensory characteristics. The highest total acidity was characteristic of forest and buckwheat honey, while the lowest total acidity was observed in acacia honey (Table 1). Total acidity of all varieties of honey did not exceed the set norms (Codex standard for honey. Codex STAN 12-1981 Codex Alimentarius Commission Adopted in 1981, Revisions 1987 and 2001). Meanwhile, the lowest pH value was found in forest and rape (3.76) honey, while the highest – in eucalyptus honey. Water content detected in the studied honey samples ranged between 18 to 20.2%. The moisture level of Lithuanian honey samples was consistent with Indian honey, with 18.7 to 21.8% (Singh and Bath, 1997), and Moroccan honey with 16.8 to 20.3% (Terrab et al., 2002). In contrast, Saudi honey had lower moisture content, with 14.0 to 16.9% (Al-Khalifa and Al-Arify, 1999), Turkish honey - with 16.3 to 17.9% (Kayacier and Karaman, 2008), and Polish honey - with 14.7 to 18% (Juszcak and Fortuna, 2006), while Chinese honey had a higher moisture content - in the range of 19.8 to 29.0% (Junzheng and Changying, 1998). It is noteworthy that moisture of rape honey somewhat exceeded the set norms, but not more than by 20% (Codex standard for honey. Codex STAN 12-1981 Codex Alimentarius Commission Adopted in 1981, Revisions 1987 and 2001). The evaluation of the microstructure of honey samples showed that acacia honey did not have crystals, forest honey was characterized by accumulation of large crystals, and crystal size progressively decreased in, accordingly, buckwheat, eucalyptus, and rape honey, forming an integral crystalline structure (Table 1).

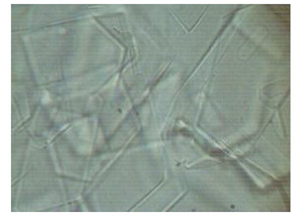
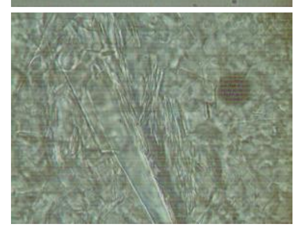
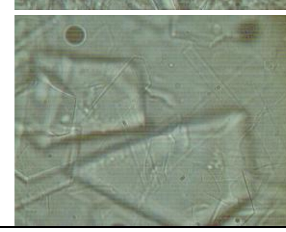
Rheology of honey

Rheological characteristics of honey samples at the temperatures of 20 and 30°C

The analysis of the relationship between the shear stress of the studied systems and the shear rate showed that at the temperatures of 20 and 30°C, all honey samples showed characteristics of non-Newtonian substances (Figure 1). The results did not confirm most literature data that honeys from different origins exhibit the Newtonian behavior (Junzheng and Changying, 1998; Bhandari et al., 1999; Mossel et al., 2000; Al-Malah et al., 2001; Sopade et al., 2002). However, there are also reports indicating non-Newtonian flow characteristics of certain honeys. For example, Indian Karvi honey and New Zealand Manuka honey were found to exhibit thixotropic behavior, while a Nigerian honey and eucalyptus honeys exhibited dilatant flow behavior (Munro, 1943; White, 1975; Mossel et al., 2000). Also, it was reported that German, *P. moniliformis* and Galician honeys exhibit pseudoplastic behavior (Smanalieva and Senge, 2008; Queiroz et al., 2005; Gomez-Diaz et al., 2006).

Curves presented in Figure 1 show that the greatest shear stress at the temperatures of 20 and 30°C was observed in eucalyptus honey, while the lowest in acacia honey. Meanwhile, rape honey at 20°C and greater shear rate did not flow (the curve was chaotic). Honey of this sort did flow at the temperature of 30°C. The smallest space between up and down curves was observed in acacia honey. Data presented in Table 2 show that the highest flow consistency index (K) and thixotropy at both temperatures was seen in eucalyptus honey, and the lowest in acacia honey. At the temperature of 20°C, the lowest flow behavior index (n) was observed in eucalyptus and forest honey, although the flow consistency index of eucalyptus honey was nearly by two-fold higher than that of forest honey. Data in Table 1 show that large crystals predominated in forest honey, which might have affected poor flow behavior of this honey. Different sizes and forms of honey crystals are forme

Table 1. Physicochemical characteristics of different varieties of honey.

Variety (number)	Color	Scent	Total acidity (meq/kg)	Moisture (%)	pH	Microstructure
Buckwheat (1)	Yellow-brown	Specific, rich	24.17 ± 0.60	19.1 ± 0.1	3.97 ± 0.02	
Eucalyptus (2)	Yellow	Mild	19.67 ± 0.44	18.2 ± 0.0	4.39 ± 0.01	
Acacia (3)	Clear, yellowish	Weak, mild	11.33 ± 0.33	19.1 ± 0.1	3.86 ± 0.01	
Rape (4)	Yellowish-whitish	Sour	14.17 ± 0.67	20.2 ± 0.0	3.76 ± 0.01	
Forest (5)	Yellow	Mild, waxy	24.50 ± 0.58	18.9 ± 0.1	3.74 ± 0.01	

due to presence of sugars and their influence on tautomerism of glucose. Rheological characteristics of honey are affected by honey crystals (Smanalieva and Senge, 2008). Acacia honey did not have any crystalline structure, and thus had the lowest flow consistency index and the highest flow behavior index. The flow characteristics of acacia honey were similar to Brasil honey of *P. moniliformis* (Queiroz et al., 2005). Crystalline structure was also characteristic of buckwheat honey (Table 1), but its flow consistency index was lower, compared to that of forest and eucalyptus honey – the varieties with a typical crystalline structure. The flow behavior index of buckwheat honey had an intermediate position between forest and acacia honey (Table 2). The highest thixotropy at the temperature of 20°C was observed in eucalyptus honey (202433 Pa/s), and the lowest in acacia honey (7793 Pa/s).

In addition to that, studies showed that viscosity and flow ability were more dependent on the biological origin of the honey because even though moisture was the highest in rape honey, compared to other honey varieties (Table 1), yet the honey did not flow at 20°C (Figure 1A). The evaluation of the flow behavior and rheological characteristics of rape honey at the temperature of 30°C showed that this sample had the highest consistency coefficient, although its thixotropy was similar to that of forest honey, whose flow consistency index was lower by 4 times. This shows that at 30°C rape honey demonstrated elastic properties and, with decreasing shear rate, returned to its initial state better than eucalyptus honey with a lower flow consistency index did.

Data presented in Table 2 show that that temperature

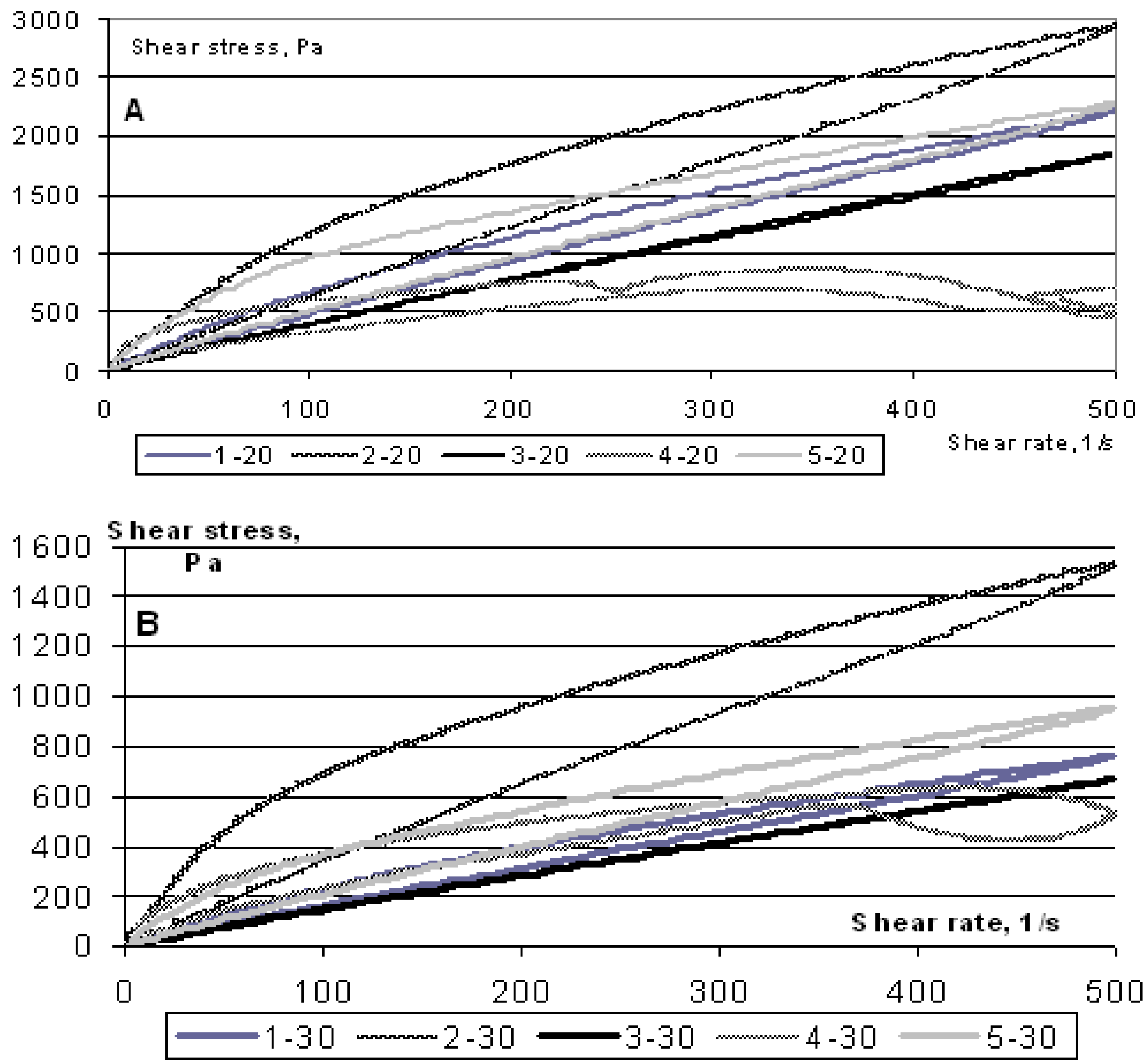


Figure 1. Flow curves of different varieties of honey at temperatures of (A) 20°C and (B) 30°C.

change by 10°C had different effects on rheological properties of different varieties of honey, which indicates that the biological origin of honey also plays a role, K value and thixotropy of eucalyptus honey dropped by half, while n value remained unchanged. In other varieties of honey, K value ant thixotropy decreased by three times, while n value remained unaltered. Only thixotropy of acacia honey was an exception it dropped by half from 7793 to 3663 Pa/s, and was by over 8 times lower than that of buckwheat honey, and over 28 times lower, compared to that of eucalyptus honey.

The evaluation of these findings confirms literature data indicating that temperature and biological origin of honey affect its rheological characteristics (Yoo, 2004). Statistical evaluation of the rheological characteristics of different varieties of honey at the temperatures of 20 and 30°C is provided in Table 3. Data presented in Table 3 shows that most numerous statistically significant differences were found between thixotropy and flow behavior indices of different varieties of honey. This indicates that even at similar consistency coefficients, the flow behavior of honey and its ability to return to the initial state after deformation differ.

Rheological characteristics of honey samples at the temperature of 40 and 50°C

At the temperatures of 40 and 50°C, all varieties of honey demonstrated pseudoplastic substance properties (Figure 2). The viscosity all honey samples decreased with increasing temperature as expected (Kayacier and Karaman, 2008). Curves presented in Figure 2 show that at the temperature of 40°C, the highest shear stress was observed in eucalyptus honey, while the lowest in acacia and forest honey. At the temperature of 50°C, the flow

Table 2. Rheological characteristics according to Ostwald de Waele's mathematical model in different varieties of honey at the temperatures of 20 and 30°C.

Property/ sample	20°C			30°C		
	K, (Pa·s)^n	n	Thixotropy, Pa/s	K, (Pa·s)^n	n	Thixotropy, Pa/s
1	23.58 ± 1.16	0.7344 ± 0.01	75173 ± 4434	8.13 ± 0.52	0.7313 ± 0.01	27825 ± 885
2	119.59 ± 23.83	0.5219 ± 0.04	202433 ± 9663	56.03 ± 4.07	0.534 ± 0.01	105577 ± 3775
3	5.31 ± 0.12	0.9436 ± 0.003	7793 ± 1399	1.86 ± 0.04	0.9482 ± 0.002	3663 ± 118
4	-	-	-	86.23 ± 14.76	0.3298 ± 0.03	59345 ± 5428
5	67.77 ± 2.36	0.564 ± 0.006	138850 ± 1050	22.30 ± 0.32	0.6014 ± 0.004	52850 ± 1509

Table 3. Statistical evaluation of the rheological characteristics of honey at the temperatures of 20 and 30°C.

Variety	Variety	Property					
		20°C			30°C		
		K	n	Thixotropy	K	n	Thixotropy
1	2	Y[a]	Y	Y	N	Y	Y
	3	N[a]	Y	Y	N	Y	Y
	4	-	-	-	Y	Y	Y
	5	N	Y	Y	N	Y	Y
2	3	Y	Y	Y	Y	Y	Y
	4	-	-	-	N	Y	Y
	5	N	N	Y	N	N	Y
3	4	-	-	-	Y	Y	Y
	5	N	Y	Y	N	Y	Y
4	5	-	-	-	Y	Y	N

[a]Here and further on: Y – a statistically significant difference detected; N – no statistically significant difference detected; level of significance α = 0.05.

curves of all samples were similar, except for the flow curve of eucalyptus honey, where the greatest shear stress change under the influence of shear rate was observed.

Data presented in Table 4 show that at the temperature of 40°C, K value in all honey samples decreased by 6 to 7-fold, compared to the K value registered at the temperature of 30°C (Table 2). An exception was acacia honey whose K value dropped by 3-fold. The highest K value at the temperature of 40°C was observed in rape and eucalyptus honey (Table 4). Those two varieties of honey were also characterized by the highest thixotropy, respectively, 18180 and 22707 Pa/s. At the temperature of 40°C, acacia honey showed the least deviation from the characteristics of Newtonian fluids, while the deviation of eucalyptus honey was the greatest. At the temperature of 50°C, K values in all samples approximated 1, while n values varied from 0.7263 (rape honey) to 0.8814 (acacia honey). The highest thixotropies at that temperature were also observed in rape honey (5084 Pa/s) and eucalyptus honey (4183 Pa/s).

Acacia honey that had no crystals at room temperature underwent less pronounced changes of the rheological characteristics with increasing temperature (Table 4). The obtained findings confirmed literature data indicating that sudden temperature-related changes in rheological characteristics occur due to the decomposing/melting of honey crystals (Smanalieva and Senge, 2008). The statistical evaluation of the rheological characteristics of honey at the temperatures of 40 and 50°C is provided in Table 5. Data presented in Table 5 show that at the temperature of 40°C, the rheological characteristics of all varieties of honey differed statistically significantly, and only buckwheat and acacia honey demonstrated similar consistency coefficients and thixotropies. Meanwhile, at the temperature of 50°C, the differences diminished again. Statistically significant differences in all rheological characteristics were observed only between rape honey

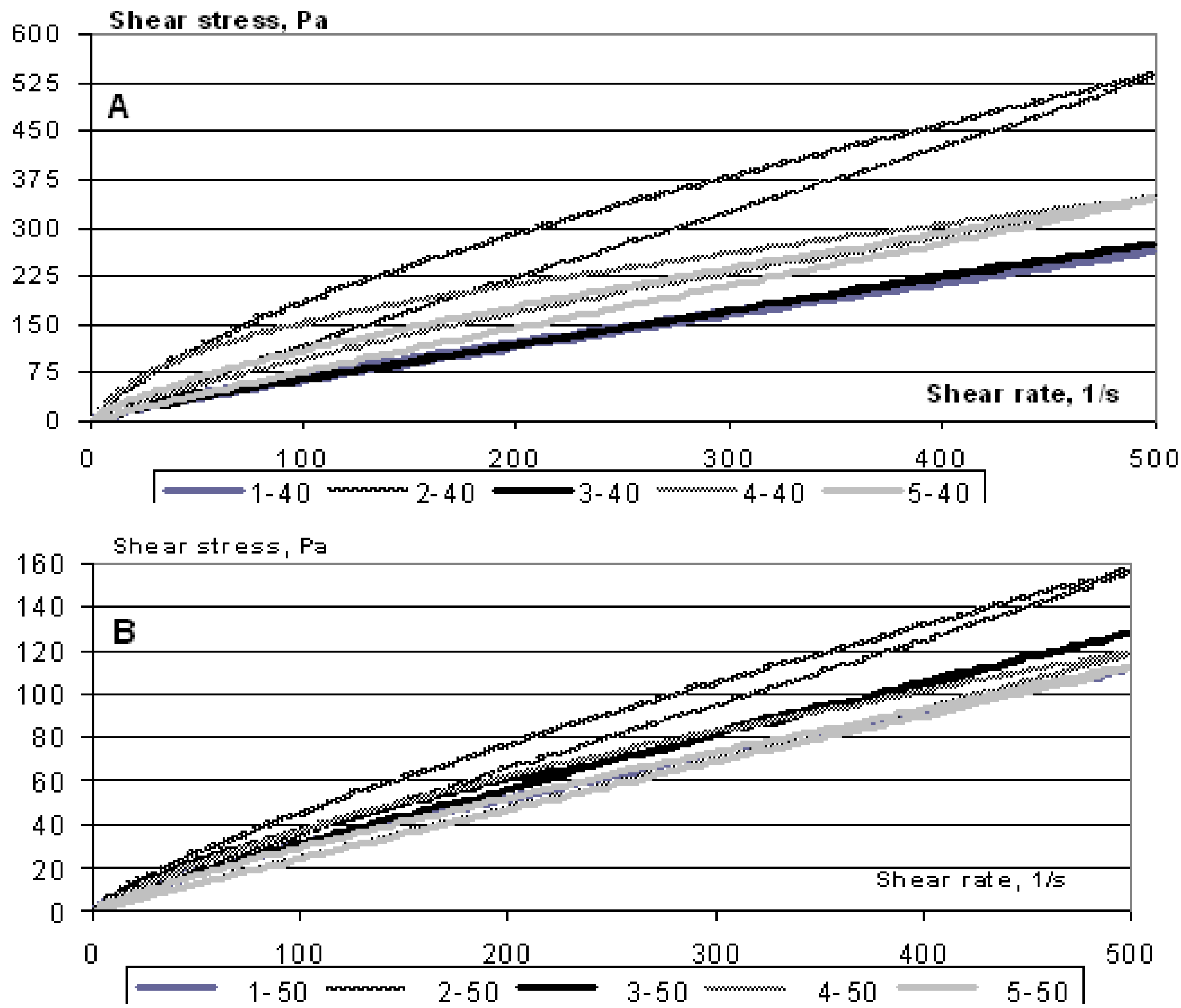


Figure 2. Flow curves of different varieties of honey at the temperatures of (A) 40°C and (B) 50°C.

and buckwheat, acacia and forest honey.

In addition, the effect of temperature on each variety of honey was assessed. The statistical evaluation of these data is presented in Table 6 which shows that rheological characteristics of buckwheat and eucalyptus honey did not differ statistically significantly at the temperatures of 40 and 50°C, and only the flow behavior index at these temperatures showed statistically significant differences between acacia and rape honey. It is noteworthy that the flow behavior index of acacia honey was nearly independent of the temperature, and statistically significant differences were observed only between the temperatures of 40 and 50°C. Meanwhile, the flow consistency index of this honey was, conversely, statistically significantly different at all temperatures, except for 40 and 50°C. The rheological characteristics of buckwheat and forest honey demonstrated the highest number of temperature-related statistically significant differences.

Correlation between rheological and physicochemical characteristics of honey

Spearman's criterion was used to determine correlations between rheological characteristics of honey at 20°C and its physicochemical properties. Very strong statistically significant correlations were found between thixotropy and the flow consistency index (direct), and between thixotropy and the flow behavior index (inverse). Strong statistically significant correlations were observed between the rheological characteristics and the moisture level of honey. Yanniotis et al. (2006) and Lazaridou et al. (2004) also reported that rheological parameters and moisture content were highly related. The moisture level directly correlated with the flow behavior index and inversely correlated with the flow consistency index and thixotropy. This is confirmed by literature data indicating that the moisture level affects the rheological characteristics

Table 4. Rheological characteristics according to Ostwald de Waele's mathematical model in different varieties of honey at the temperatures of 40 and 50°C.

Property/ sample	40°C			50°C		
	K (Pa·s)^n	n	Thixotropy (Pa/s)	K (Pa·s)^n	n	Thixotropy (Pa/s)
1	1.19 ± 0.10	0.8665 ± 0.01	3915 ± 209	0.47 ± 0.002	0.8696 ± 0.002	626 ± 107
2	7.29 ± 0.57	0.6910 ± 0.01	22707 ± 1172	1.16 ± 0.04	0.7853 ± 0.003	4183 ± 42
3	0.51 ± 0.01	0.9145 ± 0.001	1402 ± 91	0.52 ± 0.10	0.8814 ± 0.04	1593 ± 62
4	13.2 ± 0.03	0.5228 ± 0.001	18180 ± 532	1.30 ± 0.08	0.7263 ± 0.01	5084 ± 207
5	3.54 ± 0.06	0.7342 ± 0.001	12230 ± 50	0.61 ± 0.01	0.8422 ± 0.003	1982 ± 100

Table 5. Statistical evaluation of the rheological characteristics of honey at the temperatures of 40 and 50°C.

Variety	Variety	Property					
		40°C			50°C		
		K	n	Thixotropy	K	n	Thixotropy
1	2	Y	Y	Y	Y	N	Y
	3	N	Y	N	N	N	Y
	4	Y	Y	Y	Y	Y	Y
	5	Y	Y	Y	N	N	Y
2	3	Y	Y	Y	Y	N	Y
	4	Y	Y	Y	N	N	Y
	5	Y	Y	Y	Y	N	Y
3	4	Y	Y	Y	Y	Y	Y
	5	Y	Y	Y	N	N	N
4	5	Y	Y	Y	Y	Y	Y

Table 6. Statistical evaluation of the effect of temperature on the rheological characteristics of different varieties of honey.

Temperature (°C)	Temperature (°C)	Property														
		Buckwheat			Eucalyptus			Acacia			Rape			Forest		
		K	n	Tx[b]	K	n	Tx	K	n	Tx	K	n	Tx	K	n	Tx
20	30	Y	N	Y	Y	N	Y	Y	N	Y	-	-	-	Y	Y	Y
	40	Y	Y	Y	Y	Y	Y	Y	N	Y	-	-	-	Y	Y	Y
	50	Y	Y	Y	Y	Y	Y	Y	N	Y	-	-	-	Y	Y	Y
30	40	Y	Y	Y	N	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y
	50	Y	Y	Y	N	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y
40	50	N	N	N	N	N	N	N	Y	N	N	Y	N	N	Y	Y

[b]Tx – thixotropy.

(Yoo, 2004). No statistically significant correlations between the rheological characteristics and pH or total acidity were found.

Conclusion

The water content in the studied honey samples ranged between 18 and 20.2%. The highest total acidity was characteristic of forest and buckwheat honey, and the lowest of acacia honey. The lowest pH value (3.76) was found in forest and rape honey, and the highest in eucalyptus honey. Moisture levels significantly correlated with the rheological characteristics. All varieties of honey demonstrated non-Newtonian characteristics at all the studied temperatures. At the temperature change of 20 to 30°C, statistically significant differences were found between varieties of honey with respect to thixotropy and flow behavior indices. This indicates that different varieties of honey differently return to their initial state despite similar flow consistency coefficients.

At the temperature of 40°C, no significant differences were found, except between flow consistency coefficients and thixotropy of buckwheat and acacia honey. Meanwhile, at the temperature of 50°C, statistically significant differences in rheological characteristics were found only between rape honey and buckwheat, acacia, and forest honey. The rheological characteristics of honey were affected by temperature (especially by changes from 20 to 40°C); statistically significant differences were found when evaluating changes in rheological characteristics at changing temperatures. Acacia honey was least sensitive to temperature changes.

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