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Correlation between water activity and moisture content of Turkish flower and pine honeys

Seher SERİN[1], Kamile Nazan TURHAN[2], Mahir TURHAN[1]

Abstract

Water activity (a_w) and moisture content (MC) of Turkish liquid flower and pine honeys were determined. Samples (706 flower and 257 pine) were collected during the honey harvesting seasons of 2010-2014 from 137 apiaries in locations with different climatic conditions all over the land. Up to date, this work is the first one seeking for a correlation between a_w and MC for Turkish honeys, and also it is the largest and longest one among similar works to the best of the researchers' knowledge. The ranges of a_w and MC values of the Turkish honeys were in agreement with the literature. a_w was determined between 0.470 and 0.563 for the flower honeys, and between 0.492 and 0.589 for the pine honeys. MC was measured between 15.0 and 20.4% (m/m) for the flower honeys and between 15.1 and 20.4% (m/m) for the pine honeys. Statistically different linear regression equations (a_w versus MC) fitted data of the flower and pine honeys with significantly high coefficients of determinations (R^2> 0.848), small mean absolute errors (< 1.39%) and no biases. The linear equations were analogous to equations giving the correlation between a_w and MC for other honeys in the literature.

Keywords: water activity; moisture content; flower honey; pine honey; Turkey.

Practical Application: Turkish honeys have linear correlations between water activity and moisture content.

1 Introduction

Turkey is one of the major honey producers in terms of quantity, variety and quality. It is in the second place as of number of beehives (~ 4.4 million) and the fourth place as of amount of honey production (~ 102 000 tons/year) in the world (Turkish Statistical Institute, 2015). Turkey has a very diverse indigenous flora for flower honey production thanks to more than 10 000 flower types suitable for the nectar forage (Nakilcioğlu & Ötleş, 2015). It is leader in pine honey production by having almost 92% of the world's production (Yücel, 2013). Honey is an important commodity in Turkey for its social and economic impacts. Almost 182 000 families live off the honey production and it has a share of almost 6% in animal production revenue of Turkey (Saner et al., 2011).

Moisture is critical for honey as for other foods. Moisture content is taken as a key indicator for the maturity, density, viscosity, state, stability, and important for the quality and processing characteristics of honey. Honey is accepted and assessed, or rejected based on its moisture content in the industry. Not the moisture content but the water activity is responsible for the quality and process attributes of honey as in other foods (Zamora & Chirife, 2006). However, since measuring the moisture content (MC) is much more practical and economical than measuring the water activity (a_w), in the industry honey is evaluated in terms of water by determining MC. Refractometry is the effective method used to measure MC of honey.

The best possible way to assess honey quality with regard to water is being knowledegable about its a_w and MC, and establishing a correlation between them. The correlation could be established to study a wide range of a_w and MC using moisture sorption isotherms (MSI) which is mostly sigmoidal in shape. It could also be established to work a narrow range of a_w and MC for practical purposes which corresponds to a portion of the MSI obtained at the same temperature. A considerable amount of effort has been spent for practical purposes for honeys from various geographies in the world (Table 1). Some of these works revealed significant linear correlations between a_w and MC and some resulted in no correlation. Among them, the largest one was conducted by Gleiter et al. (2006) using 294 samples, and the longest one was conducted by Cavia et al. (2004) using samples harvested during 3 years.

Contrary to the importance of Turkey in the World's honey production and significant contribution of honey to Turkey's socio economical state, a comprehensive work revealing the relationship between a_w and MC was not conducted for Turkish honeys yet to the best knowledge of the authors. Kayacier & Karaman (2008) reported some a_w and MC data for some selected Turkish honeys. This workwas not aiming to find a correlation between them, and in fact the data was too limited to deduce such a correlation. It was about rheological and physicochemical characteristics of selected Turkish honeys.

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[1] *Department of Food Engineering, University of Mersin, Ciftlikkoy, Mersin Turkey*
[2] *Department of Food Engineering, Izmir University of Economics, Balcova, İzmir Turkey*
*Corresponding author: mahirturhan@gmail.com

The purpose of the current work is to search for a correlation between a_w and MC of Turkish honeys to contribute to survey efforts to identify its characteristics. It is the first work looking for such a relationship between a_w and MC in Turkish honeys, and it is the largest (964 samples) and longest one (4 years) compared to works conducted for other honeys up to date to the best knowledge of the workers.

2 Materials and methods

Cleaned honey samples were donated to our laboratory by a commercial honey plant in water and air proof jars. Honeys were obtained from 237 different apiaries during the honey harvesting seasons of 2011-2014. Apiaries were selected from different geographical locations in order to avoid obtaining samples from the same sources and to ensure the representation of Turkish honeys. Flower honeys were sunflower (147), clover (64), cotton(71), citrus (129), chesnut (85), wild flower (113), thyme (42) and mixtures of two or more of them (56). Pine honeys were from pinaries in western Turkey (the Aegean Region), mainly Mugla province.

Honey samples were analyzed for a_w and MC immediately after receiving. a_w and MC of 706 flower and 257 pine honey samples were determined. a_w was measured at 20 °C using a water activity instrument (Novasina, AW Sprint, TH-500, Switzerland). It was calibrated by saturated salt solutions provided by the supplier for every 30 measurements. MC was determined as percentage by mass (m/m) at 20 °C using a hand refractomer (ATC, Hong Kong). Both measurements were performed in triplicate, and evaluations were made using mean values.

Statistical analyses were conducted using SPSS for Windows Ver. 16.0 ($P < 0.05$) and honey samples were classified through the Discriminant Function Analysis in the SPSS.

3 Results and discussions

3.1 a_w and MC of Turkish flower and pine honeys

a_w and MC of flower honey samples were determined between 0.470 and 0.563, and 15.0% and 20.4%, respectively (Table 1). a_w and MC of pine honey samples were between 0.492 and 0.589 and 15.1% and 20.4%, respectively (Table 1). For the stability of honey, a_w should be at most 0.60, and MC is advised to be lower than 20% (Zamora et al., 2006) excluding honeys produced under humid or tropical conditions. Any flower or pine honey sample did not exceed the 0.6-limit for a_w and limited number of samples exceed the 20%-limit for MC (Figure 1). However, a_w values not greater than 0.6 can be taken as an indicator for good apiery practices in Turkey, especially with regard to harvesting and keeping honey at proper conditions.

Kayacier & Karaman (2008) and Şenyuva et al. (2009) reported a_w and MC data for some liquid Turkish honeys. Kayacier & Karaman (2008) measured a_w and MC of three monoflower honeys between 0.51 and 0.52, and 16.3 and 17.9%, respectively. They determined a_w and MC of one pine honey sample to be 0.52 and 16.6%, respectively. Şenyuva et al. (2009) reported a_w between 0.44 and 0.61 for 5 honeydew honey samples, and between 0.361 and 0.661 for 65 flower honey samples. The span of the a_w values and MC values obtained in this work are in good agreement with ones obtained for other Turkish honeys in the literature.

3.2 Comparision with other honeys in the literature in terms of a_w and MC

Summary of works giving correlations between a_w and MC of liquid honeys from different locations in the world is tabulated in Table 1. The minumum and maximum a_w values were found to be 0.41 (Adenekan et al., 2010) and 0.691 (Cavia et al., 2004) for flower honeys, respectively. For flower honeys, the smallest and greatest MC was 13.1% (Lazaridou et al., 2004) and 22.6% (Gleiter et al., 2006), respectively. The range of a_w and MC values obtained in this work is considered to be in good agreement with those obtained in other works in the literature for flower honeys.

For honeydew honeys in the literature, the minumum and maximum a_w values were 0.438 (Abramovic et al., 2008) and 0.663 (Lazaridou et al., 2004), respectively (Table 1). For them, the smallest and highest MC values were 12.6% and % 18.9% (Lazaridou et al., 2004), respectively (Table 1). As in flower honeys, the findings of this work for honeydew honeys (pine honeys) are reasonably in good agreement with findings of works on honeydew honeys in the literature.

Though Turkish pine honey has already been compared with other honeydew honeys in the literature in terms of a_w and MC, it also was compared particularly with Greek pine honeys since Turkey and Greece are the only pine honey producers in the world. The mean a_w and MC values for Turkish pine honeys were determined to be 0.532 ± 0.022 and 17.4 ± 1.3%, respectively. For Greek pine honeys, mean values of a_w and MC were calculated to be 0.588 ± 0.028 and 15.8 ± 1.4%, respectively (Lazaridou et al., 2004). The a_w and MC of Greek pine honeys exhibited a distribution between 0.559 and 0.663, and 13.9% - 18.9%, respectively (Table 1). As in the previous comparisions with other honeys in the literature, it can readily be concluded that Turkish and Greek pine honeys are comparable in terms of mean values and ranges of a_w and MC.

3.3 Correlation between a_w and MC for Turkish flower and pine honeys

a_w exhibited a linear variation versus MC for honey samples in aggregate (Figure 1). Multidiscriminant Function Analysis gathered data for flower and pine honeys apparently in two separate groups (Figure 2). So, the analysis revealed that flower and pine honeys are from different populations ($P < 0.05$) (Figure 2) in terms of the a_w-MC correlation. Namely, each honey has its own a_w-MC correlation. Based on the multidiscriminant analysis the variation of a_w versus MC was separately evaluated.

a_w of both honeys linearly increased with increasing MC with coefficients of determination (R^2) close to one (Figure 1). The very close slopes (0.014 vs 0.016) and intercepts (0.264 vs 0.262) of both linear equations show that their courses are almost parallel to each other. Practically, a_w of both honeys would exhibit the same variation against unit variation in MC.

Table 1. Works looking for a correlation between water activity (a_w) and moisture content (MC) of liquid honeys.

Source	Regression equation	R^2	Samples	MC, % m/m	a_w
Linear correlation					
This work			Turkey		
	$a_w = 0.014$ MC + 0.264	0.886	706 flower	15.0-20.4	0.470-0.563
	$a_w = 0.016$ MC + 0.262	0.848	257 pine	15.1-20.4	0.492-0.589
Manzanares et al. (2014)			Spain		
	$a_w = 0.017$ MC + 0.308[1]	0.818[1]	86 flower	15.4-17.4	0.56-0.60
Silva et al. (2016)			Brazil		
	$a_w = 0.014$ MC + 0.347	0.783	40 flower	14.3-19.0[1]	0.537-0.625[1]
Shafiq et al. (2014)			Pakistan		
	$a_w = 0.019$ MC + 0.262	0.831	10 flower	18.3-21.0	0.568-0.616
Abramovic et al. (2008)			Slovenia		
	$a_w = 0.020$ MC + 0.205[1]	0.920[1]	75 flower	14.0-18.6[1]	0.479-0.557[1]
	$a_w = 0.021$ MC + 0.210[1]	0.729[1]	75 honeydew	13.4-18.0[1]	0.438-0.591[1]
Chirife et al. (2006)			Argentina		
	$a_w = 0.018$ MC + 0.262	0.969	36 flower	15.0-21.0	0.521-0.676[1]
Gleiter et al. (2006)			Germany		
	$a_w = 0.017$ MC + 0.497	0.771	166 flower	14.1-22.6[1]	0.497-0.614[1]
	$a_w = 0.014$ MC + 0.530	0.776	128 honeydew	13.6-18.3[1]	0.523-0.610[1]
Schroeder et al. (2005)			Germany		
	$a_w = 0.018$ MC + 0.280	0.707	83 flower	14.0-21.5	0.482-0.608
	$a_w = 0.018$ MC + 0.238	0.721	106 honeydew	12.6-18.4	0.477-0.602
Cavia et al. (2004)			Spain		
	$a_w = 0.020$ MC + 0.267	0.794	90 flower	14.1-22.0[1]	0.531-0.691[1]
Beckh et al. (2004)			International		
	$a_w = 0.013$ MC + 0.334[1]	0.698[1]	19 flower	16.2-20.8	0.543-0.617
	$a_w = 0.016$ MC + 0.296[1]	0.821[1]	11 honeydew	15.1-20.3	0.523-0.630
Lazaridou et al. (2004)			Greece		
	$a_w = 0.013$ MC + 0.339[1]	0.698[1]	9 flower	13.8-17.9	0.540-0.584
Salamanca et al. (2001)			Colombia		
	$a_w = 0.272$ MC + 0.016[1]	0.956	96	18.8-19.6	0.574-0.590
Estupinan et al. (1998)			Gran Canaria		
	$a_w = 0.020$ MC + 0.255	0.662	60 flower	NA	0.562-0.661
Sanz et al. (1995)			Spain		
	$a_w = 0.024$ MC + 0.138[1]	0.981[1]	21 flower	15.8-22.2	0.55-0.69
Estupinan et al. (1993)			NA		
	$a_w = 0.018$ MC + 0.248[2]	0.947	NA	NA	NA
Ruegg & Blanc (1981)	$a_w = 0.018$ MC + 0.271[3]	0.812	Various countries 88 flower& honeydew	NA	NA
No correlation					
Boussaid et al. (2015)			Tunisia		
	$a_w = 0.012$ MC + 0.390[1]	0.226[1]	152 flower	17.2-20.1	0.56-0.65
Al-Mahasneh et al. (2012)			Jordan		
	$a_w = 0.033$ MC + 0.030[1]	0.306[1]	64 flower	16.1-17.3	0.495-0.557
Adenekan et al. (2010)			Nigeria		
	$a_w = 0.001$ MC + 0.488[1]	0.003[1]	10 flower	14.6-22.1	0.41-0.57
Gomes et al. (2010)			Portugal		
	$a_w = 0.012$ MC + 0.729 [1]	0.042 [1]	5 flower	15.9-17.2	0.47-0.56
Lazaridou et al. (2004)			Greece		
	$a_w = 0.007$ MC + 0.471[1]	0.140[1]	14 pine	13.9-18.9	0.559-0.663
	$a_w = 0.007$ MC + 0.463[1]	0.107[1]	10 fir	13.0-15.2	0.550-0.609

[1]Determined by workers of this work; [2]Determined by Salamanca and others (2001); [3]Determined by Abramovic and others (2008).

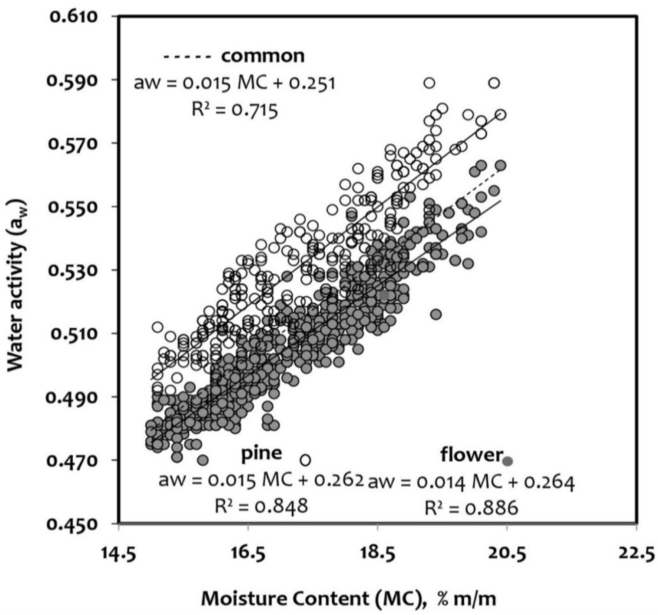

Figure 1. Variation of a_w versus MC and fit of regression equations for Turkish liquid flower and pine honeys.

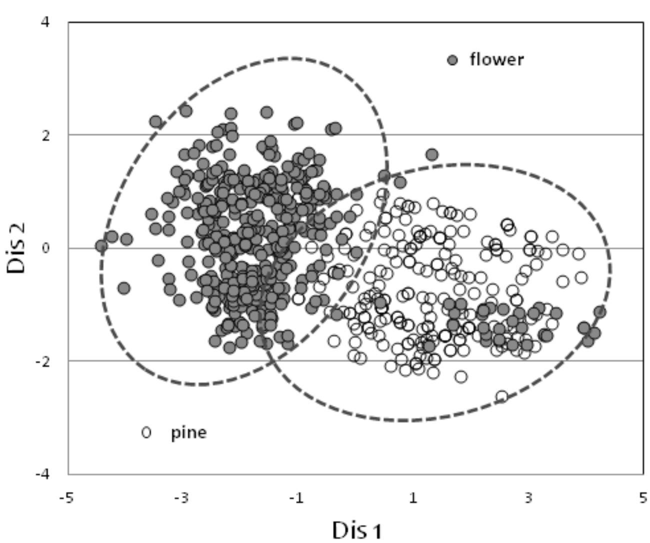

Figure 2. Discrimination analysis for Turkish liquid flower and pine honeys.

The parallelism and the lower a_w values for flower honeys than those of honeydew honeys at the same MC was also reported by Abramovic et al. (2008), Gleiter et al. (2006), and Schroeder et al. (2005). The lower a_w values of flower honey samples than those of pine honey samples at the same MC could be based on their higher monosaccharides content. Abramovic et al. (2008) and Gleiter et al. (2006) stated that flower honeys characteristically have lower a_w than honeydew honeys at the same MC due to having higher monosaccharide (glucose and fructose) content.

A common linear equation was obtained using all data points altough the multi discriminant analysis revealed that the honeys were from different populations. Its slope (0.015) and intercept (0.251) were pretty close to those of specific regression equations for flower and pine honeys and parallel to them (Figure 1). The correlation of the common equation was weaker than those of the specific equations ($R^2 = 0.715$ versus $R^2 = 0.886$ and $R^2 = 0.848$) (Figure 1).

Deviation of calculated a_w values from the experimental ones was determined using both specific and common regression equations. The mean of absolute errors were 1.00% and 1.32% in case of the flower honey for the specific and common regression equation, respectively. In case of the pine honey, it was 1.39% and 3.23% for the specific and common regression equation, respectively.

Percent residues of $a_w \left(\left[a_{w,\ experimental} - a_{w,\ calculated}\right] \big/ a_{w,\ experimental} x100\right)$ are presented in Figure 3 for flower and pine honeys using specific and common regression equations. In case of specific equations, residues showed no bias and randomly scattered around the abscissa between -4.49% and 5.03% for the flower honey (Figure 2a) and between 4.13% - 4.66% for the pine honey (Figure 2c). In case of common equation, they showed relatively biased distribution around the abscissa for both honeys. Deviations piled up below the abscissa for the flower honey between -5.83% and 3.78% (Figure 2b) and above it for the pine honey between -0.91% - 7.55% (Figure 2d).

The common equation could be supposed to be practical and dependable to calculate a_w from MC, or vice versa, despite of the discriminant analysis above, due to its small means of absolute error for both flower honey (1.39%) and pine honey (3.23%). However, evident bias of residues around the abscissa would make its use technically erroneous (Figure 3).

3.4 Comparision with other honeys in the literature in terms of the correlation between a_w and MC

Previous works conducted under similar conditions to those in this work (at 20 °C and/or 25 °C using a refractometer and a water activity instrument) for other honeys from various geographies in the world showed either a linear correlation or no correlation between a_w and MC (Table 1).

A considerable number of previous works for other honeys showed a significant positive linear correlation between a_w and MC as in this work (Table 1). In some, the correlation was quite strong with $R^2 \geq 0.90$ (Abramovic et al., 2008; Chirife et al., 2006; Salamanca et al., 2001; Sanz et al., 1995; Estupinan et al., 1993). For flower honeys, the slope was between 0.013 (Lazaridou et al., 2004) and 0.024 (Sanz et al., 1995), and the intercept was between 0.138 (Sanz et al., 1995) and 0.497 (Gleiter et al., 2006). For honeydew honeys, the slope was between 0.014 (Gleiter et al., 2006) and 0.021 (Abramovic et al., 2008), and the intercept was between 0.238 (Schroeder et al., 2005) and 0.53 (Gleiter et al., 2006). The slope and intercepts for Turkish flower and pine honeys were within the ranges of slopes and intercepts for other honeys in the literature. The comparativeness of slopes points that a_w of honeys harvested in different geographies and at different times give almost the same response against the varying MC.

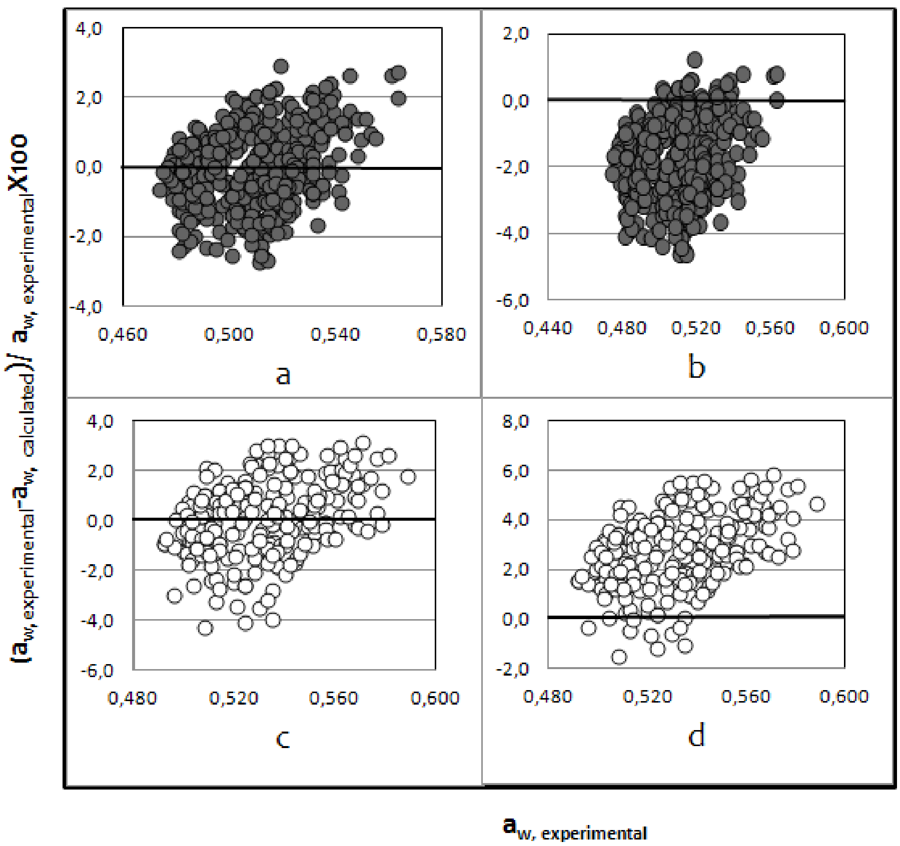

Figure 3. Percent residues from specific equations (a-flower honey, c-pine honey) and common equation (b-flower honey, d-pine honey) regressed for Turkish liquid flower and pine honeys.

This work did not conform to some previous works. Data of Boussaid et al. (2015), Al-Mahasneh et al. (2012), Adenekan et al. (2010), Gomes et al. (2010) and Beckh et al. (2004) exhibited no correlation between a_w and MC with insignificant R^2 values for flower honey samples (Table 1). The same was observed by Lazaridou et al. (2004) for 24 honeydew samples. (Table 1). Though Turkish and Greek pine honeys were comparaple with respect to mean values and limits of a_w and MC values, they were not comparative with respect to correlation between a_w and MC. a_w of Greek honeys did not exhibit a correlation versus MC (Table 1; Lazaridou et al., 2004).

4 Conclusions

Turkish liquid flower and pine honeys showed parallel positive linear correlations for a_w versus MC. The flower honeys have lower a_w values than pine honeys at the same MC. This work is in close agreement with considerable amount of works in the literature in terms of values of a_w and MC, and the correlation between them.

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