Highlights:

- South African honey were evaluated using the Agricultural Standards Act as benchmark
- Evaluation of the quality parameters from local and imported honey over 10 years
- Comparing the physico-chemical parameters of honey from different floral origins
- On average 90% local and 92% imported honey is compliant
- Significant differences were found in honey from different floral origin

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Monitoring the quality of honey: South African case study

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ABSTRACT

The popularity of honey as a high-valued commodity is growing and consequently, honey adulteration is on the rise affecting the honey quality. The quality of the honey on the South African market was evaluated using the Agricultural Product Standards Act, 1990 as assessment tool. Various physico-chemical characteristics were tested which indicated compliance of >80% for all honey samples. A canonical variate analysis using 95% confidence regions indicates significant differences between the quality of local and imported honey with total acid, sucrose and ash as the parameters mostly distinguishing between the groups. Honey produced from agricultural crops differed significantly from all other forage types. The parameters that mostly distinguished between forage types were Lund, hydroxy-methyl-furfural and ash content. Even though honey sold on the South

African market is generally in accordance with national and international standards, an overall declining trend in quality was observed and it should be continuously monitored.

Keywords: *Honey, Quality parameters, Adulteration, Floral origin*

1. INTRODUCTION

Honey, as defined in the Codex Alimentarius Standards, is a natural product produced by honey bees from the nectar of flowers that contains no added foreign substances (Codex Alimentarius, 2001). It consists of various sugars (i.e. fructose, glucose, sucrose and maltose), water, trace elements, vitamins, proteins and organic acids. Honey is well known for its medicinal properties and sensory characteristics such as its unique aroma and sweet taste. The latter is due to the predominance of fructose (European Commission, 2002; Dezmirean, Marghitas, & Dezmirean, 2011; Zhou, Taylor, Salouros, & Prasad, 2018). Consumers generally perceive it as a healthier and natural sweetening alternative to table sugar (Kumar A, Ansari, & Walia, 2018).

Honey is an authentic product with a unique chemical fingerprint determined by its production environment, e.g. geographical and botanical origin as well as processing procedures (European Commission, 2002). The rich diversity of plant species in South Africa includes agricultural crops, forestry, natural forage, vegetation units, weeds and suburban plants, which are pollen and nectar sources for bees during honey production (Guelpa, Marini, du Plessis, Slabbert, & Manley, 2017).

Currently, South Africa can only produce 50% of the market demand for honey (2000 tons). To compensate for this shortage, South Africa imports honey from various countries including China, Argentina and Romania (IDC, 2016). South Africa exports limited

amounts of honey mostly to African countries including Namibia (41%), Botswana (26%), Lesotho (10%) and Zimbabwe (9%). South Africa is ranked 57th in the world for honey exports and imports (IDC, 2016). In South Africa, approximately 50% of honey produced originates from *Eucalyptus* spp., followed by citrus, fynbos and sunflower (Masehela, 2017). The physico–chemical composition of honey is determined by various parameters including its sugar content (i.e. fructose, glucose, sucrose and maltose), pH, total acidity, free acid, lactone, moisture, ash, specific rotation, protein and hydroxyl-methyl-furfural (HMF) content (Bogdanov, S; Lullman, C; Martin, P; Von-Der Ohe, W; Russman, H; Vorwohl, G; Persano Oddo, L; Sabatini, A-G; Marcazzan, GL; Piro, R; Flammini, C; Morlot, M; Lheritier, J; Borneck, R; P, Marioleas.; Tsigouri, A; Kerkvliet, J; Ortiz, A; Ivanov, T; D'Arcy, B;, 1999; DAFF, 2000; Codex Alimentarius, 2001). The compilation of specific standards describing the physico-chemical composition of honey is pivotal for the characterization and evaluation of its chemical composition and regulation of possible adulteration (Codex Alimentarius, 2001).

Honey is an easy target for fraud, which entails the addition of adulterants such as sugar syrups, molasses, and natural syrups such as maple syrup to pure honey to increase yield for economic gain (Guelpa et al., 2017). Adulterated honey has been on the increase, particular with sugars such as fructose (40%), glucose (30%), maltose (8%) and sucrose (2%). Another fraudlent practice is the masking of botanical and geographical origin (Olawode, Tandlich, & Cambray, 2018). In a study done by Zhou, et al (2018) examining 100 honey samples from 19 different countries showed that 27% of commercial honey samples tested were of questionable authenticity. Of these adulterated honey, 52% were from Asia, 28% from Europe and 18.4% Australia.. Various adulterated honey complies with a set of quality criteria suitable for consumer usage. It, however, fails as an authentic product as it contains added substances (Paiva, 2013). The continuous monitoring of the

quality of food products on the market is required to ensure the production of authentic products.

Regularly revised qualitative and quantitative tools are necessary in the global and national market to implement an effective food control system. The assessment tool used to evaluate the quality of honey available on the South Africa market is the Agricultural Product Standards (APS) Act 119 of 1990, 2000 (DAFF, 2000). According to the APS Act, all animal and processed products produced locally or imported should be analysed for compositional requirements. The combination of analytical techniques, standards and legislation determines the efficiency of law enforcement to ensure the quality of different products. These legislations are according to international standards such as the International Honey Commission (IHC) and Codex Alimentarius Honey standards (Bogdanov, S; Lullman, C; Martin, P; Von-Der Ohe, W; Russman, H; Vorwohl, G; Persano Oddo, L; Sabatini, A-G; Marcazzan, GL; Piro, R; Flammini, C; Morlot, M; Lheritier, J; Borneck, R; P, Marioleas.; Tsigouri, A; Kerkvliet, J; Ortiz, A; Ivanov, T; D'Arcy, B;, 1999; Codex Alimentarius, 2001).

The purpose of this study was to evaluate and compare the quality of imported and locally produced honey available on the South African market by analysing the data generated by the Department of Agriculture, Forestry and Fisheries (DAFF), in South Africa from 1998 to 2017. Honey is perceived as an easy target for adulteration and an escalation in the adulteration practices is reported worldwide, therefore, it is hypothesised that more than 20% of the honey on the South African market may not comply with the APS Act. Chemical composition can play a role in the authentication of honey, therefore the chemical composition of honey samples from different floral sources e.g. agricultural

crops, forestry, indigenous genera vegetation units and mixed flora on the local market were also compared.

2. MATERIALS AND METHODS

2.1 Sampling

To evaluate the quality of imported and locally produced honey from different regions in the country, as well as imported honey, 857 (local: n=638; imported: n=70 and unknown n=149) honey samples available to consumers on the South African retail market were analysed over a period of 19 years from 1998 to 2017 as part of the monitoring program of the quality of honey by the Department of Agriculture, Forestry and Fisheries (DAFF) in South Africa. Samples were randomly selected by DAFF food inspectors at retail level and sent to the sub-directorate National Analytical Services of DAFF for analyses. Local samples (n=638) originated from all provinces in South Africa namely: KwaZulu-Natal (NTL) (n=103), Northern Cape (NC) (n=6), Eastern Cape (EC) (n=38), Gauteng (GP) (n=258), Free State (FS) (n=19), North West (NW) (n=19), Limpopo (LIM) (n=30), Mpumalanga (MP) (n=44), unknown origin (UNK) (n=149), Western Cape (WC) (n=121) and imported (IMP) (n=70). Imported samples originated from China (n=13), Argentina (n=7), Romania (n=5), India (n=4), Zambia (n=4), Egypt (n=3), Kuwait (n=3), Lesotho (n=2), Singapore (n=1), Australia (n=1), New Zealand (n=1), Zimbabwe (n=1) and from unknown origin (n=25). Towards identifying the different quality groupings of honey locally produced, a subset of 382 honey samples of known floral sources were selected from the original samples. This subset of samples originated from agricultural crops (n=139): avocado, canola, citrus, grape, kidney blossom, litchi, lucerne, macadamia, mango, onion and sunflower; forestry (n=106): eucalyptus; indigenous genera (n=22): acacia, aloe and

wag-'n-bietjie; vegetation units (n=76): field, forest, fynbos, indigenous, mixed flora, wildflower, polyflora; and mixed flora (n=39): polyflora were selected for analyses.

All samples were analysed in duplicate using methods recommended by the Official Methods of Analysis (AOAC), the International Honey Commission (IHC) and the Codex Alimentarius Honey Standards (AOAC, 1995; Bogdanov, S; Lullman, C; Martin, P; Von-Der Ohe, W; Russman, H; Vorwohl, G; Persano Oddo, L; Sabatini, A-G; Marcazzan, GL; Piro, R; Flammini, C; Morlot, M; Lheritier, J; Borneck, R; P, Marioleas.; Tsigouri, A; Kerkvliet, J; Ortiz, A; Ivanov, T; D'Arcy, B;, 1999; Codex Alimentarius, 2001). The physico-chemical parameters tested were sugars (fructose, glucose, sucrose and maltose), reducing sugars (sum of fructose, glucose and maltose), fructose/glucose ratio, pH, total acidity (free acid and lactone), moisture, ash, Lund's precipitate and hydroxy-methyl-furfural (HMF) (DAFF, 2000). Although specific rotation is not defined by either IHC or Codex, it was determined in this study as an additional quality parameter.

Accuracy was verified through the Food Analysis Performance Assessment Scheme (FAPAS) that included both inter- and intralaboratory proficiency schemes (FAPAS, 2019). However, the physico-chemical parameters tested depends on the availability of such tests, hence, only sugars (fructose, glucose and sucrose), pH, free acid, moisture and HMF accuracy were verified through FAPAS. Intra-laboratory tests where the same samples were analysed by different analysts in the same laboratory were used as verification for the rest of the analyses. Validation data is summarised in Table 1. Performance in a FAPAS proficiency test is considered fit-for-purpose when a z-score lies within a range of ±2 (Fera Science Ltd, 2016). Relative standard deviation (RSD) < 5 % were acceptable for intra-laboratory analyses.

Table 1: Summary of proficiency and intra-laboratory testing.

Physico-chemical parameter	**Standards and requirements for compliance**	
	FAPAS	**Intra-laboratory testing**
	Z-score (-2 ≤ z ≤2)	**<5% Relative standard deviation (RSD)**
Sucrose (%)	-0.3 ≤ z ≤ 2.0	
Fructose (%)	-1 ≤ z ≤ 1.7	
Glucose (%)	z ≤ 2.0	
pH-Value	z ≤ 2.0	
Hydroxy-methyl-furfural (mg HMF/kg)	-2.0 ≤ z ≤ 2.0	
Moisture (%)	-0.4 ≤ z ≤ 2.0	
Free acid (meq/kg)	-0.5 ≤ z	
Reducing sugars (%) (Sum of fructose, glucose and maltose)		< 4 %
Ratio of fructose:glucose		< 5 %
Total acid (meq/kg)		< 3%
Lund (cm^3)		< 5 %
Specific rotation (°)		< 3 %
Ash (%)		< 2 %

2.2 Evaluation of the physico-chemical properties

2.2.1 Sugars

All chemicals are of analytical grade (>95%) unless otherwise specified. A High-Performance Liquid Chromatograph (HPLC) Hewlett Packard 1100 equipped with a Refractive Index detector (Chemetrix) thermostated at 30°C was used to analyse the fructose, glucose, sucrose and maltose content. Degassed acetonitrile:water (80:20) mobile phase and a flow rate of 1.50 ml/min was used for separation. A diluted honey solution containing 5 g of honey dissolved in 100 ml distilled water was prepared and filtered with a 0.45 µm polytetrafluoroethylene (PTFE) filter. Thereafter, 5 µl of diluted honey solution was injected onto a Supelcosil LC-NH_2 HPLC column (250 mm length x 4.6 mm diameter, 5 µm particle size). A 1 % (99% purity) sugar standard mix containing fructose, glucose, sucrose and maltose was used as standard bought from Sigma-Aldrich. ChemStation Software was used for identification and quantification of sugars, which were reported as a percentage (%) (Bogdanov, Martin, & Lullman, 1997).

2.2.2 pH and total acidity

The pH was measured with a Eutech CyberScan PCD 6500 pH-meter (Heyns Lab Supplies). An acid-base tritration was used to determine the total acidity of each honey sample. For this analysis, 10 g of honey sample was dissolved in 75 ml carbon dioxide-free, distilled water in a 250 ml beaker using a magnetic stirrer. The pH-meter was calibrated prior to analyses with standard pH-buffers (Heyns Lab Supplies) with a pH of 4, 7 and 10 respectively. The free acid of each honey sample was then determined by a

direct titration of each honey solution with 0.05 N Sodium hydroxide (NaOH) to pH 8.3. This was followed by the addition of 10 ml (excess) 0.05 N NaOH which was immediately titrated back to pH 8.3 with 0.05 N Hydrochloric acid (HCl) to determine the lactone content (lactonic acidity). A blank test was done by titrating 75 ml of carbon dioxide free water with 0.05 N NaOH to a pH 8.3 (AOAC, 1995a). The free acid and lactone content were subsequently used to calculate the total acidity.

Calculations for total acidity were as follows:

Free acid (meq/kg) = (ml NaOH titrated–ml blank) x 50/sample mass (g)

Lactone (meq/kg) = (10–ml HCl titrated) x 50/sample mass (g)

Total acidity (meq/kg) = Free acid+Lactone

2.2.3 Moisture content

The moisture content was determined using Refractive Index (RI) in combination with the Chataway table. An automatic digital refractometer, Atago RX-5000α (Bashumi Instruments & Control Services), calibrated with distilled water was used for the measurement. A drop of honey was placed on the surface of the prism and a refractive index reading was taken at 20°C and converted to a percentage (g/100 g) using the Chataway table (AOAC, 1995b).

2.2.4 Ash content

The ash content was determined by the gravimetric method described by Liberato, Morais, Magalhaes, Magalhaes, Cavalcanti, Silva (2013). Firstly, a platinum crucible was dried, cooled in a desiccator and weighed ±0.001 g (M_2). Thereafter, approximately 5±0.001 g (M_0) of honey was weighed into the platinum crucible and heated on a hotplate in a fume cupboard until carbonised. It was then incinerated overnight in a muffle furnace (Heyns

Lab Supplies) at 600°C to a constant weight. The platinum crucible was subsequently cooled in a desiccator and immediately weighed ±0.001 g (M_1) (Liberato, et al., 2013). The percentage ash was calculated using the following equation:

$$Ash\% = (M_1-M_2)/M_0 \times 100$$

Where: M_0 = nominal weight of honey

M_1 = weight of crucible + ash

M_2 = weight of crucible

2.2.5 Lund's Reaction

Approximately 5 g honey sample was weighed and dissolved in 50 ml water. Thereafter, 20 ml of this solution was transferred to two separate 100 ml crow receivers. This was followed by the addition of 5 ml tannic acid (0.5 %) (Heyns Lab Supplies) to one of the crow receivers. This solution was then diluted with distilled water to a volume of 40 ml. Subsequently, 5 ml of tungstophosphoric acid (2 %) (Heyns Lab Supplies) was added to the second crow receiver, which was also diluted with distilled water and made up to a volume of 40 ml. Both mixtures were then shaken, closed and allowed to stand for 24 hours in a dark cupboard at room temperature. The tungstophosphoric and tannic acid mixtures were respectively used to precipitate nitrogenous compounds and albuminoids (protein content) within the honey samples. If a combined precipitate of more than 0.6 ml formed, the honey was considered to be pure (White, JW, 1957; de Almeida Muradian, et al., 2013; Salazar, de Freitas, da Luz, Bersch, & dos Santos Salazar, 2017).

Lund was calculated as:

Lund (protein precipitate) = Tannic acid precipitate + Tungstophosphoric acid precipitate

2.2.6 Hydroxy-methyl-furfural (HMF)

White's spectrophotometric method as prescribed by the IHC was used to determine the HMF content (White, JW, 1957; International Honey Commission, (IHC), 2009). Approximately 5 g honey was diluted in 25 ml water to which 0.5 ml 15 % Carrez 1 (Potassium Hexacyanoferrate (II)) (Heyns Lab Supplies) and 0.5 ml 30% Carrez 2 (Zinc Acetate) (Heyns Lab Supplies) reagents were added. Water was then added to a final volume of 50 ml in a volumetric flask and mixed. This solution was then filtered through Whatman No 1 filter paper. The first 10 ml of the filtrate was discarded. Aliquots of 5 ml honey solution were then transferred to two test tubes which contained either 5 ml distilled water (honey sample) or 5 ml 0.2 % sodium bisulphite solution ($NaHSO_3$) (reference sample) respectively and mixed well before being transferred to 10 mm quartz cuvettes. The absorbency at 284 nm and 336 nm of both samples were respectively measured within an hour using an Agilent Cary 100 double-beam UV-Visible spectrophotometer (Chemetrix). Each quartz cuvette was filled with a honey solution or the reference solution respectively (International Honey Commission, (IHC), 2009).

The spectrophotometer was calibrated with the reference solution. If the absorbance at 284 nm exceeded 0.6, the samples and blank reference was diluted with water and sodium bisulfite (Heyns Lab Supplies (60.3 %)) 0.2 % in the same proportion respectively. The following equation was used to calculate the HMF in mg/kg:

HMF (mg/kg) = $(Abs_{284}–Abs_{336})$ x 149.7 x 5 x Dilution factor/Weight of honey sample (g)

Where:

Abs_{284} = absorbance at 284 nm

Abs_{336} = absorbance at 336 nm

149.7 = Constant.

2.2.7 Specific Rotation

An automatic digital polarimeter, Atago AP-300 (Bashumi Instruments and Control Services), was used to determine the specific rotation of the respective honey samples. For this analysis, approximately 26 g of honey was dissolved in distilled water to which 5 ml of a clarifying agent (aluminium potassium disulfate [KAl(SO4)2·12H2O] / alumina cream) (Labchem) was added (AOAC, 1995c). This solution was then mixed by stirring it with a glass rod. It was then transferred into a 100 ml volumetric flask, made up to volume with distilled water and filtered through Whatman 2V filter paper into a 200 mm glass tube with a bubble trap. After the instrument was calibrated with distilled water, the tube containing the honey solution was placed into the instrument which took a rotation reading at 20 °C (AOAC, 1995d).

2.2.8 Data analysis

All data regarding the quality of the local and imported honey was summarized in Excel and imported into GenStat (VSN International, 2017) for data evaluation. The data was filtered by removing all extreme outliers to prevent data skewing in the subsequent analyses (Krzanowski, 1988). The filtered dataset was used to perform a canonical variate analysis (CVA) to determine the quality groupings firstly of honey originating from various geographic regions and secondly of local honey produced from various forage types namely agricultural crops, forestry, indigenous genera, vegetation units and mixed flora.

The variates used for the analyses were the nine standard honey quality parameters as determined by the APS act. The logarithms of sucrose, total acid and HMF, as well as the square root of ash were used to stabilize variances and to normalise the data for both data sets.

3. RESULTS AND DISCUSSION

The compliance of the honey samples to the APS Act standards (excluding specific rotation) ranged from 80% to 94% with a mean of 90% and 92% for the local and imported honey samples respectively. Amongst the local samples, the lowest compliance was found in the Northern Cape (NC) (80%) whereas the highest was in Limpopo (LIM), North West (NW) and Free State (FS) (94%). Figure 1 shows the percentage (%) compliance for the local and imported honey samples. The high average compliance rate of the local (90%) and imported (92%) honey samples demonstrates that most of the honey sold on the South African market is in accordance with the APS Act (DAFF, 2000; Codex Alimentarius, 2001).

Compliance of locally produced and imported honey in South Africa according to physico-chemical parameter requirements of the Agricultural Products Standards Act (Act 119 of 1990) is reported in Table 2. [Honey is non-compliant if it does not complies to the prescribed legislation per physico-chemical parameter and confined to the definition of honey as defined in the APS Act (DAFF, 2000). The non-compliance of the various parameters tested could be due to variations in pre- and post-production processes or adulteration (Al-Farsi, et al., 2018; Oroian, Olariu, & Ropciuc, 2018). The local samples

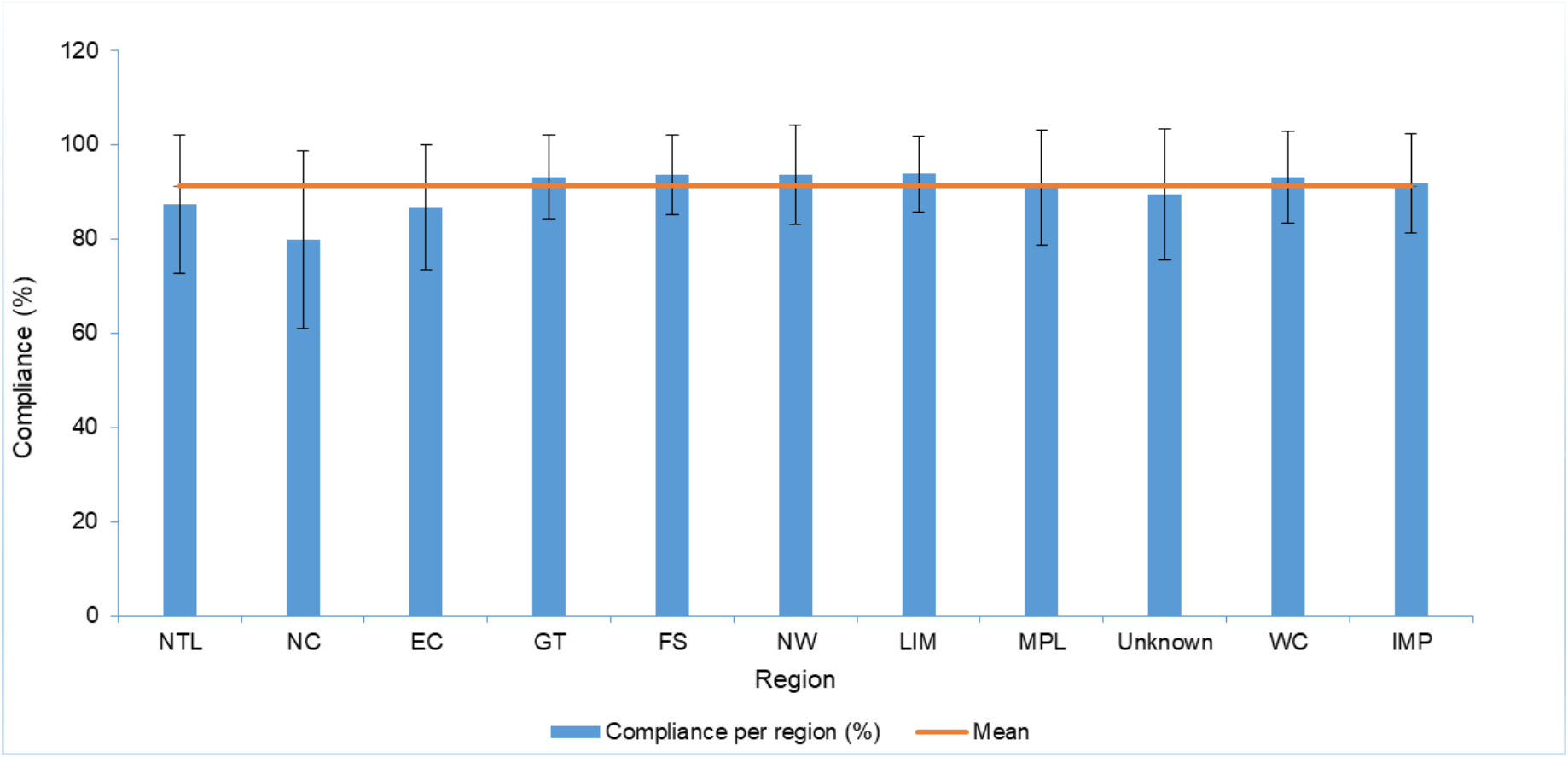

Fig. 1. Compliance of locally produced and imported honey in South Africa for honey samples obtained from 1998 to 2017

had the highest compliance rate for HMF content (97.9%). The imported samples had the highest compliance rate for moisture and ash content (99 %).

Specific rotation is an additional quality parameter the IHC proposes to distinguish between blossom and honeydew honeys and no limits have been set internationally (Bogdanov, S; Lullman, C; Martin, P; Von-Der Ohe, W; Russman, H; Vorwohl, G; Persano Oddo, L; Sabatini, A-G; Marcazzan, GL; Piro, R; Flammini, C; Morlot, M; Lheritier, J; Borneck, R; P, Marioleas.; Tsigouri, A; Kerkvliet, J; Ortiz, A; Ivanov, T; D'Arcy, B;, 1999; DAFF, 2000). Specific rotation of honey is the result of carbohydrates ability to rotate linear polarised light. Negative specific rotation of nectar honeys results from the predominance of fructose, while honeydew honeys have positive values due to the lower content of fructose and higher contents of di- and oligosaccharides that have positive specific rotation. In addition,the differences in honey specific rotation resulting from different carbohydrate profiles can also contribute to nectar honey characterisation. It was found that both the local samples (21 %) and imported samples (30 %) have a low compliance rate to the standards set in the APS act.

In South Africa, honey is produced from an estimated 30 000 diverse plant species (Guelpa et al., 2017). In addition, entomological sources such as European bees and African bees also contribute to variation (da Silva, Gauche, Gonzaga, Costa, & Fett, 2016). Two bee species, namely *Apis mellifera scutellata* and *Apis mellifera capensis* are responsible for honey production in South Africa (Gous, Willows-Munro, Eardley, & Swanevelder, 2017). *A. mellifera scutella* occurs in the northern parts of the western and southern cape region whereas *A. mellifera capensis* is present in the western and southern Cape regions (Masehela, 2017). Adulteration entails directly adding commercial

Table 2: Compliance of physico-chemical parameters of locally produced and imported honey in South Africa according to requirements of the Agricultural Products Standards Act (Act 119 of 1990).

Physico-chemical parameter	Standards and requirements for compliance	Compliance of local honey (%)	Compliance of imported honey (%)
Sucrose (%)	* ≤5	87.3% n=758 Average=2.22 Std Dev=2.95	93.5% n=61 Average=1.27 Std Dev=1.71
Reducing sugars (%) (Sum of fructose, glucose and maltose)	* ≥65 (flowers); * ≥60 (honeydew)	85.7% n=784 Average=71.7 Std Dev=6.96	86.0% n=62 Average=72.0 Std Dev=6.57
Ratio of fructose:glucose	*Shall not be less than 1.0:1	80.4% n=784 Average=1.12 Std Dev=0.156	85.7% n=62 Average=1.16 Std Dev=0.206
Total acid (meq/kg)	* ≤40	96.1% n=729 Average=23.7 Std Dev=9.04	93.7% n=59 Average=24.7 Std Dev=13.26
Moisture (%)	* ≤20	97.3% n=780 Average=16.8 Std Dev=1.72	98.6% n=66 Average=17.1 Std Dev=1.22
Lund (cm^3)	* ≥0.6	92.3% n=767 Average=1.78 Std Dev=0.955	90.4% n=69 Average=2.20 Std Dev=1.34
Hydroxy-methyl-furfural (mg HMF/kg)	* ≤40	97.9% n=746 Average=10.1 Std Dev=12.4	94.0% n=63 Average=15.7 Std Dev=21.4
Specific rotation (°)	* Direct and immediate specific rotation - of an aqueous solution containing 26 g of floral honey in a total volume of 100 ml, shall not be less laevorotatory than -10 degrees at 20 °C.	20.8% n=764 Average=-13.2 Std Dev=6.47	29.9% n=64 Average=-14.2 Std Dev=7.97
Ash (%)	*≤0.6	97.1% n=767 Average=0.228 Std Dev=0.162	98.6% n=65 Average=0.163 Std Dev=0.146

* Agricultural Product Standards Act (APS Act No 119 of 1990)

syrup, cane and other sugars to the honey (Olawode, Tandlich, & Cambray, 2018). It can also be done indirectly by feeding bees with a concentrated sucrose solution within the beehives, which encourages bees to collect pollen instead of nectar (Crane, 1990).

For the comparison in quality of local and imported samples, the first two canonical variates (CV1 and CV2) accounted for 71.9 % of the total variation among groups. A plot of the first two canonical mean scores per region using 95 % confidence indicated that the imported samples (IMP) differed significantly from all other samples and contrasted mostly with the NTL, NC and EC regions (Figure 2). Furthermore, the regions FS and GT were most similar, as were MP, NW, LIM and UNKNOWN (UNK). The scores found for each of the CVs were then correlated with the original parameters to find those that are the most important in discriminating between the groups. The parameters mostly distinguishing between groups were the logarithms of total acid ($r = 0.81$), sucrose ($r = 0.65$), and to a lesser extent the square root of ash ($r = 0.55$) and specific rotation ($r = 0.54$).

The difference in quality between the locally produced and imported honey could be due to the fact that all honey that is imported into South Africa has to be irradiated as specified by the Agricultural Pests Act, 1983 (Act No 36 of 1983) (DAFF, 1983). Irradiation significantly decreases the moisture, vitamin E contents and HMF level (Hussein, Yusoff, Makpol, & Mohd Yusof, 2014).

The variation in the sucrose values, which were 0-32.40 % and 0-8.84 % for the local and imported honey, respectively, is possibly due to the large variety of plants in South Africa. The sucrose level in honey is used to indicate its degree of maturity, botanical origin and is the most common indicator for adulteration (Soares, Amaral, Oliviera & Mafra, 2017). It

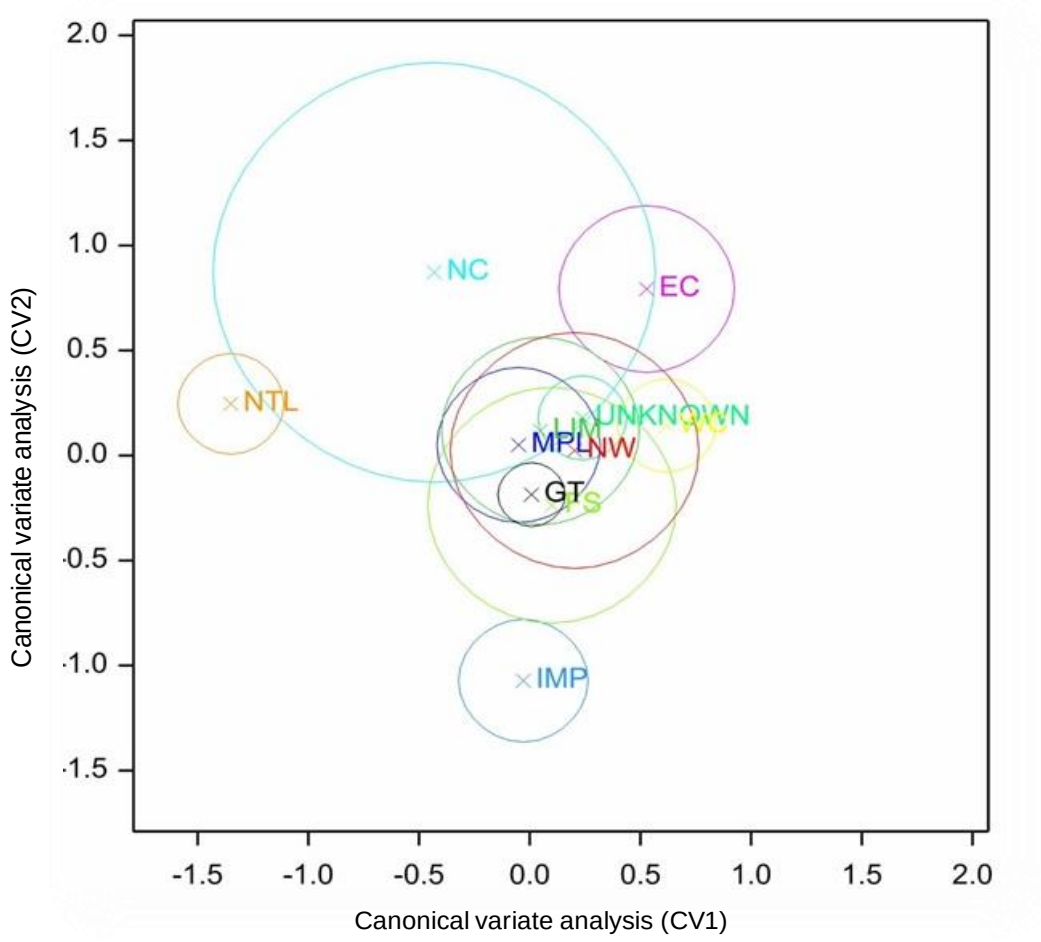

Fig. 2. CVA analyses showing plot of mean scores for 9 physico-chemical parameters.

has been reported that early harvested honey has a higher sucrose content as the invertase has not broken it down to fructose and glucose yet (Chua & Adnan, 2014).

The interrelationship between the individual sugars could possibly explain the high level of variability observed in the F/G ratio, which varied from 0.536 to 2.27 and 0.787 to 1.69 in the local and imported honey, respectively (Olawode, Tandlich, & Cambray, 2018). The F/G ratio is an indication of the maturity of honey as well as honey blends (Salazar, de Freitas, da Luz, Bersch, & dos Santos Salazar, 2017). The lower the F/G ratio, the higher the tendency of the honey to crystallise (Halouzka, Tarkowski, & Cavar Zeljkovic, 2016). The decomposition of sucrose to glucose and fructose influences its invert sugars, F/G ratio and specific rotation indicating an interrelationship between the individual sugars.

The acidity level varied for the local and imported honey between 3.870-88.99 meq/kg and 5.120 to 88.25 meq/kg, respectively. The total acid content of honey, which prevents deterioration, is used to determine whether fermentation of fructose has taken place, which subsequently leads to an increase in HMF (da Silva, Gauche, Gonzaga, Costa, & Fett, 2016). Variation in the acidity level in the sampled honey may be due to variation in harvest season, floral sources, geographical origin, acids produced by bacteria and the minerals present (Silva, Sousa, & Taveira, 2017).

The ash content is used to indicate floral origin and the purity of honey (Salazar, de Freitas, da Luz, Bersch, & dos Santos Salazar, 2017). Factors influencing the ash content include geographic origin, processing practices as well as pollution (da Silva, Gauche, Gonzaga, Costa, & Fett, 2016). These may have contributed to the variability of the ash in local honey (0.228-0.001 %) and in imported honey (0.163-0.002 %) observed amongst the honey samples.

South Africa's rich diversity of plant species provides enough bee forage to produce various types of honey with distinct characteristics (e.g. monofloral and polyfloral) (Guelpa, Marini, du Plessis, Slabbert, & Manley, 2017; Cengiz, Tosun, & Topal, 2018). Since mislabelling of origin is adulteration, it is important to classify and identify the origin of honey in relation to its physico-chemical properties (Chua & Adnan, 2014)). Consequently, the quality groupings of different forage types was determined by a canonical variate analysis (CVA) to determine if any similarities between forage types exists. For the comparison in quality within local samples from different botanical origins, the first two canonical variates (CV1 and CV2) accounted for 92.1% of the total variation among groups.

A plot of the first two canonical mean scores per region using 95 % confidence regions indicated that the agricultural crops differed significantly from all other forage types (Figure 3). Furthermore, mixed flora and vegetation differed significantly from forestry but not from each other. The parameters that mostly distinguished between forage types were Lund (r= +0.64), HMF (r= 0.63) and, as with the previous CVA (Figure 1), ash content (r= -0.86) and to a lesser extent the logarithm of total acid (r= 0.58). Both the Lund and HMF physico-chemical parameters are influenced by the sugar profile and these can be changed by adulteration. In addition, the HMF is also influenced by various factors including the presence of organic acids, pH, moisture content and storage time (White, 1957; da Silva, Gauche, Gonzaga, Costa, & Fett, 2016).

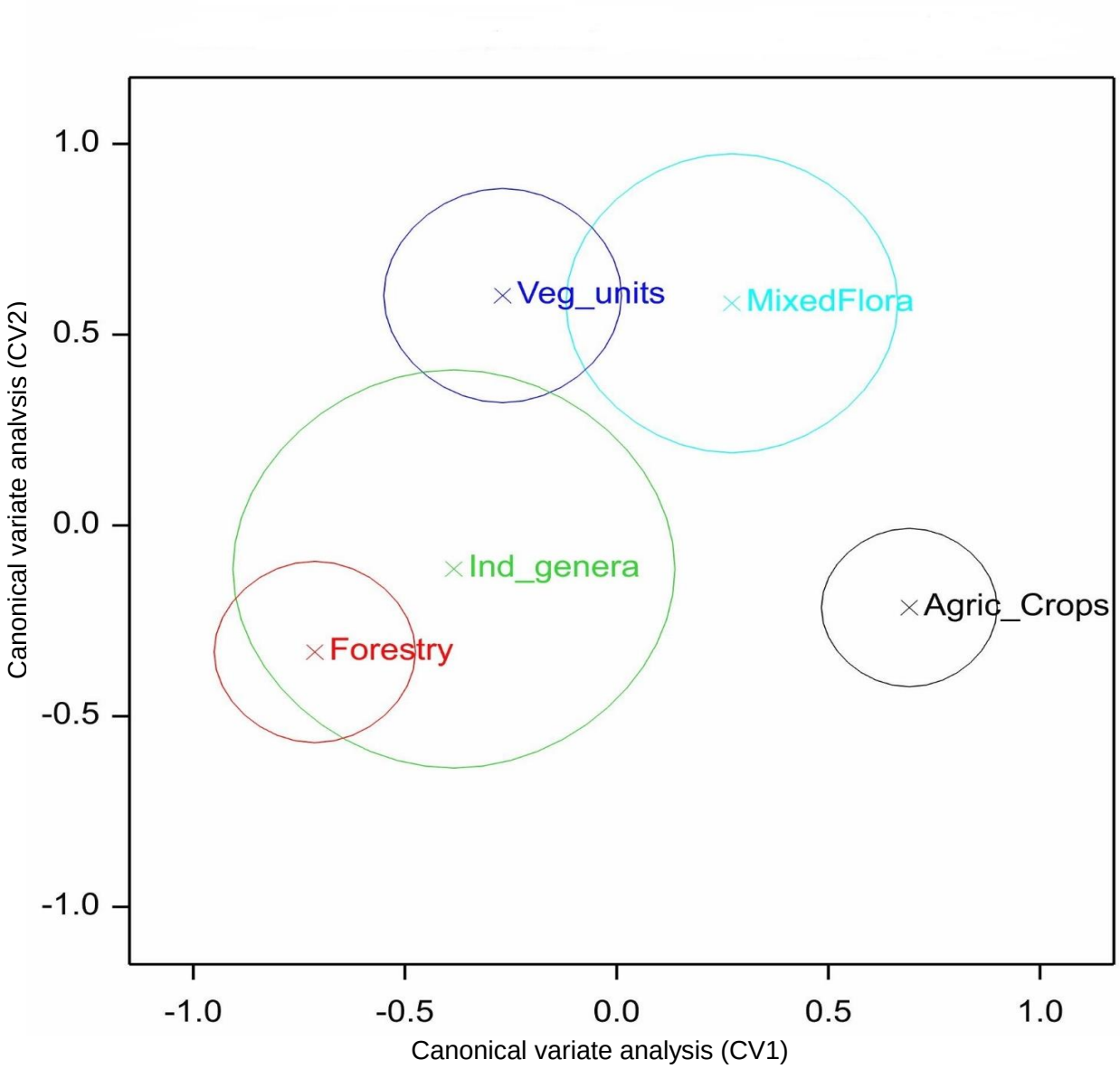

Fig. 3. CVA Analysis showing plot of mean scores for five forage types

Agric_Crops - Agricultural Crops; Ind_genera - Indigenous genera; Veg_units - Vegetation units

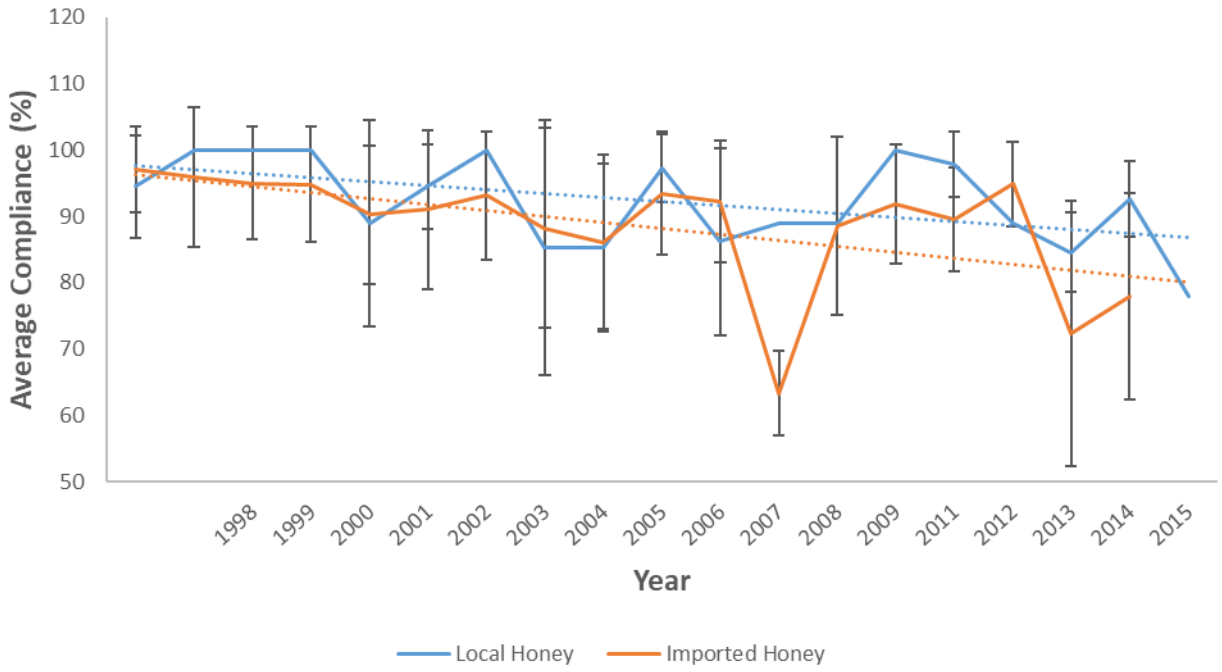

Fig. 4. Quality of locally produced and imported honey in South Africa from 1998 to 2017

The quality of honey is a multifactorial parameter determined various factors including bee-species and the botanical- and geographical production environment (da Silva, Gauche, Gonzaga, Costa, & Fett, 2016; Soares, Amaral, Oliveira, & Mafra, 2017).

Global honey production pressures such as the declining honeybee population may lead to increased incidences of adulteration (da Silva, Gauche, Gonzaga, Costa, & Fett, 2016). Even though most of the honey sold on the South African market is in accordance with regulations specified by the APS Act, a notable decrease in the quality of the South African honey samples was observed between 2008 to 2011 and 2014 to 2017 respectively (Figure 4). Between 2008 - 2009, South Africa experienced a severe drought, which may have influenced honey production. During this period, honey imported from other countries increased and more blended honey was sold on the market.

A limitation to the study is that samples were grouped together according to the address on the label of the containers. Mislabelling of geographical and botanical origin is considered an indirect form of adulteration (Codex Alimentarius, 2001; European Commission, 2002). This type of adulteration is growing worldwide (Soares, Amaral, Oliveira, & Mafra, 2017).

4. CONCLUSIONS AND RECOMMENDATIONS

According to this study, most of the local and imported honey samples analysed complied to the APS Act and is generally of acceptable quality. This is mainly due to the enforcement of the regulatory framework of South Africa, which ensures that honey available on the market is of acceptable quality. Authentication does however, not just

entail the evaluation of the quality of honey products but is also linked to consumer and market demands as it protects the consumer against adulterated, falsely labelled and fake products on the market.

Regulatory frameworks need to be assessed and revised more frequently and implemented more strictly. In addition, the interaction between consumers, producers and legislator's regional norms/quality criteria should be established for different types of honey as this is not specified in the South African legislation. Proper characterization of honey can increase the consumer's awareness of honey on the market. More rigorous methodology to determine quality should be developed and encouraged to ensure the integrity of this sought-after product on the market.

Significant differences in some of the physico-chemical parameters were observed between honey from different floral sources, with honey from agricultural crops accounting the biggest variation. Research on the floral origin and different agricultural crops should be encouraged to investigate the possibility of labelling honey from a specific floral source as a product of origin. This could be an economic incentive for farmers to continually produce a high quality product. An example of this is Manuka honey, New Zealand's most popular honey.

Although DAFF currently only uses standard analytical tests as recommended by the IHC to determine if certain physico-chemical parameters are within set boundaries of the APS Act, new analytical techniques with higher accuracy should be implemented in future. Methods that are increasingly being used internationally include nuclear magnetic resonance (NMR), Infrared, chemometric-intergrated techniques, biosensor and carbon

isotope analyses. The latter can be used to determine from which carbon source plants (C3/4) honey was produced and to verify authenticity.

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6. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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REGION	SUCROSE	MALTOSE	GLUCOSE	FRUCTOSE	INVERT_SUGARS	REDUSING_SUGARS
LIM	2.33	2.10	37.30	39.20	76.50	78.60
GT	5.23	6.78	30.00	38.40	68.40	75.18
GT	2.50	5.20	32.10	39.00	71.10	76.30
LIM	1.45	3.13	36.30	37.30	73.60	76.73
GT	1.69	3.64	35.00	36.70	71.70	75.34
UNKNOWN	9.58	5.41	31.00	38.20	69.20	74.61
GT	1.80	2.25	35.30	37.10	72.40	74.65
MPL	2.55	2.85	36.90	39.00	75.90	78.75
MPL	1.97	4.46	30.70	38.40	69.10	73.56
MPL	2.03	3.96	31.40	39.30	70.70	74.66
UNKNOWN	0.56	7.04	33.00	38.80	71.80	78.84
MPL	0.41	2.01	38.90	41.30	80.20	82.21
UNKNOWN	1.02	1.95	30.40	37.60	68.00	69.95
GT	0.60	2.36	36.00	40.20	76.20	78.56
GT	0.60	2.36	36.00	40.20	76.20	78.56
GT	1.70	7.21	35.40	39.50	74.90	82.11
LIM	0.52	3.14	35.80	38.50	74.30	77.44
GT	0.29	2.01	41.70	40.50	82.20	84.21
WC	2.52	3.10	34.60	40.00	74.60	77.70
WC	4.41	2.56	37.20	43.00	80.20	82.76
WC	3.38	2.79	35.70	41.20	76.90	79.69
UNKNOWN	2.25	2.17	35.60	38.60	74.20	76.37
WC	1.30	3.29	35.90	40.50	76.40	79.69
NTL	4.10	2.67	37.30	37.30	74.60	77.27
GT	0.61	3.49	34.50	38.80	73.30	76.79
GT	5.76	4.25	28.80	34.80	63.60	67.85
GT	0.67	3.30	29.60	34.50	64.10	67.40
UNKNOWN	3.86	4.39	27.90	30.80	58.70	63.09
GT	3.73	3.55	32.30	33.60	65.90	69.45
GT	3.35	3.49	28.10	35.90	64.00	67.49
LIM	3.06	5.95	28.30	33.50	61.80	67.75
EC	5.84	2.49	30.10	36.20	66.30	68.79
EC	6.45	3.99	31.70	35.10	66.80	70.79
WC	7.04	4.02	31.50	34.80	66.30	70.32
WC	3.00	3.42	31.10	35.40	66.50	69.92
WC	1.34	2.28	31.20	39.30	70.50	72.78
GT	6.86	3.98	31.70	32.40	64.10	68.08
UNKNOWN	3.38	6.03	30.10	33.80	63.90	69.93
UNKNOWN	0.00	2.86	28.10	31.90	60.00	62.86
UNKNOWN	1.34	3.32	32.10	34.40	66.50	69.82
UNKNOWN	1.34	2.48	33.90	35.20	69.10	71.58
GT	1.34	3.10	34.70	33.60	68.30	71.40
WC	5.10	3.87	30.30	33.90	64.20	68.07
GT	5.52	3.00	30.60	33.00	63.60	66.60
LIM	2.02	3.86	30.30	35.20	65.50	69.36
WC	0.428	5.69	29.40	35.30	64.70	70.39
UNKNOWN	3.99	2.58	35.70	34.10	69.80	72.38

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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