Mineral composition of New Zealand monofloral honeys

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Abstract

The objective of this study was to determine the mineral content in ten New Zealand monofloral honeys, in order to distinguish whether New Zealand monofloral honeys are a good source of minerals compared to honeys from other parts of the world. The ten monofloral honeys were collected from a local honey factory (Airborne Honey Ltd, Leeston), Clover, Honeydew, Kamahi, Manuka, Nodding Thistle, Rata, Rewarewa, Tawari, Thyme and Vipers Bugloss honeys were been investigated. The water content, water activity, pH, conductivity, colour and mineral content were evaluated. The water activity was averaged for all the ten New Zealand monofloral honeys and set to 0.59 a_w, which indicates a high stability and long shelf life as a food stuff. A strong correlation between total mineral content, pH, conductivity and colour was obtained. Higher mineral content gives a higher pH, lower conductivity and a darker colour of the honeys. Alltogether 18 different minerals were found in the New Zealand monofloral honeys, Al, As, B, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Zn. The most abundant minerals were potassium, phosphorus and calcium with the values ranging between 34.8 - 3637.6, 29.5 - 255.3 and 7.21 - 94.31 mg/kg respectively. The amount of lead found in New Zealand monofloral honeys was low ranging between 0.01-0.04 mg/kg.

Keywords: Monofloral honey, mineral content, pH, conductivity, colour, water activity

Sammanfattning

Syftet med den här studien var att undersöka mineralinnehållet i tio sorthonungar från Nya Zeeland och där igenom urskilja om sorthonung från Nya Zeeland är en god källa av mineraler som är nödvändiga för det dagliga intaget. Tio sorthonungar hämtades från en lokal honungs fabrik (Airborne Honey Ltd, Leeston, Nya Zeeland), Klöver, Honeydew, Kamahi, Manuka, Nodding Thistle, Rata, Rewarewa, Tawari, Timjan och Vipers Bugloss har undersökts. Vattenhalten, vattenaktiviteten, pH, konduktiviteten, färg och mineralinnehållet har utvärderats. Medelvärdet för vattenaktiviteten uppmättes till 0.588 a_w, vilket indikerar hög stabilitet och ger en lång hållbarhet som livsmedel. Ett starkt samband mellan totala mineralhalten, pH, konduktivitet och färgen på honungen påvisades. Ju högre mineralhalt desto mörkare färg och högre pH och konduktivitet. Sammanlagt detekterades 18 olika mineraler i Nya Zeeländsk sorthonung, Al, As, B, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Zn. De högst förekommande mineralerna var kalium, fosfor och calcium med värden som varierade mellan 34.75 - 3637.57, 29.5 - 255.3 och 7.21 - 94.31 mg/kg för respektive av mineralerna. Halten av bly var förhållandevis låg med värden som varierade mellan 0.01-0.04 mg/kg.

Nyckelord: Sorthonung, mineralinnehåll, pH, konduktivitet, färg, vattenaktivitet

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Introduction

Background

Honey is naturally produced by honeybees (*Apis mellifera*) collecting nectar from flowers and turning it in to a product known to be a healthier choice of sweetener than sugar (Crane, 1975). The popularity for honey has increased in recent years due to health claims and is considered as a desirable ingredient in a range of different foodstuffs.

New Zealand is world leading in producing honeys of the monofloral variety and the fact can partly be explained by New Zealand being an island. The native flora found here are not be found anywhere else in the world, which has created a wide range of honey types and honey flavours which only can be produced from the nectar of native New Zealander flowers. Monofloral honey is distinguished from poly floral honey types by there characteristic smell and taste, depending on what sort of main flower nectar the bees have collected. The honeys can also differ in e.g. colour and mineral contents (Tan *et al.,* 1988).

To distinguish the quality of the honey a wide range of parameters are used such as colour, sugar content, pH, water activity and mineral analysis (Conti, 2000). The mineral content in honey is dependent on the nutrients found in the nectar, which is dependant on the plants absorption of the minerals from the soil and environment (González-Miret *et al*., 2005).
An example of this is that environmental contamination with heavy metals has been shown to be detectable in honeys (Przybylowski & Wilczynska 2001).
So far no mineral analysis has been conducted on New Zealand monofloral honeys thus it would be highly interesting to look in the possibility comparing the mineral contents with honeys from other parts of the world.

Aim

The aim of this study is to perform mineral analysis on New Zealand monofloral honeys in order to compare the mineral content of these honey types with honeys from the rest of the world. No research has been preformed on the source of the mineral content of New Zealand monofloral honey. Further research investigating the native New Zealand flowers in the sheltered environment, having an effect on the mineral content of honey should be considered.

Literature study

Honey is considered to be the only sweetener used by humans which has not been processed in any industrial way. Due to this knowledge an increasing interest of honey as a more natural alternative for sweetener than sugar has increased the world consumption of honey in resent years (Üren *et al.,* 1997; Al-Khalifa *et al.,* 1999; Conti, 2000). Higher demand raises a request to distinguish the mineral content in honey in order to see if honey can be a good source of certain minerals required in our daily diet. It has been indicated that honey can be used as an environmental marker which makes it even more interesting to compare the mineral content of honeys produced in different areas of the world (Pryzybylowski *et al.,* 2001).

Characterisation of honeys

Honey is produced by honeybees using blossoms and nectar from flowers and plants, the bees also produces honeydew which is a type of honey produced from plant fluids which have been secreted by insects (*Hemiptera*) and the secretion is then collected by the honeybees. Honeydew is produced in a much smaller amount than the floral honeys (Crane, 1975).
It is well known that honey produced from different flowers and pollens develop a product with significant differences in colour, taste, viscosity and other physical characteristics. To be able to separate the different honey types from each other and to be able to distinguish what plant source the honey is made out from, a wide range of methods is being used. The most common one is pollen identification and total pollen count. The pollen count can differ widely especially if the nectar is collected from flowers low in pollen. This means for example that the main flower source only may represent 20 % of the total pollen count (Senanayake, 2006).

Depending on the access to flowers, mono or polyfloral honeys are produced, the limit for being able to call a honey monofloral are complex and many factors have to be considered. The colour, conductivity, pollen identification and taste together give the possibility to distinguish what botanical origin the main nectar has. Also pH, sugar composition, mineral content and hydroxymetylfurfural (HMF) is measured in order to distinguish the quality and origin of the honey (Anklam, 1998; Senanayake, 2006).

Composition of honey

Honey is a complex food stuff and the composition of honey is highly dependant on several factors such as the botanical origin of the floral source, the geographic location and seasonal climate variations of the environment where the nectar has been collected. Honey consists mainly of the monosaccharide’s fructose and glucose (table 1), the mineral content is about 0.04%-0.2% depending if it is a light or a dark honey type. The amount of vitamins in honey is extremely low and it is almost impossible to measure and to get a reliable result (Anklam, 1998).

Table 1. Average composition of New Zealand honeys and ranges of values as percentage of honey.

Component	Average	Range
Moisture	17.5	16.2 – 19.1
Fructose	40.0	38.4 – 42.0
Glucose	36.2	32.4 – 40.2
Sucrose	2.8	1.5 – 4.8
Ash	0.18	0.04 – 0.39
Nitrogen	0.040	0.023 – 0.077

Modified after Crane, (1975).

Mineral composition

The mineral composition has been studied in honeys from a wide range of countries from many different botanical origins, in order to survey the mineral contents and how it is affected by the environment and floral sources. In order to determine the mineral content different methods have been used. Two main different methods have been reported in order to investigate the mineral content, atomic absorption spectroscopy and emission spectroscopy (Rodriguez-Otero *et al.,* 1993; Üren *et al.,* 1997; Al-Khalifa & Al-Arify 1999; Fernández-Torres *et al.,* 2005).

The total mineral content in honey has the range of 0.04% - 0.2% depending whether the honey is light or dark coloured, the darker the honey the higher mineral content (Anklam, 1998). In monofloral honey from Spain eleven minerals were detected, B, Ba, Ca, Cu, K, Mg, Mn, Na, P, Sr, and Zn from honey from four different botanical origins. Where K, Ca and P showed the highest values with 1935-4.34 mg/kg, 341-42.59 mg/kg and 154.3-51.17 mg/kg for the phosphors (Fernández-Torres *et al.,* 2004). In a study on honey from the Czech Republic eight minerals were detected including; Al, Ca, Cu, Mg, Mn, Ni, S and Zn in order to find a relationship between mineral content and botanical origin. They found that the honey origins from Czech Republic had a higher value of Ni compared with honeys from other parts of the world. This has also been found in honey from both Poland and Slovakia where they have reported the same high values of Ni in the honeys that originate from their countries (Golob *et al.,* 2004; Lachman *et al.,* 2006; Madejczyk & Baralkiewicz, 2008).
Twenty seven different minerals have been detected in honeys from nine different countries though none of the honeys investigated contained all of these twenty minerals. Studies conducted on mineral content in honeys is in most cases focused on a group of minerals rather than the total content, or range which makes it complex to compare the minerals in different honey types with different geographical origins. Golob *et al.,* (2004) reported sixteen different minerals from Slovenian honeys which can be compared to twelve minerals found in Polish honeys or twenty four minerals found in Spanish honeys (Terrab *et al.,* 2004; Madejczyk & Baralkiewicz, 2008). Eleven of the minerals (As, Ba, Cd, Co, Cr, Mo, Ni, Pb, Se, Sr ,V) found in the Spanish honeys are to be considered as trace minerals.

New Zealand's source of unique flora

As New Zealand is an island, it has an environment found nowhere else in the world, has created a unique flora with many flowers only found growing in New Zealand. Examples of these are Manuka, Kamahi, Rata, Rewarewa and Tawari. These native plant species as botanical source has given monofloral honeys with uniquely different characteristics compared to honeys produced in other parts of the world (Stephens, 2006). Tan *et al.,* (1988) showed that honeys which origins from native New Zealand flowers had higher amounts of organic compounds compared to monofloral honeys origins from European flowers. No recent studies have documented the mineral profile of honey sourced from native New Zealand flora.

Material and Methods

Sampling of honey

Ten monofloral honeys were collected from Airborne Honey Ltd, Leeston, New Zealand during 2007. The thyme honey from 2007 was not properly labelled and therefore a thyme honey was collected from the production in 2009. The batch number and package size is presented in Table 2, all batch numbers can be used to identify the origin and production date of the honey using the Airborne Honey Ltd batch number scheme. The honey was stored in the dark at 4ºC prior the mineral analysis.

Table 2. Monofloral honeys used for mineral analysis.

Honey	Batch number	Package size (g)
Clover	070612	250
Honeydew	064731	250
Kamahi	053032	500
Manuka	064251	250
Nodding Thistle	061323	500
Rata	060751	500
Rewarewa	064131	250
Tawari	074821	500
Thyme	091342	500
Vipers Bugloss	080531	250

pH measurement

The honey samples were heated in a water-bath at 25ºC and stirred until completely homogenous. Two pH measurements were performed, one on the homogenous honey sample and one on a 4X dilution of the homogenous honey.

Five grams of honey was accurately weighed into a beaker and 20 ml of DI water was added. The exact amount of honey for each dilution was calculated from each of the individual honeys moisture content, as determined by refractometry. The samples were stirred using a magnetic stirrer and the exact temperature was documented. The pH meter (SevenEasy™, Mettler Toledo Switzerland) was calibrated with pH standards 4.01±0.02 and 7.01±0.02 (BDH, UK) prior to each measurement.

The homogenous undiluted honey samples were measured directly using a Inlab®427 spear tip pH probe (Mettler Toledo, Switzerland). The 4X diluted honey samples were measured using a standard pH probe (Eutech Instruments, Thermo Fisher Scientific, Waltham, USA). All samples were measured in triplicate and the average pH value was calculated.

Mineral analysis

All equipment used for mineral analysis was thoroughly cleaned with 10% HCl (AnalaR®, BDH, UK) and dried before any procedures begun. The 100 ml Teflon® microwave digestion vessels were also soaked in Decon 90® (Decon Laboratories Ltd, England) solution, following the manufactures instructions, prior to being cleaned with 10% HCl.

One gram of honey was accurately weighed into a 100 ml Teflon® microwave digestion vessel, in triplicate. Into the microwave digestion vessel 2 ml of hydrogen peroxide (30%, AnalaR®, BDH, UK) and 5 ml of nitric acid (69%, Aristar®, BDH, UK) was added and left over night to digest. Using an ICP multi-element standard solution (CertiPUR®, Merck, Germany) containing 23 different elements Ag, Al, B, Ba, Bi, Ca, Cd, Co, Cr, Cu, Fe, Ga, In, K, Li, Mg, Mn, Na, Ni, Pb, Sr, Tl and Zn, a 20ppm multi-element standard was prepared in 1M nitric acid (Aristar®, BDH, UK). This was used as the standard blank and for recovery determination, as outlined in Table 3.

Table 3. Mineral analysis sample, blanks and standards solvent additions.

	Honey	HNO_3	H_2O_2	Multi-element standard	DDI water
Honey	1 g	5 ml	2 ml	--	--
Honey + Spike	1 g	5 ml	2 ml	1 ml	--
Acid blank	--	5 ml	2 ml	--	--
Water blank	--	5 ml	2 ml	--	1 ml
Standard blank	--	5 ml	2 ml	1 ml	--

The samples were then digested in a microwave oven digester (Milestone Ethos Sel, Sorisole, Italy) according to the program in Table 4. After digestion the samples were quantitatively transferred to a 25 ml volumetric flask and made up to volume with DDI water (18.2 megaohms). The mineral analysis was preformed using a Varian Axial ICP-OES (Palo Alto, USA) with a SP3 autosampler. All samples were run twice, with and without an ultrasonic nebuliser (Cetac 5000 UT, Nebraska, USA) attached prior to the autosampler.

Table 4. Microwave digestion operating conditions

Step	Temperature ºC		Run time (min)	
	Start	Finish	Start	Finish
1	Ambient	100	0	5
2	100	140	5	10
3	140	140	10	15

A recovery experiment was performed by spiking thyme honey with 20 ppm of the ICP multi-element standard mixture (CertiPUR®, Merck, Germany), as outlined in Table 3. The recovery result for the ICP multi-element standard solution in thyme honey ranged from 92.2-123.4%, across all the minerals determined.

Moisture content
The moisture content of each honey was measured using two different methods, AOAC method 925.10 (AOAC, 2002) and by using a honey refractometer, (ATAGO HHR-2N, Japan). Briefly, ten grams of honey was accurately weighed into a glass beaker and dried overnight in an oven set at 105ºC ± 0.5 The samples were then placed in a desiccator, until they were at room temperature, prior to final weighing. All samples were carried out in triplicate and the moisture content expressed as a percentage.

Water activity
The water activity (a_w) was measured using an AquaLab model CX-2 (Decagon Devices Inc., Pullman, USA) at room temperature. The water activity meter was calibrated using a 0.760 ± 0.003 a_w NaCl salt standard and 0.500 ± l0.003 a_w LiCl salt standard (Formula Foods, Christchurch, New Zealand). The reading reliability was checked by measuring DDI water which had a reading of 1.003 a_w at 20^{o}C. The honey samples were held in room temperature and 5g was accurately weighed into a plastic sample cup (Figure 1). This cup was then fitted into the machine and the readings were documented.

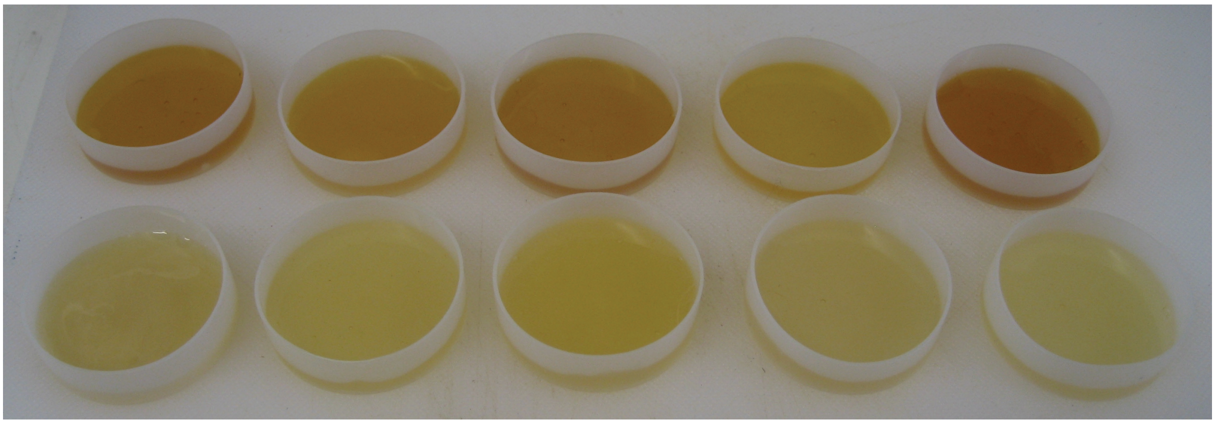

Figure 1. *Top row from the left;* Honeydew, Thyme, Rewarewa, Kamahi, Manuka. *Bottom row;* Rata, Tawari, Clover, Vipers Bugloss, Nodding Thistle.

Colour
The honey colour was measured using a Pfund colour grader (Koehler Instrument Co. Inc., Germany). The Pfund colour grader is commonly used in the honey industry and the colour intensity is measured in mm along an amber coloured glass wedge. The scale runs from 0 (colourless) to 140 (black).
Honey samples were heated to 50^{o}C, then centrifugated at 3,500 rpm for 5 minutes. Six readings of each honey sample were taken, three from each side of the glass wedge and are averaged in order to minimize the source of error.

Conductivity

The conductivity was measured using a Riac CM 100/E conductivity meter with an YSI 3418 electrode (YSI, Yellow Springs, USA). The conductivity meter was calibrated in 20°C using Oakton® conductivity calibration standard solutions. The honey was diluted with DI water 4X using the same method as in the pH measurement. This ensured the conductivity measurement was performed on equal amounts of dry matter from each honey. All measurements were performed in triplicate.

Results

Moisture content

The dry matter was measured with two different methods, using a honey refractometer and the standard AOAC method 925.10 (AOAC, 2002). In table 5 it can be seen that the moisture content varies between the different measurements and is not consequent for highest and lowest amount comparing the different honeys.

The honey with the highest moisture content, as determined by the AOAC was the nodding thistle (20.6%), however the result using the honey refractometer is 17.6%, the third highest value. It needs to take in to consideration that the AOAC method were done in triplicate and the measurement using the refractometer only represent one reading, which gives a less reliable result.

Table 5. The moisture content of monofloral honeys using two different methods.

	Percent moisture (±SE)	
Honey	AOAC	Refractometer*
Clover	17.5 (0.12)	17.9
Honeydew	17.9 (0.11)	15.7
Kamahi	16.8 (0.08)	17.0
Manuka	18.7 (0.21)	17.8
Nodding Thistle	20.6 (0.61)	17.6
Rata	18.0 (0.20)	18.0
Rewarewa	16.5 (0.06)	16.5
Tawari	18.8 (0.13)	18.0
Thyme	18.3 (0.14)	17.0
Vipers Bugloss	19.0 (1.34)	16.4

* = only one reading

Water activity (a_w), pH and conductivity

The water activity was measured on two replicates of each honey type and every sample was measured twice. The values have then been averaged for each honey type and the total averages for all honeys have been calculated. The water activity across the ten honeys ranged between 0.56-0.61 a_w where Rewarewa recorded the lowest value, 0.564 a_w ± 0.004 and Rata the highest, 0.613 a_w ± 0.007 (Table 6).

The pH was measured both on solid honey and honey diluted 4X with water. The pH ranged between 3.46 and 4.96 (Table 6). Vipers Bugloss had the lowest value 3.46 ± 0.20 and honeydew the highest, 4.96 ± 0.05. The conductivity ranged between 0.83 – 5.95 mS/cm with Vipers Bugloss and Honeydew having the highest and lowest values, 5.95 ± 0.08 and 0.833 ± 0.06 respectively (Table 6).

Table 6. The water activity, pH and conductivity of monofloral honey (values are parameters of the standard error of the mean value).

Honey	Water activity (a_w)	pH (solid honey)	pH (honey+H_2O)	Conductivity (mS/cm)
Clover	0.577 (0.002)	3.61 (0.03)	3.67 (0.02)	3.85 (0.13)
Honeydew	0.587 (0.005)	4.96 (0.05)	5.04 (0.01)	0.83 (0.06)
Kamahi	0.575 (0.014)	4.72 (0.18)	4.78 (0.04)	1.48 (0.12)
Manuka	0.598 (0.011)	4.21 (0.03)	4.21 (0.02)	1.65 (0.06)
Nodding Thistle	0.588 (0.006)	3.63 (0.16)	3.69 (0.01)	4.74 (0.004)
Rata	0.613 (0.007)	3.82 (0.04)	3.99 (0.01)	1.67 (0.08)
Rewarewa	0.564 (0.005)	4.16 (0.04)	4.27 (0.01)	1.79 (0.07)
Tawari	0.600 (0.006)	4.54 (0.10)	4.57 (0.02)	2.18 (0.09)
Thyme	0.575 (0.004)	3.98 (0.22)	3.96 (0.01)	3.27 (0.14)
Vipers Bugloss	0.608 (0.003)	3.46 (0.20)	3.57 (0.01)	5.95 (0.08)
Mean	0.588	4.11	4.17	2.74

Minerals and Colour

The mean mineral content for 18 different minerals detected in the ten monofloral honeys can be seen in Table 8. Some minerals were not detected (n.d. in Table 8) in some honeys and are presumed to not be present and some minerals are represented in very small amounts. Minerals reported with levels below 1-2 mg/kg are considered to be less reliable, with a relatively high source of error due to the small amount.

The pH and conductivity is dependant on the amount of ions in the honey, which is correlated to the overall total mineral content. Due to this correlation a comparison between total mineral content, pH, conductivity and colour is presented in Table 7. Figure 2 represents the total mineral content as a function of the pH, conductivity and colour.

The total mineral content was calculated by adding all detected mineral amounts for each honey type. The total mineral content is positively correlated to the pH (0.776) and negatively correlated to the conductivity (0.972). The total mineral content show a weak positive correlation to Pfund colour measurement (0.319).

Table 7. Honeys presented in order of total mineral content in comparison with the pH, conductivity and colour.

Honey	Total mineral content (mg/kg)	pH -	Conductivity (mS/cm)	Colour (mm)
Honeydew	4,055.84	5.04 (0.01)	0.83 (0.06)	88
Kamahi	1,926.83	4.78 (0.04)	1.48 (0.12)	48
Rewarewa	1,541.73	4.27 (0.01)	1.79 (0.07)	85
Manuka	1,474.00	4.21 (0.02)	1.65 (0.06)	100
Rata	1,135.29	3.99 (0.01)	1.67 (0.08)	25
Tawari	1,050.84	4.57 (0.02)	2.18 (0.09)	37
Thyme	470.29	3.96 (0.01)	3.27 (0.14)	80
Clover	415.51	3.67 (0.02)	3.85 (0.13)	32
Nodding Thistle	310.86	3.69 (0.01)	4.74 (0.004)	16
Vipers Bugloss	126.05	3.57 (0.01)	5.95 (0.08)	25

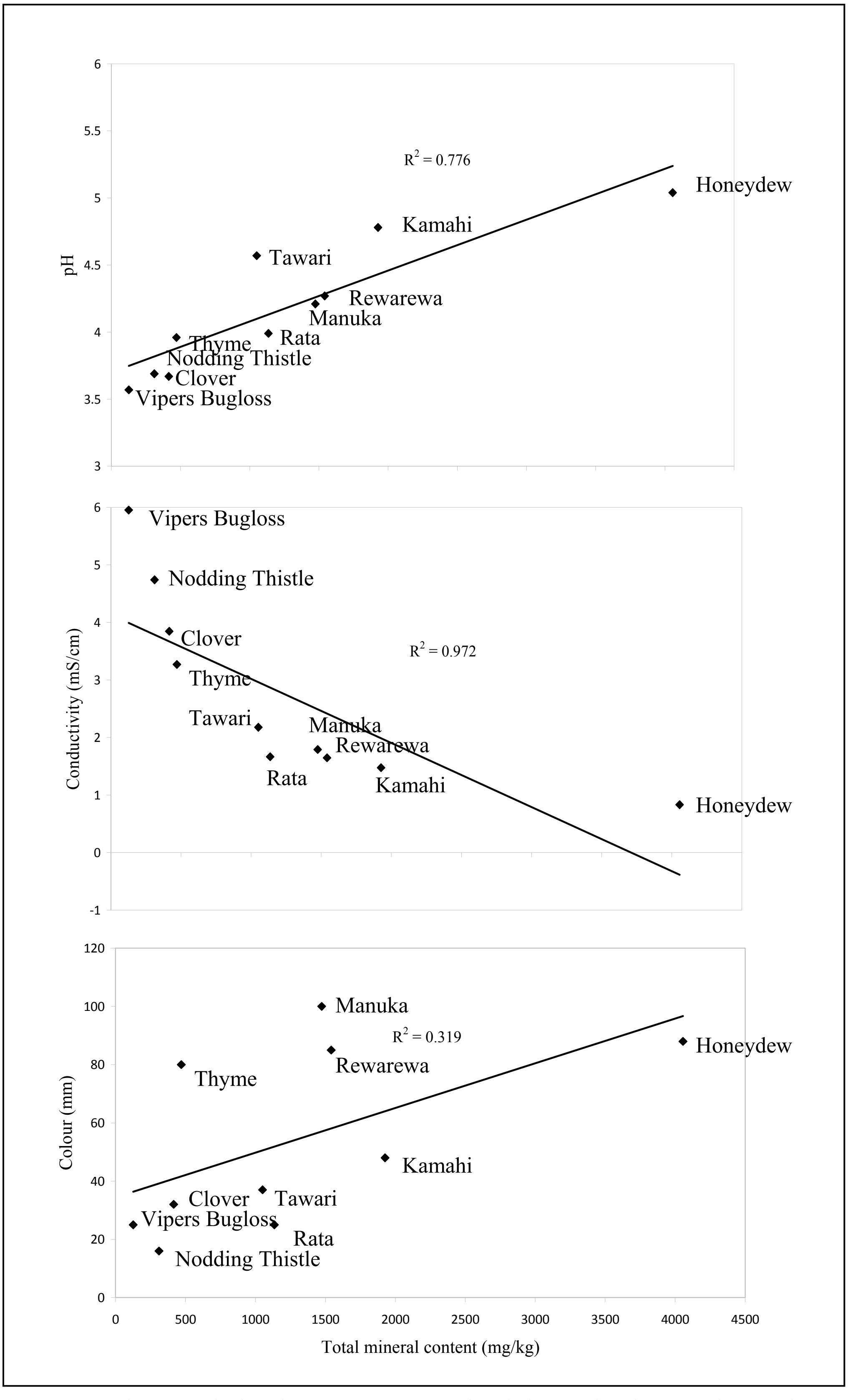

Figure 2. The correlation between pH, conductivity and colour to the total mineral content of ten New Zealand monofloral honeys.

Table 8. Mineral analysis of monofloral honey (mg/kg, fresh weight, (±SE)).

Mineral	**Clover**	**Honeydew**	**Kamai**	**Manuka**	**Nodding Thistle**	**Rata**	**Rewarewa**	**Tawari**	**Thyme**	**Vipers Bugloss**	**Mean [range]**
Al	0.21 (0.11)	5.42 (0.00)	2.65 (0.30)	1.22 (0.25)	n.d.	n.d.	21.32 (1.11)	0.68 (0.23)	0.90 (0.1)	n.d.	6.6 [0.21-21.32]
As	0.04 (0.01)	0.07 *	0.17 *	0.08 *	0.11 *	0.12 *	0.04 *	0.05 *	n.d.	0.04 (0.01)	0.08 [0.04-0.17]
B	6.66 (0.20)	2.25 (0.49)	5.23 (0.19)	4.94 (0.05)	6.08 (0.38)	3.40 (0.42)	3.72 (0.09)	3.63 (0.19)	n.d.	3.92 (0.16)	4.42 [2.25-6.66]
Ca	69.20 *	7.21 (0.84)	40.94 (7.00)	40.52 (1.48)	20.55 (3.45)	81.97 (1.77)	54.29 (2.17)	94.31 *	39.00 (0.63)	60.77 (21.70)	50.92 [7.21-94.31]
Cd	0.27 *	0.01 *	n.d.	0.01 *	0.45 *	0.05 *	0.07 *	0.05 *	n.d.	0.28 *	0.149 [0.28-0.01]
Cr	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.43 *	0.12 *	n.d.	0.55 *	0.37 [0.12-0.55]
Cu	0.22 (0.03)	0.18 (0.02)	0.22 (0.01)	0.35 (0.03)	0.13 (0.01)	0.18 (0.03)	0.70 (0.01)	0.14 (0.02)	n.d.	0.09 (0.001)	0.25 [0.70-0.09]
Fe	1.59 (0.32)	3.39 (1.62)	1.00 (0.10)	1.86 (0.21)	1.90 (0.01)	0.94 (0.002)	2.71 (0.87)	0.67 (0.42)	1.33 (0.086)	1.67 (1.17)	1.706 [0.67-3.39]
K	225.63 *	3,637.57 (13.36)	1,772.31 (60.47)	1,284.70 (57.68)	200.07 (17.01)	796.37 (25.64)	1,287.39 (13.80)	957.72 (76.14)	335.49 (25.11)	34.75 *	1053.2 [34.75-3637.57]
Mg	13.30 (0.83)	86.33 (5.11)	18.11 (0.83)	27.87 (0.25)	9.41 (0.22)	21.66 (0.40)	40.15 (0.61)	13.15 (0.71)	9.96 (0.082)	7.52 (0.18)	24.75 [7.52-86.33]
Mn	0.46 (0.01)	0.43 (0.01)	1.07 (0.04)	2.15 (0.04)	0.18 *	0.44 (0.04)	4.75 (0.27)	0.74 (0.01)	0.18 (0.03)	0.18 (0.02)	1.04 [0.18-4.75]
Mo	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.01 *	0.01 *	n.d.	n.d.	0.01
Na	17.35 *	8.51 *	17.01 *	7.90 *	10.38 *	109.90 (6.32)	31.13 (1.52)	21.02 (4.02)	14.97 (0.63)	1.10 *	23.93 [109.90-1.10]
Ni	0.43 *	0.65 (0.13)	0.11 *	0.20 (0.06)	0.21 (0.02)	0.05 (0.001)	0.19 *	0.09 *	0.02 (0.004)	0.31 *	0.23 [0.02-0.65]
P	53.63 (0.19)	255.30 (3.52)	40.26 (0.19)	74.31 (0.55)	43.83 (0.35)	29.50 (0.37)	46.31 (0.18)	34.94 (1.07)	46.13 (0.16)	36.17 (0.07)	46.04 [29.5-255.3]
Pb	n.d.	n.d.	n.d.	0.04 *	0.01 *	n.d.	0.01 *	n.d.	0.003 (0.0028)	0.02 *	0.017 [0.01-0.04]
S	24.62 (0.19)	46.06 (0.81)	27.10 (0.01)	27.48 (0.26)	16.50 (0.34)	93.91 (0.36)	51.62 (0.40)	20.46 (0.15)	22.31 (0.53)	13.41 (1.05)	28.347 [13.41-93.91]
Zn	1.90 *	2.46 (0.11)	0,65 *	0.37 (0.07)	1.05 (0.19)	0.20 *	0.61 *	1.90 *	n.d.	1.44 (0.56)	1.18 [0.20-2.46]

* = only one determination, n.d.= not detected

Discussion

Water activity

The average water activity found in the New Zealand monofloral honeys was 0.59 a_w and according to Troller and Christian, (1978) the water activity limit for having any viable microorganisms 0.60 a_w. A value below 0.60 a_w indicates that honey is highly stable and will have a long shelf life. Abramoviĉ *et al.,* (2007) showed that the water activity in Slovenian honeydews and honeys had a slighter bigger difference between lowest value and highest compared to the New Zealand honeys. For the Honeydew the values 0.483-0.591 a_w were reported and for the floral honeys 0.479-0.557 a_w. In thirteen honeys from Spain Sanjuan *et al.,* (1996) reports the water activity to range from 0.570 to 0.622 a_w. In four different honeys from Turkey the water activity ranged from 0.51 to 0.52 a_w (Kayacier & Karaman 2007). This data shows that the water activity in honey is quite stable worldwide and is in most cases below 0.6 a_w which is the limit for mould and any other microorganisms to grow. Honey is thanks to its low water activity stable as food stuff and has a long shelf life.

pH and conductivity

In order to get a reliable and comparable result for the pH and conductivity the honey was diluted, so as each sample had the equivalent amount of dry matter. Acquarone *et al.,* (2006) showed that pH and conductivity depends on the dilution factor of the honeys. The conductivity was measured due to the fact that conductivity is an indirect way of measuring the total mineral content in the honey. This can be explained with that sugars in solutions are poor conductors and any addition of minerals adds up the ability to conduct electricity.
The honeydew showed the highest values and Viper Bugloss honey showed the lowest values for both pH and conductivity. The result for all honeys showed a strong relationship between the pH and conductivity which has been reported by Acquarone *et al.,* (2006). The relationship is due to that both properties are functions of the ion concentration in the honeys. This also correlates with the result where the total mineral content strongly correlates with the pH (R^2 =0.776) and the conductivity (R^2 = 0.972).

Minerals

The total mineral content of the monofloral honeys from New Zealand showed that Honeydew had the highest and Vipers Bugloss had the lowest amount of minerals. With the range between 126.05 – 4055.84 mg/kg for all ten honeys. Honeydew from Slovenia is also reported to having a very high total amount of total mineral content with an average of 3680 mg/kg. (Golob *et al.,* 2005). According to Anklam, (1998) and Fernandes-Torres *et al.,* (2005) darker coloured honeys have a higher total mineral content, which is consistent with the result found in the ten New Zealand honeys. The New Zealand Honeydew had largest amount of total minerals (4,055.84 mg/kg) and the second to darkest colour (88 mm). Vipers Bugloss had the lowest amount of total minerals (126.05 mg/kg) and the second to lightest colour (25 mm). This result indicates that there is a trend that correlates the colour with the total mineral content.

The most abundant minerals found were potassium, phosphorus and calcium with the range between 34.75 – 3,637.57, 29.5 – 255.3 and 7.21 – 94.31 mg/kg respectively. This result correlates to the most abundant minerals found in honeys from the Canary Islands, Spain. Where K, Ca and P were reported as the most abundant occurring minerals, the K had a slighter lower highest value but a higher lowest value with the range between 669-1845 mg/kg compared to the New Zealand monofloral honeys (Fernández-Torres *et al.,* 2005). Potassium has been reported as the most abundant mineral in honeys from Spain, Poland, Slovenia, Portugal and Italy (Conti, 2000; Golob *et al.,* 2005; Terrab *et al.,* 2005; Madejczyk & Baralkiewicz, 2008; Silva *et al.,* 2009). The observation of P and Ca being in the top three most abundant minerals is reported by Conti, 2000; Golob *et al.* 2005; Terrab *et al.* 2005; Madejczyk & Baralkiewicz 2008; Silva *et al.* 2009.

The difference between P and Ca levels compared to K is large. As much as 72% of all the minerals detected were K in Spanish honeys (Fernádez-Torres 2005), which very similar to our results of 73% K in New Zealand honeys.

All together 18 different minerals were detected in ten different New Zealand monofloral honeys. All of the minerals have been detected previously, from a wide range of different types of honey from other parts of the world.

Hernándes *et al.,* (2004) found in Canary Island honey the trace minerals; Li, Rb and Sr which were not found in the New Zealand honeys.

The total content of heavy metals in New Zealand had the mean of 1.18 mg/kg for Zn, 0.149 mg/kg for Cd and 0.017 mg/kg for Pb, these values can be compared to the amount of heavy metals found in Polish honeys with 7 .76 mg/kg for Zn, 0.015 mg/kg for Cd and 0.048 mg/kg for Pb. The amount of Cd is slightly higher in the New Zealand honey but the amount of Zn and Pb is lower, 6.6 times lower for the Zn and 2.8 times lower for Pb compared to the Polish honeys (Przybylowski & Wilczyńska, 2001).

Conclusions

New Zealand monofloral honeys have a water activity below 0.6 a_w which correlates well to values from honeys around the world from different botanical sources. The low water activity makes the New Zealand monofloral honeys a safe food stuff with long self life.

18 minerals were found in ten different New Zealand monofloral honeys. Potassium (K) was the most abundant mineral, making up 73% of the total mineral content, with calcium (Ca) and phosphorus (P) the next most abundant. This pattern correlates well to the total mineral content found in other honeys worldwide.

The total mineral content ranged from 126.05 mg/kg for Viper Bugloss to 4,055.84 mg/kg for Honeydew across the ten monofloral honeys. This compared well to results reported for European type honeys. The total mineral content of Honeydew honey from New Zealand was greater than any other Honeydew honeys reported in the literature.

The amount of heavy metals detected in the New Zealand monofloral honey is very low, which indicates that the New Zealand environment is not contaminated with high amounts of zinc, cadmium or lead. Strong positive and negative correlations between total mineral content, pH, conductivity and colour have been shown for the New Zealand monofloral honeys. This is consistent with research on other types of honey from different botanical sources and geographical locations, worldwide.

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