Effect of floral locations on physicochemical and thermal honey bee properties

Felix Uzochukwu Asoiro[1*], Meshack Imologie Simeon[2], Chinenye Eberechukwu Azuka[3]

(1, Department of Agricultural and Bioresources Engineering, University of Nigeria, Nsukka, Enugu State, 410001, Nigeria
2. Department of Agricultural and Bioresources Engineering, Federal University of Technology, Minna, Nigeria
3. Department of Food Science and Technology, University of Nigeria, Nsukka, Enugu State, 410001, Nigeria)

Abstract: The effects of floral location on the physicochemical and thermal parameters of honey bee samples from Enugu North senatorial zone were evaluated. For physicochemical properties, a 14×5×10 completely randomized design (CRD) with a total of 700 observations (14 physicochemical properties as responses × 5 levels of floral location as treatment × 10 replications) was conducted. For thermal properties, a 3×5×10 CRD with a total of 150 observations (3 thermal properties as responses × 5 levels of floral location as treatment × 10 replications) was also conducted. Floral location had significant effects ($P \leq 0.05$) on viscosity, electrical conductivity, sugar content, free acidity, ash content, moisture content, density, pH, colour, thermal heat conductivity and thermal heat diffusivity except, fructose/glucose (F/G) ratio and specific heat capacity. Viscosity of honey decreased as temperature increased with samples from Igbo-Eze South more viscose than those from other floral locations. Fructose had the highest mean value (35.26 g/100g), followed by glucose (31.92 g/100g) and sucrose (1.47 g/100g). All samples were generally acidic and of very high quality standard as Udenu, Igbo-Eze South and Nsukka honeys were adjudged extra white in colour while Igbo-Eze North and Igbo- Etiti were white honey. Values for thermal heat conductivity and thermal heat diffusivity were 0.44 W $m^{-1o}C^{-1}$ and 3.51 m^2s^{-1}; 0.43 W $m^{-1o}C^{-1}$ and 3.84 m^2s^{-1}; 0.44 W $m^{-1o}C^{-1}$ and 2.43 m^2s^{-1}; 0.44 W $m^{-1o}C^{-1}$ and 2.84 m^2s^{-1}; and 0.45 W $m^{-1o}C^{-1}$ and 2.69 m^2s^{-1} for Igbo- Eze North, Udenu, Igbo-Eze South, Igbo-Etiti and Nsukka respectively. Honey is a promising food rich in essential minerals. Knowledge of its physicochemical and thermal properties is inevitable to facilitate its postharvest processing.

Keywords: moisture content, fructose, free acidity, density, thermal heat diffusivity, viscosity, electrical conductivity

Citation: Asoiro, F.U., M.I. Simeon and C.E. Azuka. 2022. Effect of floral locations on physicochemical and thermal honey bee. Agricultural Engineering International: CIGR Journal, 24 (1):260-275.

1 Introduction

Honey is the natural sweet, viscous substance with specific aroma, produced by honeybees (Apis Mellifera) from the nectar of plants or from secretions of living parts of plants or excretions of plant sucking insects on the living parts of plants, which the bees collect, transform by combining with specific substances of their own, deposit, dehydrate, store and leave in the honeycomb to ripen and mature (Codex Alimentarius Commission [CAC], 2001; Jaafar et al., 2017; Silva et al., 2017; Oroian et al., 2018; Nayik et al., 2018). Honey is considered the oldest sweetening substance consisting mainly of 70% sugars such as glucose and fructose (Nayik et al., 2016). Honey consists of valuable ingredient, possesses valuable nourishing, healing and prophylactic properties. Honey is perhaps one of the most complex foodstuffs produced by

Received date: 2021-01-14 **Accepted date:** 2021-07-21

***Corresponding Author: Felix Uzochukwu Asoiro,** Department of Agricultural and Bioresources Engineering, University of Nigeria, Nsukka, Enugu State, 410001, Nigeria. Tel.: +2348063588320. Email: felix.asoiro@unn.edu.ng.

nature and certainly the only sweetening agent that can be used by humans without any processing (Khaled, 2007). Bee honey can be a good source of major and trace elements needed by humans. The general features and elemental composition of honey depend on its botanical and geographical origin as well as floral locations (Can et al., 2015; Jandric et al., 2015; Jaafar et al., 2017; Bilandzic et al., 2017; Boussaid et al., 2018). The concentration of mineral compounds ranges from 0.1% to 1.0% that varies widely depending on the particular floral location (Silva et al., 2017; Belay et al., 2017), pedoclimatic conditions and extraction technique (Babarinde et al., 2011; Nigussie et al., 2012). The dominant element in honey is potassium, followed by chlorine, sulphur, sodium, phosphorus, magnesium, silicon, iron and copper (La Serna *et al*., 1999). Bee honey can contain metals up to 0.17%. Metals such as Cr, Co, Cu, Fe, Mn and Zn are essential for humans, and they may play an important role in a number of biochemical processes. Some of them are present at the trace level, being toxic if they exceed safety levels. As a foodstuff used for healing purposes, honey must be free of any objectionable content and should contain only small amounts of pollutants, such as heavy metals (Khaled, 2007).

Honey has a variety of uses. Honey provides a good source of energy, used in cooking, baking, as a spread on bread, and as an addition to various beverages, such as tea, and as a sweetener in some commercial beverages. It is also used in the fermentation of alcoholic beverages, blood sugar control, cough suppressant, and can be used to boost immunity. It also has antioxidant and antimicrobial properties. Natural honey was found to be a suitable alternative for healing wounds, burns and various skin conditions and also to have a potential role in cancer care (Badolato et al., 2017). The intrinsic properties of honey have been reported to affect the growth and survival of microorganisms by bacteriostatic or bactericidal actions (Mudasar et al., 2013). It is high in carbohydrates and adds useful varieties to diets. Most honey have fructose and glucose, it is more readily digestible than cane sugar. Honey varies in taste, aroma and colour according to its source.

The physicochemical and thermal parameters are of vital importance to industries using honey. Constituents such as minerals (Silva et al., 2017), moisture content (Singh and Singh, 2018), reducing sugars (Oroian et al. 2018), electrical conductivity (Silva et al., 2017; Esriche et al., 2017), free acidity (Bergamo *et al*., 2018),viscosity (Belay et al., 2017), sucrose content (Boussaid et al., 2018) and Hydroxymethylfurfural (HMF) (Kędzierska-Matysek et al., 2016), specific heat capacity, thermal heat conductivity and thermal heat diffusivity have been shown to influence the nutritional, granulation, storage, flavor and textural quality of honey. The medicinal values of honeys are also due to these constituents. Therefore, the International Honey Commission (IHC) has proposed certain constituents as quality criteria for honey. In order to have a beneficial effect, honey must be free of any adulterants or contaminant (Wu et al., 2017; Bilandzic et al., 2017). High concentration of metals in honey can be a source of illness to human beings, especially heavy metals (Aghamirlou et al., 2015). Artificial honeys can be produced from carbohydrate sources that have glucose-fructose composition that are within a close range with that of natural honey. These artificial honeys often have similar taste and physical appearance as natural honeys, but they lack the medicinal and nutritional properties of natural honeys because of the absence of the minor constituents that are present in natural honeys (James et al., 2009).

Industrial treatments of commercial honeys during extraction and storage affect the quality of honey. One of the most common treatments in the honey industry is thermal treatment (Zarei et al., 2019) which could create some changes in the physicochemical and thermal properties of honey. Knowledge of the thermal properties of honey is expedient for quality evaluation and for the design of processing equipment. Thermal properties of foods and beverages must be known to perform the various heat transfer calculations involved in designing storage and refrigeration equipment and estimating process times for refrigerating, freezing, heating, or drying of foods and beverages (ASHRAE, 2006). Because the thermal properties of foods and beverages strongly depend on physico-chemical composition and temperature, and because many types of food are available, it is nearly impossible to experimentally determine and tabulate the thermal properties of foods and beverages for all possible conditions and compositions. Thermo-physical properties often required for heat transfer calculations include density, specific heat, thermal conductivity, and thermal diffusivity.

Many researchers have worked on various properties of natural honey in different parts of the world, which have been compared with international standard (Jandric et al., 2015; Can et al., 2015; El Sohaimy et al., 2015; Vázquez- Quiñones et al., 2017); James et al., 2009; Mehryar et al., 2013; Alqarni et al, 2016; Samborska et al., 2019; Oroian et al., 2016; Silva et al., 2017; Sobrino-Gregorio et al., 2017; Humphrey and Dykes, 2008; Ramaswamy et al., 2007; and Božiková and Hlavác, 2013). However, very little information is available in literature on the physicochemical and thermal properties of Nigerian indigenous honey from Enugu North senatorial zone, despite the huge honey production potential of the region. Therefore, understanding the physiochemical and thermal properties of honey is very important in determining the nutritional quality assessment, economic value and in the design of processing equipment, packaging material and evaluation of the storage conditions of honey.

The aim of this study is to evaluate honey samples from different floral locations within Enugu North senatorial zone based on their physicochemical and thermal properties, and compare the values obtained in each local government area with others, as well as the international standards.

2 Materials and methods

2.1 Raw materials

About 75 cm^3 honey samples were sourced directly from local honey producers in different floral location of each Local Government Area of Enugu North senatorial zone, Enugu State, Nigeria. Honey sample from Udenu (6.5219N, 7.532E at 335 m above sea level) was collected at Obollo-Afor main market, that of Igboeze-North Local Government (6.5960 N, 7.27 E at 364 m above sea level), was collected from Eke market at Ogurute Enugu-Ezike. Sample from Nsukka Local Government Area (6.7703 N, 7.43 E at 430 m above sea level) was collected at Afor-Opi market, that of Igbo-Etiti (6.4259 N, 7.2555 E at 268 m above sea level) was sourced at Nkwo Ogbede market and that of Igbo eze-South (6.5827 N, 7.2130 E at 386 m above sea level) was sourced at Eke Ovoko market. Honey samples was extracted manually by hand or wooden press, preserved using sterilized amber glass bottle and kept in the dark at 20°C prior to analyses, which was not longer than two months after extraction from the hive. Study lasted between August, 2018 to September, 2018.

2.2 Determination of honey physical and chemical properties

2.2.1 Determination of viscosity

Viscosity of the honey was measured using a well calibrated digital Ostwald viscometer (Brookfield digital viscometer USA (model DV-E MA 02346–1031) at a shear rate of 5 rpm (Babarinde et al., 2011; Boussaid et al., 2018). The viscosity of honey samples was measured at temperatures of 25 and 60°C.

2.2.2 Determination of electrical conductivity

The electrical conductivity (μS cm^{-1}) at 20% (dry matter basis) in distilled water at 25° C was evaluated by using a conductivity meter Tec-4MP model (TECNAL, São Paulo, SP, Brazil), according to the method used by IHC (2009), Silva et al. (2017) and Bergamo et al. (2018).

2.2.3 Determination of sugar content, Fructose+Glucose (F+G) and Fructose/Glucose(F/G)

The reducing sugar such as glucose, fructose and sucrose content of the honey samples were determined spectrophotometrically according to AOAC (2000) method and slightly modified method previously reported by Esriche *et al*. (2017), Bussaid *et al*. (2018) and Bergamo *et al*. (2018). F+G were mathematically computed by adding the values of F to the values of G while F/G was determined by evaluating the ratio of F to G.

2.2.4 Determination of free acidity

Free acidity was measured titrimetrically following the AOAC method (AOAC, 2000). This involves immersing the electrode of the pH metering the solution, stirring with a magnetic stirrer and titrating to pH of 8.5

by adding a solution of 0.05 N of NaOH (Boussaid et al., 2018)

2.2.5 Determination of ash content

The ash content was determined by incinerating 5 g of the honey samples in a muffle furnace at a temperature of 550°C for 5 hours according to the method described by AOAC (2000) and Boussaid et al. (2018). Finally, the ash content (%) was calculated, using Equation 1.

$$Ash\ content\ (\%) = \frac{M_A - M_T}{M_A} \times 100 \quad (1)$$

Where, M_A is mass of honey sample before testing (g) and M_T is mass of honey sample after testing (g).

2.2.6 Determination of moisture content

Moisture content of the honey samples were measured using a digital Abbe refractometer (Abbe-type model T1 Atago, Bellevue, Washington, USA) at 20ºC, after homogenizing the sample and using distilled water as reference material, according to AOAC method 969.38 (AOAC, 2012). The corresponding moisture content values were obtained from the Chataway table. HPLC-UV chromatographic, by interpreting the refractive index determined (Escriche et al., 2017; Bergamo et al., 2018; Guo et al., 2019).

2.2.7 Determination of density

Abbe's refractometer was used to determine the density of honey (Alqarni et al., 2016).

2.2.8 Determination of pH

pH of the honey samples was determined according to the IHC (2009). About 10 g of honey sample in 75 cm^3distilled water was used for the measurement of pH. The pH was measured using a digital pH meter (Beckman, California, USA) according to the method described by Jaafar et al. (2017), Silva et al. (2017), and Guo et al. (2019).

2.2.9 Determination of colour

The undiluted honey samples were filtered with Whatman filter paper and 2 cm^3 of each filtrate was measured directly with a Pfund chromometer (Hanna Instruments, Padova, Italy) (Guo et al., 2019) to determine the colour in millimeter (mm) Pfund scale. The colours of honey were classified based on the Pfund scale readings: average scale reading ≤ 8 mm Pfund: water white; 8 mm Pfund< reading ≤ 16 mm Pfund: extra white; 16 mm Pfund< reading ≤ 34 mm Pfund: white; 34 mm Pfund< reading ≤ 50 mm Pfund: extra light amber; 50 mm Pfund< reading ≤ 85 mm Pfund: light amber (Guo et al., 2019).

2.3 Determination of thermal properties

2.3.1Specific heat capacity

Determination of specific heat capacity was by electrical heating method (Maxwell, 1970), with slight modification. A copper calorimeter was first weighed empty and reweighed when about two-third full of sample. The ammeter, voltmeter and heating coil (constant wire) were connected. A plastic stirrer and a thermometer were also fitted into the container through the holes in the wooden lid. The current was switched on after the initial temperature of the sample had been recorded. The rheostat was adjusted to give a suitable steady current. The liquid was stirred gently while being heated. The final temperature was read after the current was switched off. The specific heat of the sample was calculated using Equation 2

$$C_1 = \frac{M_1 \times VIt}{M_1(T_2 - T_1)} - M_C C_C \quad (2)$$

Where, C_1 is specific heat capacity of the sample (kJ kg^{-1} K^{-1}), C_C is specific heat capacity of the calorimeter = 400 J $kg^{-1}K^{-1}$, M_C is mass of calorimeter =0.077 kg, M_1 is mass of sample = 0.056 kg, I is current (A), V is voltage (V), t is time taken (sec), T_2 and T_1 are final and initial temperatures (K) respectively.

2.3.2 Thermal conductivity

Non-steady state technique by Hopper and Lepper (1950) with slight modification was used in determining thermal conductivity of the honey samples. Hot wires were used. The sample was measured using a measuring cylinder and gently poured into the pipe of which the two openings were closed with a cork. A constantan wire was inserted into the material and the terminals were connected. When the key in the circuit was closed, there was a conversion of energy from electrical energy to heat energy which flow out radially from the wire into the sample and the quantity of heat passing through the wire were recorded by the use of Ammeter and voltmeter connected in the circuit. There was a change in temperature of the wire and the logarithm time was used to calculate the thermal conductivity of the sample (Equation 3) (Hopper and Lepper, 1950)

$$K = \frac{VI}{4\pi(T_2 - T_1)}\left(In\frac{t_2}{t_1}\right) \quad (3)$$

Where, K is thermal conductivity (W m^{-1} ^{o}C^{-1}), T_1 is initial temperature (^{o}C), T_2 is final temperature (^{o}C), t_1 and t_2 are the initial and final time (s) respectively, V is voltage (V) and I is current (A).

2.3.3 Thermal diffusivity

The method of derivative according to Singh and Heldman (2001) was used in computing the thermal diffusivity of honey samples. Equation (4) by Singh and Heldman (2001) was used for the calculation of thermal diffusivity.

$$\alpha = \frac{K}{\rho \times C_P} \quad (4)$$

Where, α is thermal diffusivity (m^2 s^{-1}), K is thermal conductivity (W m^{-1} ^{o}C^{-1}), ρ is density (kg m^{-3}), C_P is specific heat capacity (kJ kg^{-1} ^{o}C^{-1}).

2.4 Statistical analysis of data

For physicochemical properties, a 14×5×10 completely randomized design (CRD) with a total of 700 observations (14 physicochemical properties as responses × 5 levels of floral location as treatment × 10 replications) was conducted. For thermal properties, a 3×5×10 CRD with a total of 150 observations (3 thermal properties as responses × 5 levels of floral location as treatment × 10 replications) was also conducted. Data were analyzed using descriptive and inferential statistics with SPSS, version 21; Excel software, Windows 10; Prism Graph 6 and Minitab 16. Multiple comparisons test was performed using the least significant difference (LSD) and Fisher ratio (F_r), and statistical significance was set at $\alpha = 0.05$. Pearson correlation coefficients were made using SPSS, version 21 and results presented in Duncan Multiple Range format.

3 Results and discussion

The results of the physico-chemical properties of honey from floral locations in Enugu North senatorial zone are presented in Table 1 while the thermal properties of the honey samples are shown in Table 2.

Table 1 Physico-chemical properties of honey samples from floral locations in Enugu-North senatorial zone

Properties	Physico-chemical properties							
	Floral Locations							
	Replication	Igbo-Eze North	Udenu	Igbo-Eze South	Igbo-Etiti	Nsukka	Mean	Std Dev.
Viscosity @ 25^{o}C (cSt)	10	17.18_{cd}	12.16_{a}	18.16_{d}	16.07_{c}	14.35_{b}	15.58	2.38
Viscosity @ 60^{o}C (cSt)	10	13.85_{cd}	10.71_{a}	11.74_{b}	14.01_{d}	12.85_{c}	12.63	1.40
Electrical conductivity(µS cm^{-1})	10	216.8_{b}	226.5_{d}	225.4_{cd}	223.9_{c}	211.45_{a}	220.81	6.46
Fructose, F (g 100 g^{-1})	10	35.5_{a}	33.38_{a}	34.52_{a}	38.84_{b}	34.04_{a}	35.26	2.15
Sucrose (g 100 g^{-1})	10	1.58_{c}	1.04_{a}	1.57_{c}	1.37_{b}	1.8_{d}	1.47	0.29
Free acidity (%)	10	0.38_{a}	0.39_{a}	0.71_{b}	0.38_{a}	0.35_{a}	0.44	0.15
Ash Content (%)	10	0.21_{b}	0.57_{d}	0.16_{b}	0.06_{a}	0.33_{c}	0.27	0.20
Moisture content (%)	10	21.64_{c}	19.68_{b}	22.55_{c}	16.59_{a}	22.12_{c}	20.52	2.45
Density (g cm^{-3})	10	1.00_{b}	1.00_{b}	1.25_{d}	0.82_{a}	1.2_{c}	1.05	0.17
Glucose, G (g 100 g^{-1})	10	31.36_{a}	30.78_{a}	31.64_{a}	35.22_{b}	30.62_{a}	31.92	1.89
pH	10	5.05_{b}	5.7_{c}	4.7_{a}	4.75_{a}	4.87_{a}	5.01	0.41
Colour (cm, Pfund)	10	1.83_{c}	1.38_{b}	1.99_{c}	1.71_{bc}	0.86_{a}	1.55	0.45
F+G (g 100 g^{-1})	10	66.86_{a}	64.16_{a}	66.16_{a}	74.06_{b}	64.66_{a}	67.18	3.99
F/G	10	1.14_{a}	1.08_{a}	1.09_{a}	1.1_{a}	1.11_{a}	1.10	0.02

Note: cSt is centistoke

Table 2 Thermal properties of honey samples from Enugu-North senatorial zone

Properties	Thermal properties							
	Floral Locations							
	Replication	Igbo-Eze North	Udenu	Igbo-Eze South	Igbo-Etiti	Nsukka	Mean	Std Dev
Specific heat capacity (kJ kg^{-1} $^oC^{-1}$)	10	1.3_a	1.46_a	1.53_a	1.64_a	1.41_a	1.47	0.13
Thermal heat conductivity (W m^{-1} $^oC^{-1}$)	10	0.44_a	0.43_a	0.44_{ab}	0.44_{ab}	0.45_b	0.44	0.01
Thermal heat diffusivity ($\times 10^{-4}$) (m^2 s^{-1})	10	3.51_{bc}	3.84_c	2.43_a	2.84_{ab}	2.69_a	3.06	0.59

3.1 Physicochemical properties

Analyses of variance (ANOVA) (Table 3) showed that physicochemical properties, floral location and the interaction between physicochemical properties and floral location had significant effect ($p \leq 0.05$) on honey quality, with the interaction of physicochemical properties and location having more effects, followed by physicochemical properties and then location. Based on this there is the need for pair wise comparison.

Table 3 Analysis of variance (ANOVA) on the effect of physicochemical properties (PCP) and floral location of honey

Dependent Variable:Measurements		Tests of Between- Subjects Effects				
Source		Type III Sum of Squares	Df	Mean Square	F	Sig.
Intercept	Hypothesis	7778038.744	1	7778038.744	1.967	.184
	Error	5.136E7	12.988	3.955E6[a]		
PCP	Hypothesis	5.143E7	13	3956423.467	165.026	.000
	Error	1246679.066	52	23974.597[b]		
Location	Hypothesis	89322.188	4	22330.547	.931	.453
	Error	1246679.066	52	23974.597[b]		
PCP * Location	Hypothesis	1246679.066	52	23974.597	9.517E3	.000
	Error	1587.046	630	2.519[c]		

a. MS(PCP) + MS(Location) - MS(PCP * Location)

b. MS(PCP * Location)

c. MS(Error)

3.1.1 Viscosity

The viscosity of natural honey samples has been reported to have strong dependence on temperature and floral location (Nayik et al., 2018; Zarei et al., 2019). Viscosity decreased as temperature increased. Mean viscosity value at 25 °C (15.58cSt) was higher than that at 60 °C (12.63cSt). Honey samples from Igbo-Eze South Local Government Area at room temperature was more viscose than the rest of all the honey samples. Igbo-Etiti honey samples had the highest viscosity (14.01cSt) followed by Igbo-Eze North (13.85 cSt). This quality is good for long term storage of honey. Regression analyses revealed that viscosity of honey at 25°C ($Y = 18.09 - 9.44X$) and at 60 °C ($Y = 13.95 - 4.97X$) have linear relationship with ash content (Figure 1).

3.1.2 Electrical conductivity

Electrical conductivity is directly related to the concentration of mineral salts, organic acids, proteins and ash content. It is very useful in the determination of the floral origin and purity of honey samples (Bergamo et al., 2018). Honeydew honeys usually possess high electrical conductivity ($\geq$ 0.8 mS cm^{-1}) with blossom or combination of blossom and honeydew honeys having low values ($\leq$0.8 mS cm^{-1}) (Silva et al., 2017). Bergamo et al. (2018) had earlier reported a range of values (0.16 to 0.72 mS cm^{-1}) for some blossom honeys and also for honeydew honeys (1.07 to 1.78 mS cm^{-1}). Can et al. (2015) had also reported electrical conductivity values (1.5-0.3 mS cm^{-1}) for honey samples. Other reports presented electrical conductivity values (0.89-0.43 mS cm^{-1}) for Lithuanian monofloral honey and values of 3.13-0.21 mS cm^{-1} for hetero floral honey, with dark honeys exhibiting higher values. Manika honeys has also been reported to have an electrical conductivity of 0.66 mS cm^{-1}. Escriche et al. (2017) and Kędzierska-Matysek et al. (2016) had in like manner, reported electrical conductivity value ranges of 1.3-0.87 mS cm^{-1} and 4.2-0.25 mS cm^{-1} respectively for some honey samples. In a related study, Boussaid et al. (2018) documented values 0.89-0.39 mS cm^{-1} for Tunisian honey samples from six floral locations. In this study, Udenu had the highest electrical conductivity values (226.5 µS cm^{-1}), while Nsukka recorded the least electrical conductivity values (211.45 µS cm^{-1}) for honey samples investigated. None of the analyzed honey types showed electrical conductivity values greater than 800 µS cm^{-1}, suggesting that honeys from Enugu senatorial zone are blossom honey and of high quality. The electrical conductivity values from Enugu North senatorial zone ranged between 226.5 - 211.45 µS cm^{-1}, all of them below the maximum acceptable limit by international standard and clearly within the range of values (300-150 µS cm^{-1}) reported by Can et al. (2015).

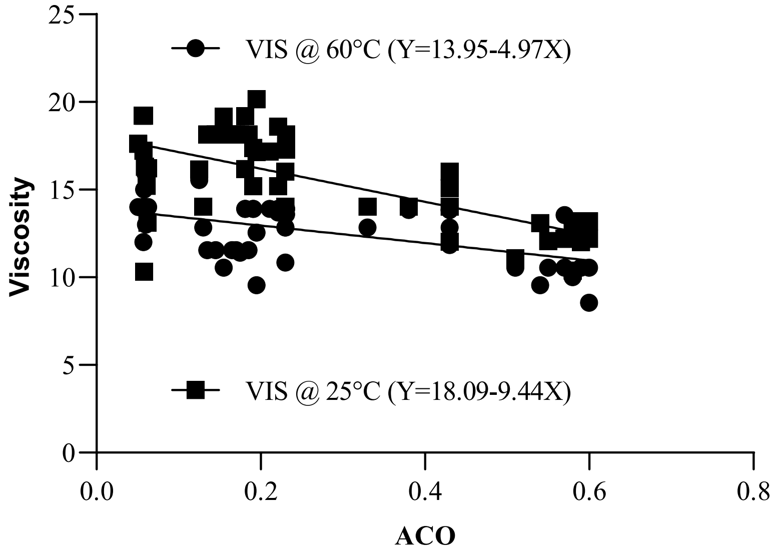

Figure 1 Effect of honey viscosity on ash content at various temperatures

3.1.3 Sugar content, Fructose+Glucose (F+G) and Fructose/Glucose (F/G)

Generally, the sugar content of honey (fructose, sucrose and glucose) comes from the sugars from the nectars of flowers as well as enzymes present in the honey bee which depend on the floral and regional origin (Can *et al*., 2015). Fructose had the highest mean value (35.26 g 100 g^{-1}), followed by glucose (31.92 g 100 g^{-1}) and sucrose (1.47 g 100 g^{-1}). The dominance of fructose over glucose (Table 1) is one way in which honey differs from commercial invert sugars. For honeys of good quality, the fructose content should exceed the glucose content (Can et al., 2015; Oroian et al., 2016; Oroian et al., 2018). The sucrose content is used to indicate adultration and improper handling of honey (Wu et al., 2017). Inadequate maturation or prolonged artificial feeding of bees with sucrose syrups may cause high levels of sucrose (Guo et al., 2019). The mean sucrose contents of the honey samples determined were 1.58, 1.04, 1.57, 1.37 and 1.8 g 100 g^{-1} for Igbo-Eze North, Udenu, Igbo-Eze South, Igbo-Etiti and Nsukka respectively which were lower than the international standard limit (5 g 100 g^{-1}) (CAC, 2001). Sucrose values for Udenu, Igbo-Eze South, Igbo-Etiti and Nsukka were all significant ($p \leq 0.05$) while that of Igbo-Eze North and Igbo-Eze South were not significant ($p \geq 0.05$). The values obtained for sucrose content of all the honey samples from different floral locations were all within the limits of international standards. Exponential model best fitted the relationship between sucrose and electrical conductivity ($Y = 10.66X^{-0.28}$) (Figure 2). The mean fructose value for honey from Enugu South senatorial zone was 35.26 g/100g. Igbo-Etiti had the highest fructose value (38.84 g 100 g^{-1}), followed by Igbo-Eze North (35.5 g/100g), while Udenu had the lowest (33.38 g 100 g^{-1}). Glucose values for Igbo-Eze North, Udenu, Igbo-Eze South and

Nsukka were not significant at 95% confidence level. However, they were all significantly different ($p \leq 0.05$) from values for Igbo-Etiti (Table 1). Oroian *et al*. (2016) had earlier reported value ranges of sucrose (0 – 1.9 g 100 g^{-1}), fructose (35.2 – 37.1 g 100 g^{-1}), glucose (28.2 – 32.7 g 100 g^{-1}), F+G (68.3 – 78 g 100 g^{-1}) and F/G (1.06 – 1.58) for six samples of Romanian honeys that were slightly with range of values determined for honeys from Enugu North senatorial zone. F+G values for honey samples investigated ranged between 64.15-74.06 g 100 g^{-1} while F/G ranged between 1.1 -1.14 which were clearly within the range of values of 54.84 -76.18 g 100 g^{-1} and 1.16 – 2.44 for F+G and F/G respectively, earlier reported by Can *et al*. (2015). F+G of all the honeys were higher than 60 g/100 g, which is the required value according to the international regulations of quality (Codex Alimentarius Commission [CAC], 2001). The mean value of 1.1 for F/G is consistent with average ratio of 1.2 earlier reported by other study (Tappi et al., 2019).

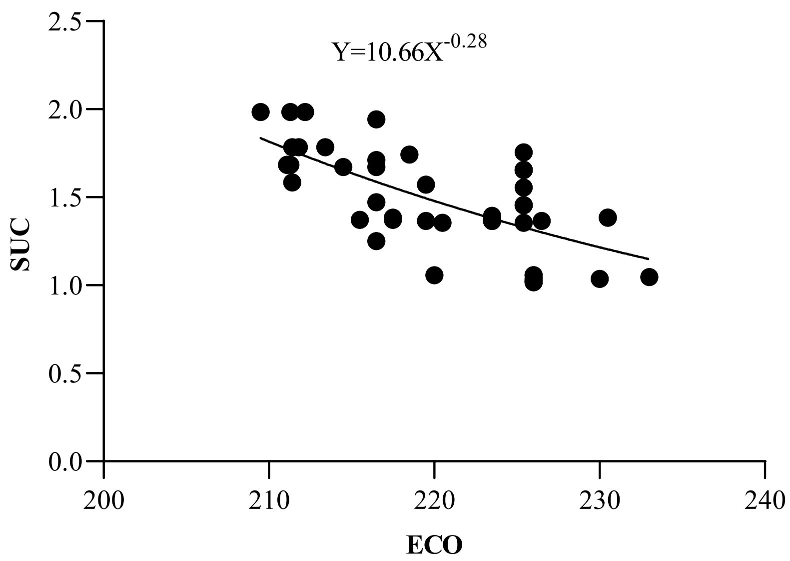

Figure 2 Plot of honey sucrose content against electrical conductivity

3.1.4 Free acidity

The state of honey deterioration is usually measured by its free acidity. Honeydew honey are usually defined by its high free acidity. About 0.57% of organic acids content in honey causes slight acidity (Silva et al., 2017; Babarinde et al., 2011). Its organic acids are derived from sugars by enzymes secreted by honey bees when transforming nectar into honey (Alqarni *et al*., 2016). The acidity of honey may be explained by taking into account the presence of organic acids in equilibrium with their corresponding lactones, or internal esters, and some inorganic ions, such as phosphate (Gomes et al., 2010). Free acidity of honey affects the hydroxymethylfurfural (HMF). Nsukka honey had the least mean free acidity value (0.35%) while Igbo-Eze South had the highest value (0.71%). Free acidity of honey from Igbo-Eze South was significant from those of Igbo-Eze North, Udenu, Igbo-Etiti and Nsukka ($p \leq 0.05$). The maximum level of free acidity allowed in honeys is 50 meq kg^{-1} (Bergamo *et al*., 2018; CAC, 2001; European Commission, 2002). Babarinde et al. (2011) and Silva et al. (2017) had reported different free acidity value ranges of 22.3 – 37.5 meq kg^{-1}, and 12.9 – 45.0 meq kg^{-1} respectively that were however, below the acceptable international limit. The values of free acidity of honey samples from Enugu North senatorial zone fell within the range of acceptability, except for Igbo-Eze South honey that fell slightly above the limit.

3.1.5 Ash content

Ash in honey shows the mineral content of the honey. The mineral content is generally small and depends on nectar composition of predominant plants in their formation. The soil type in which the original nectar-bearing plant was located also influences the quantity of minerals present in the ash. The variability in ash contents has been associated in a qualitative way with different botanical and geographical origins of honeys (Bobis et al., 2020). Standards, honey samples from Igbo-Etiti had the least ash content (0.06%) whereas Udenu honeys had the highest (0.57%). Ash content of honeys harvested from Igbo-Eze North and Igbo-Eze South were not significant ($p \geq 0.05$), whereas those from Udenu, Igbo-Etiti and Nsukka were all significant ($p \leq 0.05$). The ash content values were within the range (0.095%–0.518%) reported by Adebiyi et al. (2004). Saxena et al. (2010) had reported a range of 0.03%- 0.43% ash content in some Indian honeys of different botanical origins. Baroni et al. (2009) reported 0.2% and 0.07% ash content ash in northern and southern Cordoba Provenance, Argentina, respectively. Dos Santo et al. (2008) reported the ash contents of honey from three geographical zone ranged from 0.04 to1.03 and the zones had significant effect on the ash contents of honey samples. Values obtained in this study are in agreement with standard values of less than 0.6% specified by the CAC (2001). According to White and Landis (1980), dark honey is higher than lighter honey in ash (mineral) and contains significant qualities of minerals. The higher percentage of ash could be due to the nectar and flora of plant fed on by the bees which in turn increased the honey's mineral. In this study, the honey harvested from Igbo-Eze North, Igbo-Eze South, Igbo-Etiti and Nsukka could be said to be light honey while that from Udenu is dark honey.

3.1.6 Moisture content

Moisture content is an important factor that determines honey quality, because moisture content has correlation with honey stability against fermentation and granulation during storage. When the moisture content is high, the osmotolerant yeasts in honey can reproduce and decompose the sugar in honey into alcohol and carbon dioxide, thereby causing a bad smell and taste. The moisture content of honey is usually determined by the season and climatic conditions of production (Guo *et al*., 2019). It has been reported that matured, ripe honey has moisture content below 18.6% (Alqarni et al., 2016). Moisture content varies with floral locations (Figure 3). Moisture content was higher (22.55%) for honey samples from Igbo-Eze North and lowest for those from Igbo-Etiti (16.59%). Generally, high moisture contents suggest inadequate extraction and processing conditions, but its content can also be influenced by the climate of the harvesting region (Bergamo et al., 2018). While national beekeeping organizations in some countries (e.g. Germany, Belgium, Austria, Italy and Switzerland) have a maximum of 18%–18.5%, the European Union suggests a maximum value of 21% moisture content (Alqarni *et al.*, 2016; CAC, 2001). Floral location had significant effects on honey moisture content. Honey sample from Enugu North senatorial zone were slightly higher than the limit indicated by European Commission (2002) but however within the limit of values reported by Silva et al. (2017). The implication is that the honey samples from these floral locations have the high moisture content, apart from that harvested from Udenu and Igbo-Etiti. This means that there is the highest probability of encouraging yeast fermentation which may lead to increased in acidity for honeys from other floral locations. This may be attributed to the high relative humidity of these floral areas, the packaging material used, or it was not fully ripped before it was harvested. Moisture content of honey samples from Igbo-Etiti and Udenu floral locations have values that were within the range reported by CAC (2001) for a good quality honey. Tappi et al. (2019) reported a relatively low range for moisture content (16.5%–17.7%). Can et al. (2015) reported a range of value (16%-21%), Guo et al. (2019) reported value range of 19.3%–21.0% while Bergamo *et al.* (2018) also reported ranges of 15.2%– 18.4% and 16%–19.8% for Honeydew and blossom honey respectively. Similarly, Esriche et al. (2017), Kadzierska-Matysek et al. (2016), Oroian et al. (2018) and Silva et al. (2017) also reported ranges of 17.7%-22.1%, 17.4%–19.42%, 14.5%–19.8% and 15.53%–24.20% respectively for honey samples from different floral locality.

3.1.7 Density

Density varies with floral location (Figure 3). The density values of honey samples from Udenu and Igboeze-North were the same (1.00 g cm^{-3}), which is equal to that of water. The density of samples from Igbo-Eze-South, Igbo-Etiti and Nsukka were 1.25 g cm^{-3}, 0.82 g cm^{-3} and 1.2 g cm^{-3} respectively. Floral location had significant effects (at 95% level of confidence) on honey densities. Igbo-Eze North honey density was statistically the same with that of Udenu ($p \geq 0.05$). Honey density values for Igbo-Eze South, Igbo-Etiti and Nsukka were statistically significant ($p \leq 0.05$). Honey densities from other floral location have also been studied and reported. Alqarni et al. (2016) reported a range of 1.349 – 1.4429 g cm^{-3} while Babarinde et al. (2011) reported values of 1.2 - 1.3 g cm^{-3}. These reports were consistent with honey density values evaluated in this study.

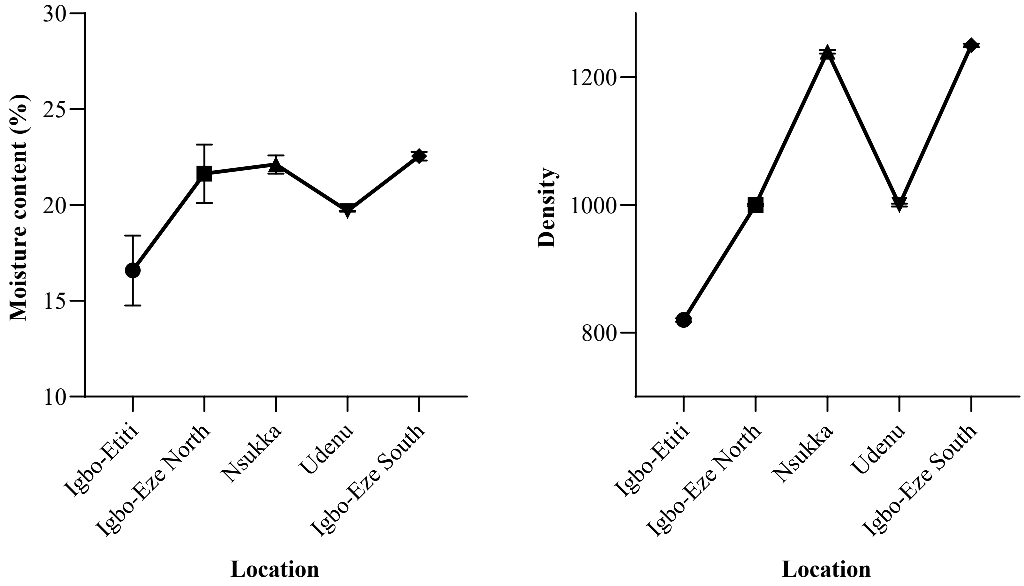

Figure 3 Relationships between moisture content (%), density (kg m^{-3}) and floral location

3.1.8 pH

The pH of honey varied with floral location and may be directly related to the pH of the nectar. Different floral locations result in different organic acids in honey (Guo et al., 2019). The pH of the honey samples studied were in the range of (4.7 – 5.7) with a mean of 5.01 ± 0.41, which are within the limit that indicates the freshness of the honey samples (pH 3.4 – 6.1) as described in the literature. This implies that all the honey samples were acidic. The pH of which was lower than the optimum pH for most bacteria. The low pH of honey is important for the stability of honey against microbiological contamination. Similar findings (3.03 – 4.73) had been reported for honeys from Saudi Arabian and six other countries by Alquarni (2016). The pH of 4.39 to 5.13 for honeydew honeys and 3.80 to 5.29 for blossom honey had also been reported by Bergamo et al. (2018). Babarinde also reported honey pH of 3.3 – 3.7 for honeys obtained from South West, Nigeria. In this study, honey samples from Igboeze-South floral location had the least pH (4.7) and that of Udenu had the highest value (5.7). The results are in line with pH analysis of honey from Umuahia by Olugbemi et al. (2013) which fell between 3.8-4.13. This also agreed with the values of pH for US honey (3.42-6.1). An exponential model best fits the relationship between pH and viscosity ($Y = 30.14X^{-4.41}$) and pH and sucrose ($Y = 4.82 + 1.24X^{-9.77}$) (Figure 4).

3.1.9 Colour

Pfund colour scale of honeys samples from Igbo-Eze North, Udenu, Igbo-Eze South, Igbo-Etiti and Nsukka floral locations were 18.3, 13.8, 19.9, 17.1 and 8.6 (cm, Pfund) respectively. Esriche et al. (2017) had reported slightly lower value range (10.4 – 14.1, cm, Pfund) for honey samples from Mozambique. Honey samples from Udenu, Igbo-Eze South and Nsukka floral locations could be classified as extra white whereas honey samples from Igbo-Eze North and Igbo-Etiti could be likened to white honey (Table 4). These findings show that honey from these areas were of very high quality and confirms the results earlier reported by Babarinde et al. (2011). Honey harvested using modern method had a lighter colour. This implies that honey harvested using modern method from man-made bee hives was of higher quality in colour compared to the honey harvested using traditional method from the wild. The darker colour of honey harvested using traditional method showed that climate and heat may modify colour through darkening action of heat. Also, amino acids are known to react rapidly with sugars while heating to produce yellow or brown materials. The darker colour of the honey harvested using traditional method could also be due to presence of soot produced while harvesting (Babarinde et al., 2011).

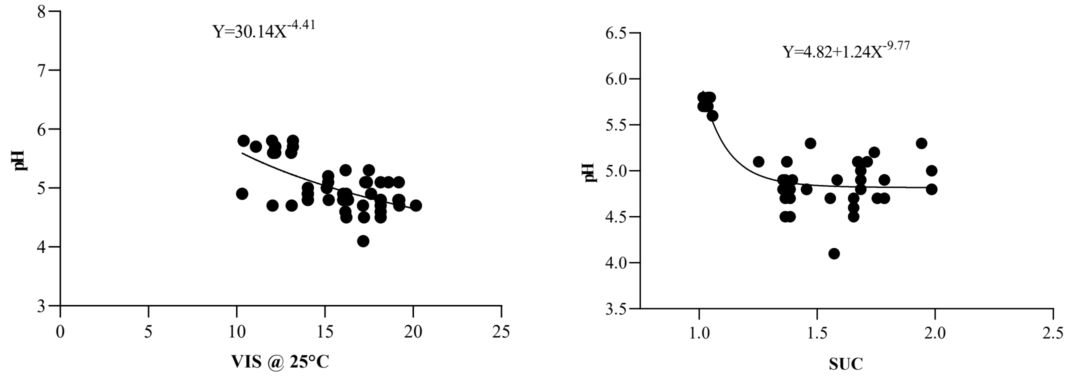

Figure 4 Relationship between pH versus viscosity (cSt) and pH versus sucrose (g 100 g^{-1}) for honey

Table 4 Colour classification based on honey samples absorbance at 560nm (Guo et al., 2019)

Colour	Pfund scale (cm)	Absorbance @ 560nm
Water white	< 8	0.0945
Extra white	8 – 16	0.189
White	16 – 34	0.378
Extra light amber	34 – 50	0.595
Light amber	50 – 85	1.389
Amber	86 – 114	3.003
Dark amber	> 114	> 3.1

3.2 Thermal properties

Analysis of variance (ANOVA) showed that thermal property, floral locations and the interaction between therma properties and floral location had significant ($p \leq 0.05$) effects on the honey quality from Enugu North senatorial zone. Thermal properties had more significant effects ($p \leq 0.05$), followed by the interaction of thermal properties and floral location, and then floral location (Table 5).

Table 5 Analysis of variance (ANOVA) on the effect of thermal property (TP) and floral locations of honey

Tests of Between-Subjects Effects						
Dependent Variable: Measurements Source		Type III Sum of Squares	Df	Mean Square	F	Sig.
Intercept	Hypothesis	411.663	1	411.663	4.738	.162
	Error	172.330	1.984	86.882^a		
Thermal Properties	Hypothesis	174.474	2	87.237	65.492	.000
	Error	10.656	8	1.332^b		
Location	Hypothesis	3.907	4	.977	.733	.594
	Error	10.656	8	1.332^b		
Thermal Properties * Location	Hypothesis	10.656	8	1.332	4.126	.000
	Error	43.585	135	.323^c		

Note: a.MS(ThermalProperties) + MS(Location) - MS(Thermal Properties * Location); b.MS(Thermal Properties * Location); c. MS(Error)

3.2.1 Specific heat capacity

Specific heat capacity is needed in situation requiring heat transfer during processing in other to avoid loss of quality. Specific heat capacity values of Igbo-Eze North, Udenu, Igbo-Eze South, Igbo-Etiti and Nsukka honey samples were 1.3 kJ kg^{-1} °C, 1.46 kJ kg^{-1} °C, 1.53 kJ kg^{-1} °C, 1.64 kJ kg^{-1} °C and 1.41 kJ kg^{-1} °C respectively, with a range of 1.3 – 1.64 kJ kg^{-1} °C and mean value of 1.47 kJ kg^{-1} °C (Table 1). Multiple comparisons showed that honey specific heat capacity was not significant ($p \geq 0.05$) to floral location. There is slightly deviation from values reported by other researchers. Values ranges (1.895 – 2.001 kJ kg^{-1} ^oC) and (1.899 – 2.015 kJ kg^{-1} ^oC) for flower and forest Slovakian honey respectively had been reported (Božiková and Hlavác, 2013). Humphrey and Dykes (2008) a mean value of 2.3 kJ kg^{-1} ^oC for honey sample.

3.2.2 Thermal heat conductivity

It was observed that the thermal conductivity of honey samples ranged between (0.43 – 0.45 W m^{-1} $^oC^{-1}$). This was in close agreement with the value of 0.392W m^{-1} $^oC^{-1}$ reported by Božiková et al. (2018), and slightly above the value reported for flower (0.3379 – 0.3415 W m^{-1} $^oC^{-1}$) and forest (0.347 – 0.348 W m^{-1} $^oC^{-1}$) Slovakian honey. Humphrey and Dykes (2008) had earlier reported a mean value of 0.6 W m^{-1} $^oC^{-1}$ while Ramaswamy et al. (2007) documented a relatively low value range (0.38 – 0.4 W m^{-1} $^oC^{-1}$). These are however different from values for canola oil and clarified butter (0.29 – 0.4 W m^{-1} $^oC^{-1}$) at 700 MPa (Ramaswamy et al., 2007).

3.2.3 Thermal heat diffusivity

Thermal diffusivity of this honey samples has higher values than that of water (0.143 × 10^{-6} m^2 s^{-1}) at 25°C, according to Wikipedia (2016). Igbo-Eze North honey samples had least thermal heat diffusivity (3.51×10^{-4} m^2 s^{-1}) whereas Igbo-Eze South had the highest (2.43×10^{-4} m^2 s^{-1}) with a mean value of 3.06 $\times 10^{-4}$ m^2 s^{-1} Thermal properties of Slovak mixed flower honey(0.1242 - 0.1167 mm^2 s^{-1}) and forest honey (0.1261 – 0.1166 mm^2 s^{-1}) showed comparable results with honey samples from Enugu North senatorial zone. However, Božiková et al. (2018) had earlier reported mean value of $0.094 \times 10^{-6}\ m^2 s^{-1}$ for Slovakian honey samples. Thermal heat diffusivity of honey samples from Igbo-Eze South, Igbo-Etiti and Nsukka were not significant ($p \geq 0.05$). Similarly, Igbo-Eze North and Udenu were not significant. However, Thermal heat diffusivity for Udenu and Igbo-Eze South were significant ($p \leq 0.05$).

3.3 Statistical data analysis

Analysis of variance (ANOVA) for the different physicochemical and thermal properties of honey samples from different floral locations in Enugu North senatorial zone is clearly summarized in Table 6. All the honey parameters were significant except for SHC and F/G Table 7 presents the summarized standard deviation, variance, skewedness and kurtosis of physicochemical and thermal properties of honey. Pearson correlation of the physicochemical and thermal properties of honey from different floral location of Enugu North senatorial locations is as well presented (Table 8).

Table 6 Summary of analysis of variance (ANOVA) on the physicochemical and thermal properties of honey

Parameter	F	Sig	Remark
VIS 25	22.855	.000	Significant difference at 95% confidence level
VIS 60	15.369	.000	Significant difference at 95% confidence level
ECO	64.310	.000	Significant difference at 95% confidence level
F	7.871	.000	Significant difference at 95% confidence level
SUC	49.028	.000	Significant difference at 95% confidence level
ACI	25.418	.000	Significant difference at 95% confidence level
MC	50.726	.000	Significant difference at 95% confidence level
DEN	55947.761	.000	Significant difference at 95% confidence level
G	16.043	.000	Significant difference at 95% confidence level
pH	49.208	.000	Significant difference at 95% confidence level
COL	14.712	.000	Significant difference at 95% confidence level
F+G	16.683	.000	Significant difference at 95% confidence level
*F/G	0.622	.649	No significant difference at 95% confidence level
THC	2.728	.41	Significant difference at 95% confidence level
*SHC	0.573	.683	No significant difference at 95% confidence level
THD	4.985	.002	Significant difference at 95% confidence level

Note: VIS, Viscosity; ECO, Electrical conductivity; F, Fructose; SUC, Sucrose; ACI, Free acidity; ACO, Ash content; MC, Moisture content; DEN, Density; G, Glucose; pH, Acidity-Alkalinity level; COL, Colour; F+G, Sum of Fructose and Glucose; F/G, Ratio of Fructose to Glucose; THC, Thermal heat conductivity; SHC, Specific heat capacity; THD, Thermal heat diffusivity.

From Table 7, fifty percent of data on the physicochemical properties investigated was skewed to the left of the mean. Data of the ECO, SUC, DEN, G, F/G all were symmetrical. The F, ACO, pH, COL and F+G were moderately symmetrical. Only data of the ACI, ACO and MC were highly skewed. Data of 66.67% of the thermal properties investigated were skewed to the left of the mean. Data of THC and SHC were symmetrical with THC skewed to the left of the mean while the distribution of THD data was moderately skewed to the left. The data of VIS, ECO, F, SUC, ACO, DEN, pH and THC were light tailed, flat peaked than normal distribution with same mean and standard deviation and no outlier (platykurtic). The ACI, MC, G, COL, F+G and F/G as well as SHC and THD had data distribution that were heavy tailed than the normal distribution.

Table 7 Standard deviation, variance, skewedness and kurtosis of physicochemical and thermal properties of honey from different floral location of Enugu North senatorial zones

Properties	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness	Kurtosis
VIS25	10.32	20.16	15.58	2.63	6.91	-0.28	-1.00
VIS60	8.56	16.01	12.63	1.67	2.80	-0.42	-0.49
ECO	209.50	233.00	220.81	6.32	39.97	-0.23	-1.12
F	29.48	42.43	35.25	3.02	9.14	0.59	-0.06
SUC	1.02	1.99	1.47	0.28	0.08	-0.08	-0.81
ACI	0.28	0.90	0.44	0.16	0.03	1.31	0.93
ACO	0.05	0.60	0.27	0.18	0.03	0.69	-0.90
MC	13.59	24.54	20.52	2.45	6.01	-1.05	0.65
DEN	816.00	1254.00	1062.00	164.94	27205.47	-0.11	-1.41
G	26.62	36.22	31.93	2.23	4.97	0.29	0.11
pH	4.10	5.80	5.01	0.41	0.17	0.57	-0.30
COL	0.85	3.00	1.56	0.54	0.29	0.76	1.13
F + G	57.76	78.66	67.18	4.68	21.86	0.58	0.12
F/G	0.84	1.31	1.11	0.08	0.01	-0.14	2.11
THC	0.42	0.47	0.44	0.01	0.00	-0.39	-0.07
SHC	0.30	2.64	1.47	0.51	0.26	0.01	1.60
THD	0.00	0.00	0.00	0.00	0.00	-0.93	0.53

Note: VIS, Viscosity; ECO, Electrical conductivity; F, Fructose; SUC, Sucrose; ACI, Free acidity; ACO, Ash content; MC, Moisture content; DEN, Density; G, Glucose; pH, Acidity-Alkalinity level; COL, Colour; F+G, Sum of Fructose and Glucose; F/G, Ratio of Fructose to Glucose; THC, Thermal heat conductivity; SHC, Specific heat capacity; THD, Thermal heat diffusivity.

Table 8 Pearson correlation of physicochemical and thermal properties of honey from different floral location of Enugu Nrth senatorial locations

	VIS @ 25°C	VIS @ 60°C	ECO	F	SUC	ACI	ACO	MC	DEN	G	pH	COL	F+G	F/G	THC	SHC	THD
VIS @ 25°C	1.000																
VIS @ 60°C	0.182	1.000															
ECO	-0.026	-0.383	1.000														
F	0.261	0.337	0.165	1.000													
SUC	0.405	0.335	-0.657	-0.066	1.000												
ACI	0.415	-0.338	0.413	0.023	0.101	1.000											
ACO	-0.659	-0.546	0.070	-0.467	-0.420	-0.222	1.000										
MC	0.283	-0.222	-0.332	-0.360	0.484	0.384	0.179	1.000									
DEN	0.124	-0.310	-0.323	-0.457	0.518	0.425	0.177	0.810	1.000								
G	0.208	0.263	0.250	0.576	-0.116	-0.040	-0.519	-0.490	-0.538	1.000							
Ph	-0.594	-0.400	0.202	-0.308	-0.613	-0.294	0.784	-0.054	-0.200	-0.277	1.000						
COL	0.464	-0.018	0.418	0.149	-0.205	0.379	-0.393	-0.065	-0.193	0.230	-0.113	1.000					
F+G	0.268	0.343	0.226	0.921	-0.098	-0.005	-0.549	-0.466	-0.552	0.849	-0.331	0.206	1.000				
F/G	0.109	0.166	-0.073	0.614	0.047	0.050	-0.054	0.044	-0.021	-0.288	-0.099	-0.049	0.259	1.000			
THC	0.239	0.058	-0.171	0.319	0.201	0.026	-0.117	0.129	0.144	0.086	-0.245	-0.248	0.247	0.283	1.000		
SHC	0.124	-0.065	0.156	0.255	-0.045	0.174	-0.096	-0.118	-0.071	-0.077	-0.062	0.013	0.128	0.367	0.096	1.000	
THD	-0.370	-0.111	0.016	-0.030	-0.449	-0.452	0.424	-0.136	-0.300	0.155	0.510	-0.066	0.054	-0.189	-0.005	-0.240	1.000

Note: VIS, Viscosity; ECO, Electrical conductivity; F, Fructose; SUC, Sucrose; ACI, Free acidity; ACO, Ash content; MC, Moisture content; DEN, Density; G, Glucose; pH, Acidity-Alkalinity level; COL, Colour; F+G, Sum of Fructose and Glucose; F/G, Ratio of Fructose to Glucose; THC, Thermal heat conductivity; SHC, Specific heat capacity; THD, Thermal heat diffusivity.

From Table 8, the specific heat capacity of the honey investigated had a low positive correlation on F/G ratio ($p \leq 0.05$). Thermal heat capacity had positive influence on fructose value. Thermal heat diffusivity had a moderate negative relationship on the viscosity at 25°C, sucrose value and density; and positively correlated on the ash content and pH. About 71.43% of the physicochemical properties investigated had positive correlation ($p \leq 0.05$) on the thermal heat conductivity, against 28.59% of negative correlation ($p \leq 0.05$) on the same thermal property investigated. Specific heat capacity had negative relationship on viscosity at 60°C, sucrose, ash content, moisture content, density, glucose and colour of the honey. About 54.29% of the physicochemical properties investigated were negatively correlated ($p \leq 0.05$) on the thermal heat conductivity as against 35.71% positive correlation ($p \leq 0.05$) on the same parameter. Sucrose value had strong negative correlation ($p \leq 0.05$) on the electrochemical conductivity. Ash content was strongly negatively related on viscosity at 25°C and 60°C. Density had strong positive correlation on sucrose and moisture content. The pH of honey was positively correlated ($p \leq 0.05$) on sucrose and ash content. F+G was strongly correlated on F and G Just as F/G was strongly positively correlated ($p \leq 0.05$) on F. Similar correlation analysis had been conducted for textural and physicochemical parameters of honeys from Romanian Oroian et al. (2016).

4 Conclusion

The honey samples analysis displayed physicochemical and thermal properties influenced by floral location. Samples from Nsukka North Senatorial zone have criteria to be classified as good quality honey, except in terms of moisture, in which only two samples from Udenu and Igbo-Etiti Local Government Areas, were in accordance with the Codex Alimentarius standard, while other three samples did not meet with the standard. All other physico-chemical parameter analyzed for honey from all floral locations within Enugu senatorial zone were all in accordance with the international standard. The thermal properties also met the quality standard of most honey reported in the literature. The observed results could be used for processing, product development and storage of honey and honey-based products, as well as quality assurance.

Acknowledgement

Authors are greatly thankful to the Department of Food Science and Technology and the Department of Agricultural and Bioresources Engineering, University of Nigeria, Nsukka for providing facilities and laboratory equipment for the research.

References

Adebiyi, F. M., I. Akpan, E. I. Obiajunwa, and H. B. Olaniyi. 2004. Chemical/Physical characterization of Nigerian honey. *Pakistan Journal of Nutrition*, 3(5): 278-281.

Aghamirlou, H. M., M. Khadem, A. Rahmani, M. Sadeghian, A. H. Mahvi, A. Akbarzadeh, and S. Nazmara. 2015. Heavy metals determination in honey samples using inductively coupled plasma-optical emission spectrometry. *Journal of Environmental Health Science and Engineering*, 13(1): 39.

Alqarni, A. S., A. A. Owayss, and A. A. Mahmoud. 2016. Physicochemical characteristics, total phenols and pigments of national and international honeys in Saudi Arabia. *Arabian Journal of Chemistry*, 9(1): 114–120.

AOAC. 2000. *Official Method of Analysis of Association of Analytical Chemists*. **19th ed.** Washinghten DC., USA: Association of Official Analytical Chemists.

AOAC. 2012. *Official Method of Analysis of Association of Analytical Chemists*. **19th ed.** Washinghten DC., USA: Association of Official Analytical Chemists.

ASHRAE. 2006. *Thermal Properties of Foods: TC 10.9, Refrigeration Application for Foods and Beverages. Ashraehandbook—Refrigeration (Si)*. Atlanta, GA.

Babarinde, G. O., S. A. Babarinde, D. O. Adegbola, and S. I. Ajayeoba. 2011. Effects of harvesting methods on physicochemical and microbial qualities of honey. *Journal of Food Science and Technology*, 48(5): 628–634.

Badolato, M., G. Carullo, E. Cione, F. Aiello, and M. C. Caroleo. 2017. From the hive: Honey, a novel weapon against cancer. *European Journal of Medicinal Chemistry*, 142: 290–299.

Baroni, M. V., C. Arrua, M. L. Nores, P. Fayé, M. del Pilar Díaz, G. A. Chiabrando, and D. A. Wunderlin. 2009. Composition of honey from Córdoba (Argentina): Assessment of North/South provenance by chemometrics. *Food Chemistry*, 114(2): 727-733.

Belay, A., G. D. Haki, M. Birringer, H. Borck, A. Addi, K. Baye, and S. Melaku. 2017. Rheology and botanical origin of Ethiopian monofloral honey. *LWT - Food Science and Technology*, 75(4): 393-401.

Bergamo, G., S. K. T. Seraglio, L. V. Gonzaga, R. Fett, and A. C. O. Costa. 2018. Physicochemical characteristics of bracatinga honeydew honey and blossom honey produced in the state of Santa Catarina: An approach to honey differentiation. *Food Research International*, 116: 745-754.

Bilandzic, N., I. T. Gajger, M. Kosanovic, B. Calopek, M. Sedak, B.

S. Kolanovic, I. Varenina, D. B. Luburic, I. Varga, and M. Đokic. 2017. Essential and toxic element concentrations in monofloral honeys from southern Croatia. *Food Chemistry*, 234: 245-253.

Bobis, O., A. R. Moise, I. Ballesteros, E. S. Reyes, S. S. Duran, J. Sanchez-Sanchez, S. Cruz-Quintana, F. Giampieri, M. Battino, and J. M. Alvarez-Suarez. 2020. Eucalyptus honey: Quality parameters, chemical composition and healthpromoting Properties. *Food Chemistry*, 325, 126870.

Boussaid, A., M. Chouaibi, L. Rezig, R. Hellal, F. Donsı, G. Ferrari, and S. Hamdi. 2018. Physicochemical and bioactive properties of six honey samples from various floral originsfrom Tunisia. *Arabian Journal of Chemistry*, 11(2): 265–274.

Božiková, M., and P. Hlavác. 2013. Comparison of thermal and rheologic properties of Slovak mixed flower honey and forest honey. *Research in Agricultural Engineering*, *59*(Special Issue): S1–S8.

Božiková, M., P. Hlavá, V. Vozárová, Z. Hlavácová, L. Kubík, P. Kotoulek, and J. Brindza. 2018. Thermal properties of selected bee products. *Progress in Agricultural Engineering Sciences,* 14(S1): 37–44.

Can, Z., O. Yildiz, H. Sahin, E. A. Turumtay, S. Silici, and S. Kolayli. 2015. An investigation of Turkish honeys: Their physico-chemical properties, antioxidant capacities and phenolic profiles. *Food Chemistry*, 180: 133–141.

Codex Alimentarius Commission. 2001. *Revised Standards for Honey. Codex Standard 12-1981*. Rome: FAO.

Dos Santos, J. S., N. S. dos Santos, M. N. P. dos Santos, S. N. dos Santos, and J. J. J. Lacerda. 2008. Honey classification from semi-arid, Atlantic and Transitional Forest zones in Bahia, Brazil. *Journal of the Brazilian Chemical Society*, 19(3): 502-508.

El Sohaimy, S. A., S. H. D. Masry, and M. G. Shehata. 2015. Physicochemical characteristics of honey from different origins. *Annal of Agricultural Science*, 60(2): 279-287.

Escriche, I., F. Tanleque-Alberto, M. Visquert, and M. Oroian. 2017. Physicochemical and rheological characterization of honey from Mozambique. *LWT-Food Science and Technology,* 86(4): 108-115.

European Commission. 2002. *European Commission Council Directive 2001/110/EC of 20 December 2001 Relating to Honey*. Brussels: Official Journal of European Communities.

Gomes, S., L. Dias, L. Moreira, P. Rodrigues, L. M. Estevinho. 2010. Physicochemical, microbiological and antimicrobial properties of commercial honeys from Portugal. *Food and Chemical Toxicology,* 48(2):544-548.

Guo, P., Q. Deng, and Q. Lu. 2019. Anti-alcoholic effects of honeys from different floral origins and their correlation with honey chemical compositions. *Food Chemistry*, 286: 608-615.

Hooper, F. C., and F. R. Lepper. 1950. Thermal heat flow apparatus for determination of thermal conductivities. American Society *of* Heating*, Refrigerating,* and *Air-Conditioning* Engineers *(ASHRAE)*, 56: 309 – 322.

Humphrey, J. A. C., and E. S. Dykes. 2008. Thermal energy conduction in a honey bee comb due to cell-heating bees. *Journal of Theoretical Biology*, 250(1): 194–208.

IHC (International Honey Commission). 2009. Harmonised Methods of the International Honey Commission. Available at: http://www.ihc-platform.net/ihcmethods2009. pdf. Accessed 10 May 2016.

Jaafar, K., J. Haidar, S. Kuraydiyyah, T. Ghaddar, K. Knio, B. Ismail, and I. Toufeili. 2017. Physicochemical, melissopalynological and antioxidant properties of artisanal honeys from Lebanon. *Journal of Food Science and Technology*, 54(8): 2296–2305.

James, O. O., M. A. Mesubi, L. A. Usman, S. O. Yeye, K. O. Ajanaku, K. O. Ogunniran, O. O. Ajani, and T. O. Siyanbola. 2009. Physical characterization of some honey samples from North-central Nigeria. *International Journal of Physical Sciences*, 4(9): 464-470.

Jandric, Z., S. A. Haughey, R. D. Frew, K. McComb, P. Galvin-King, C. T. Elliott, and A. Cannavan. 2015. Discrimination of honey of different floral origins by a combination of various chemical parameters. *Food Chemistry*, 189: 52–59.

Kadzierska-Matysek, M., M. Florek, A. Wolanciuk, P. Skałecki, and A. Litwińczuk. 2016. Characterisation of viscosity, colour, 5-hydroxymethylfurfural content and diastase activity in raw rape honey (Brassica napus) at different temperatures. *Journal of Food Science and Technology*, 53(4): 2092–2098.

Khaled, A. 2007. Mineral contents and physicochemical properties of natural honey produced in Al-Qassim region, Saudi Arabia. *Journal of Food, Agriculture and Environment*, 5(3&4): 142-146.

La Serna Ramos, I., B. Me´ndezPe´rez, and C. Go´mezFerreras. 1999. *Aplicacio´N De Nuevastecnologı´Asenmielescanarias Para Sutipificacio´N Y Control De Calidad*. Tenerife: Servicio de Publicaciones de la Caja General de Ahorros de Canarias,

Maxwell, J.C. 1970. Theory of Heat. Westport, Conn.: Greenwood Press

Mehryar, L., M. Esmaiili, and A. Hassanzadeh. 2013. Evaluation of some physicochemical and rheological properties of iranian honeys and the effect of temperature on its viscosity. *American-Eurasian Journal of Agriculture and Environmental Sciences,* 13(6): 807-819.

Mudasar, M., V. Mathivanan, G. H. Nabishah, G. M. Mir, and Selvisabhanayakam. 2013. Physico-chemical analysis of honey of *apis ceranaindica* and *apis mellifera* from different regions of Anantnag district, Jammu and Kashmir.

International Journal of Pharmacy and Pharmaceutical Sciences, 5(3): 635-638.

Nayik, G. A., B. N. Dar, and V. Nanda. 2018. Rheological behavior of high altitude Indian honeyvarieties as affected by temperature. *Journal of the Saudi Society of Agricultural Sciences*, 17(3): 323–329.

Nayik, G. A., Y. Suhag, I. Majid, and V. Nanda. 2016. Discrimination of high altitude Indian honey by chemometric approach according to their antioxidant properties and macro minerals. *Journal of the Saudi Society of Agricultural Sciences*, 17(2): 200-207.

Nigussie, K., P. A. Subramanian, and G. Mebrahtu. 2012. Physicochemical analysis of Tigray honey: An attempt to determine major quality markers of honey. *Bulletin of the Chemical Society of Ethiopia*, 26(1): 127-133.

Olugbemi, O., C. H. Ikeme, and I. J. Dioha. 2013. Physicochemical analysis of honey from Umuahia, Abia state, Nigeria. *Research Journal in Engineering and Applied Sciences*, 2(3): 199-202.

Oroian, M., S. Paduret, S. Amariei, and G. Gutt. 2016. Chemical composition and temperature influence on honey texture properties. *Journal of Food Science and Technology*, 53(1): 431–440.

Oroian, M., S. Ropciuc, and S. Paduret. 2018. Honey authentication using rheological and physicochemical properties. *Journal of Food Science and Technology*, 55(12): 4711–4718.

Ramaswamy, R., V. M. Balasubramaniam, and S. K. Sastry. 2007. Thermal conductivity of selected liquid foods at elevated pressures up to 700 MPa. *Journal of Food Engineering* 83(3): 444–451.

Samborska, K., A. Wiktor, A. Jedli´nska, A. Matwijczuk, W. Jamr´oz, K. Skwarczy´nska-Maj, D. Kiełczewsk, M. Tułodziecki, L. Bła˙zowski, and D. Witrowa-Rajchert. 2019. Development and characterization of physical properties of honey-rich powder. *Food and Bioproducts Processing*, 115: 78-86.

Saxena, S., S. Gautam, and A. Sharma. 2010. Physical, biochemical and antioxidant properties of some Indian honeys. *Food Chemistry*, 118: 391–397.

Silva, L. R., A. Sousa, and M. Taveira. 2017. Characterization of Portuguese honey from Castelo Branco region. according to their pollen spectrum, physicochemical characteristics and mineral contents. *Journal of Food Science and Technology*, 54(8): 2551–2561.

Singh, I., and S. Singh. 2018. Honey moisture reduction and its quality. *Journal of Food Science and Technology*, 55(10): 3861–3871.

Sobrino-Gregorio, L., M. Vargas, A. Chiralt, and I. Escriche. 2017. Thermal properties of honey as affected by the addition of sugar syrup. *Journal of Food Engineering*, 213: 69-75.

Tappi, S., L. Laghi, A. Dettori, L. Piana, L. Ragni, and P. Rocculi. 2019. Investigation of water state during induced crystallization of honey. *Food Chemistry*, 294: 260–266.

Vázquez-Quiñones, C. R., R. Moreno-Terrazas, I. Natividad-Bonifacio, E. I. Quiñones-Ramírez, and C. Vázquez-Salinas. 2017. Microbiological assessment of honey in México. *Revista Argentina De Microbiologia*, 50(1):75-80.

White, J. W., and W. D. Landis. 1980. *Honey Composition and Properties.* **1st ed.** *Beekeeping in the US agriculture, USA.*

Wikipedia. 2016. Wikipedia Org/Wiki/Thermal_Diffusivity. Available at: https://en.wikipedia.org/wiki/Thermal_ diffusivity. Accessed on 22 February, 2016.

Wu, L., B. Du, Y. V. Heyden, L. Chen, L. Zhao, M. Wang, and X. Xue. 2017. Recent advancements in detecting sugar-based adulterants in Honey-A challenge. *Trends in Analytical Chemistry,* 86: 25-38.

Zarei, M., A. Fazlara, and N. Tulabifard. 2019. Effect of thermal treatment on physicochemical and antioxidant properties of honey. *Heliyon*, 5(6): e01894.