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Original research article

Beekeeping Practices and Physicochemical Properties of Honey Produced in Maun, Botswana

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Abstract Beekeeping sector plays a major role in rural socio-economic development and environmental conservation. Maun has been identified as one of the excellent potential areas for honeybee production in Botswana because of its suitable agroecological condition for beekeeping. Maun village is located in north-western Botswana and tourism is the main economic activity in the area. It is situated at the gateway for tourists visiting the Okavango Delta and Moremi Game Reserve. The study was conducted to assess beekeeping practices and determine the physicochemical properties of honey produced in Maun village. Honeybee production practices were assessed by conducting questionnaire survey. Three honey samples were obtained each from backyard hives and the forest and analysed for their physicochemical properties following standard procedures. Honey samples collected from backyard hives had an average moisture (%), pH, free acidity (meq/kg), total ash (%), reducing sugars (%), sucrose (%) and Hydroxymethylfurfural (HMF) (mg/kg) contents of 18.03±0.15, 4.12±0.02, 21.6±0.10, 0.14±0.01, 71.27±0.13, 1.63±0.02 and 17.67±0.21, respectively. The corresponding values for honey samples collected from the forest were 17.43±0.21, 6.45±0.17, 13.17±0.06, 0.27±0.02, 60.38±0.16, 0.84±0.04 and 20.63±0.55, respectively. Significant differences ($p<0.05$) were observed between backyard and forest honey samples for all the parameters considered. The pH, total ash and HMF contents of forest honey samples were significantly higher ($p<0.05$) than the corresponding values for backyard honey. On the other hand, the moisture, free acidity, reducing sugars and sucrose contents of backyard honey samples were significantly higher ($p<0.05$) than the corresponding values for forest honey. In Maun area, honey is mainly produced in the backyards of farmers using modern hives although some honey is collected from the forest. The dominant vegetation in the area that are used as bee forage include herbs such as rosemary (*Salvia rosmarinus*), lavender (*Lavendula angustifolia*), fennel (*Foeniculum vulgare*) and peppermint (*Mentha piperita*), strawberry plant (*Fragaria ananassa*), watermelon (*Citrullus lanatus*) and marula tree (*Sclerocarya birrea*). Honey is mostly harvested in December, and it is used for acne and flu remedy, colds, and as a sweetener. The major challenges of beekeeping in the area were reported to be pests such as wax moth, ants and yellow jackets; use of pesticides and harsh weather conditions. In conclusion, honey produced in Maun area is of good quality. Most of the physicochemical parameters of both honey types analysed in the present study were within the limits of international standards for honey.

Keywords Apicultural practices, Maun, Physicochemical properties

INTRODUCTION

Honey is a thick, golden liquid produced by honeybees. It is made using nectars of flowering plants and is saved inside beehives for consumption by bees during times of scarcity. Honey is made of sugars, water, vi-

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tamins, enzymes and minerals (Nguyen *et al*., 2019). Honeybees gather nectar from various flowering plants. Nectar is primarily a mixture of sugars mainly glucose, fructose, and sucrose, and water, but also contains free amino acids, proteins, inorganic ions, and secondary plant compounds (Carnell *et al*., 2020). The naturally occurring ratios of each sugar vary between plant species (Carnell *et al*., 2020). Honey has low moisture content of approximately 17%, which among other factors is responsible for its long shelf life. Low water content and acidic properties gives honey antiseptic qualities which makes it good for health treatments (Norton, 2018).

According to Norton (2018), the physical properties of honey vary, depending on water content, the type of flora used to produce it, temperature, and the proportion of the specific sugars it contains. The amount of water the honey absorbs is dependent on the relative humidity of the air. This hygroscopic nature requires that honey be stored in sealed containers to prevent fermentation. According to Azonwade *et al*. (2018), the average pH of honey is 3.9 but can range from 3.4 to 6.1. Honey contains many kinds of acids, both organic and amino acids. However, the types of acids and their amounts vary considerably, depending on the type of honey (Lemos *et al*., 2018).

The Government of Botswana is implementing beekeeping as a strategy to ensure sustainable livelihoods for the rural communities. The beekeeping sector plays a major role in rural socio-economic development and environmental conservation. Beekeeping is a source of food (honey, pollen, royal jelly and brood), medicinal purposes (honey, propolis, and bee venom), and raw material (beeswax, beeswax candle, cosmetic, and textile lubricants) for various industries and provides good income for the rural population (UNDP, 2005). Despite the attention given by the Government to the sector, beekeeping in Botswana is characterized by low-level technology, limited investment, low productivity, low quality and lack of market initiatives (UNDP, 2005). Moreover, very little research has been conducted to characterize the quality of honey produced in the different parts of the country.

Maun is a village located in north-western part of Botswana at the southern edge of the Okavango Delta with an immense potential for beekeeping. Maun has been identified as one of the excellent potential areas for honeybee production in Botswana (Turner and Makhaya, 2014). The vegetation type in Maun is savannah, with tall grasses, shrubs and woodlands along the Thamalakane River. The average annual precipitation is around 450 mm (Masamba and Mazvimavi, 2008) most of which is received during the summer season from November to March. The soils are most suitable for arable farming and are characterized by a slight clay, a good water holding capacity and moderate nutrient levels (Bekker and Gilika, 1996). Different vegetation units have been identified in Maun area varying in structure from grassland and shrub savanna to savanna and woodland (Bekker and Gilika, 1996). It is generally suggested that the quality of honey varies with the vegetation of an area (Gobessa *et al*., 2012). To date, no research has been conducted on the quality characteristics of honey produced in Maun area.

The results of this study will provide farmers with important information to improve honey production practices and honey quality in the study area. The information generated on quality of honey produced in Maun area will contribute to the development of quality standards for honey produced in the country in the future. Thus, this study was conducted to assess beekeeping practices and physicochemical properties of *Apis mellifera* honey produced in Maun area, Botswana.

MATERIALS AND METHODS

1. Description of the study Area

Botswana is a landlocked country located in southern Africa. The study was conducted in Maun, which is the administrative centre of the North-West District (Ngamiland) of Botswana. Tourism is the main economic activity in the area and Maun is often described as the tourism capital of Botswana. Every year about 50,000−60,000 tourists visit Maun and its thriving tourism destinations (Masamba and Mazvimavi, 2008). It is situated at the gateway for tourists visiting the Okavango Delta and Moremi Game Reserve. Maun town is spread along the wide banks of the Thamalakane River where wild animals and domestic livestock can still be seen grazing side by side on the outskirts of the town. The main commercial and economic activities in the Maun administrative region include tourism, livestock rearing and crop production, especially flood recession farming (Kujinga *et al*., 2014).

Maun is a rapidly growing urban village and it is the fifth-largest town in Botswana. As of 2011, it had a population of 55,784 (Statistics Botswana, 2016). Maximum monthly temperatures range from 22°C to 34°C while the maximum daily temperatures are in the order of 30°C to 32°C (Masamba and Mazvimavi, 2008). Average precipitation in the area is about 450 mm per year (Masamba and Mazvimavi, 2008) but it can be as high as 650 mm in some years (Anderson and Bausch, 2006). Maun is a semi-arid region where grasses, shrubs and small trees dominate the landscape. The major woodland communities in Maun and along the Thamalakane River are: *Vachellia tortilis-Gardenia volkensii*, *Combretum imberbe-Gymnosporia senegalensis*, *Philenoptera violacea-Garcinia livingstonei*, *Dichrostachys cinerea-Flueggea virosa* and *Croton megalobotrys-Colophospermum mopane* (Tsheboeng *et al*., 2020).

2. Survey

A semi-structured survey was conducted in Maun village in January 2020 to determine honeybee production practices, the major tree/shrub species used as bee forage in the area, their flowering season, honey harvest time, method of collection and handling of honey, uses of honey, constraints and opportunities for production of honey in the area. A total of 25 individuals/households were selected purposively based on their experience and involvement in beekeeping and were interviewed with face-to-face interview techniques. Participants gave their informed consent prior to their participation in the study.

3. Sampling technique and sample size

Two types of *Apis mellifera* honey samples were collected from Maun area in Ngamiland District. One of the honey samples was collected from the wild (forest) and the other honey sample was collected from backyard hives of honey farmers in Maun. The honey samples were transported to the Botswana University of Agriculture and Natural Resources (BUAN) and were kept in the refrigerator pending analysis. Analyses of the physicochemical properties of honey were carried out in the Food Science Laboratories at BUAN and the Chemistry Laboratory at the University of Botswana. The backyard honey samples were collected from Borotsi whereas the forest honey samples were collected from Chanoga. A total of six samples (three backyard and three forest) each 100 g were collected from the study areas.

4. Physicochemical properties of honey

Determination of moisture, reducing sugars, sucrose, hydroxymethylfurfural, acidity, pH and ash contents of honey samples were carried out according to the harmonized methods of the International Honey Commission (IHC, 2009) and the revised Codex Standard for Honey (Codex Alimentarius Commission, 1987).

1) Moisture content

The moisture content of honey samples was determined by measuring the refractive index of the sample using Abbe Refractometer using the relationship between refractive index and water content reading at 20°C as described in the harmonized methods of the IHC (IHC, 2009). The method is based on the principle that refractive index of honey increases with solids content. Refractive index of distilled water (1.3330) was used as a reference. The surface of the prism was covered with drops of homogenized honey sample and the prism was closed for four minutes to stabilize. The refractometer was calibrated so that the border line between the white and dark area passes through the cross point of both lines visible in the ocular. The refractive index was adjusted to read at a temperature of 20°C. Measurements were done in triplicate and average value was recorded. The mean refractive index was converted to moisture content using the following formula: moisture content = (−log10 (Corrected Refractive Index − 1) − 0.2681)/0.002243 (Codex Alimentarius Commission, 1987).

2) Reducing sugars

Reducing sugars content was determined by the modified Lane and Eynon (1923) method involving the reduction of Soxhlet modification of Fehling's solutions by titrating at boiling point (60°C) against a solution of reducing sugars in honey using methylene blue as an internal indicator (Pearson, 1971).

An accurately weighed sample of 25 g of honey was transferred from homogenized honey to 100 mL volumetric flask and 5 mL alumina cream was added to the flask. The honey was homogenized by stirring it with glass rode. The sample was diluted with water to the volumetric capacity (100 mL) of the flask at 20°C and was filtered. Ten mL of this solution was diluted to a final volume of 500 mL with distilled water (diluted honey solution).

Five mL of Fehling's solution A was pipetted into 250 mL Erlenmeyer flask and approximately 5 mL Fehling's solution B was added into it and then seven mL of distilled water was added into the mixture followed by addition of 15 mL diluted honey solution from a burette. The mixture was heated to boiling over a wire gauze for 2 minutes. One mL of 0.2% methylene blue solution was added into the mixture whilst still boiling and the titration was completed within a total boiling time of 3 minutes by repeated small additions of diluted honey solution until the indicator was decolorized. The result was calculated and expressed as follows (Pearson, 1971):

$$C = (25/W) \times (1000/Y)$$

Where, C = gram of invert sugar per 100 g honey, W = weight (g) of honey sample used, and Y = volume (mL) of diluted honey solution consumed.

3) Apparent sucrose content

Sucrose content of the honey samples was determined according to the procedures of Pearson (1971). Honey solution was prepared as for the determination of reducing sugars. Fifty mL honey solution was placed in a 100 mL volumetric flask that contained 25 mL distilled water and the mixture was heated to 65°C in a water bath for an hour. The flask was then removed from the water-bath and 10 mL of 6.34 M hydrochloric acid solution was added into it. The solution was allowed to cool for 15 minutes and brought to 20°C and neutralized with 5 M sodium hydroxide solution using litmus paper as indicator, it was then cooled again and the volume was adjusted to 100 mL (diluted honey solution). Titration was done following similar procedure as for the determination of reducing sugars. The apparent sucrose content was calculated by a difference and expressed as follows (Pearson, 1971):

Apparent sucrose content = (invert sugar content after inversion − invert sugar content before inversion) × 0.95. The result was expressed as gram apparent sucrose per 100 g honey.

4) Free acidity

Free acidity of honey samples was determined according to the procedures of Codex Alimentarius Commission (1987). Honey sample (10 g) was dissolved in 75 mL distilled water in a 250 mL beaker and stirred with a magnetic stirrer. The solution was titrated with standardized 0.1 M NaOH to a final pH of 8.50. Then the amount of NaOH solution used for titration was recorded. The result was expressed in milliequivalent (meq) of acid per kg of honey using the following equation (Codex Alimentarius Commission, 1987).

$$\text{Acidity} = 10\,V$$

Where V = the volume of 0.1 M NaOH used and 10 is the amount of honey sample used.

5) pH

Ten grams of honey sample was dissolved in 75 mL of carbon dioxide-free water (distilled water) in 250 mL beaker and stirred with magnetic stirrer. Then the pH was measured with pH-meter, which was calibrated using pH 4.0 and 7.0 buffer solutions (Codex Alimentarius Commission, 1987).

6) Total ash

Ash content of honey samples was determined according to the procedures of Codex Alimentarius Commission (1987). Quartz dish was heated in an electric furnace at 600°C and subsequently cooled in a desiccator to room temperature and the dish was weighed (m_2). Five grams of honey sample was weighed to the nearest 0.001 g (m_0) and added into the dish. Two drops of olive oil were added into the dish to prevent frothing and then the dish was placed in preheated furnace and heated for 1.5 hour at a temperature of 600°C. The dish with the ash was then cooled in a desiccator and weighed. The ashing procedure was continued until constant weight was reached (m_1). Ash (% by mass) was calculated using the following formula:

$$\text{Ash (\% by mass)} = (m_1 - m_2)/M_o \times 100$$

7) Hydroxymethylfurfural

Determination of hydroxymethylfurfural (HMF) content of honey samples was based on the measurement of absorbance of HMF at 284 nm using UV Spectrophotometer. In order to avoid the interference of other components at this wavelength, the difference between the absorbance of a clear aqueous honey solution and the same honey solution after addition of bisulphite solution was determined. The HMF content was calculated after subtraction of the background absorbance at 336 nm (Codex Alimentarius Commission, 1987).

Five grams of honey sample was accurately weighed in a small beaker. The honey sample was dissolved in 25 mL of water and transferred into a 50 mL volumetric flask. Half mL of Carrez solution I was added and mixed. Then half mL of Carrez solution II was added into the 50 mL volumetric flask and mixed and then diluted with distilled water up to the volumetric mark of the flask. A drop of ethanol was added into the mixture to suppress foam. The mixture was filtered through filter paper (general purpose filter paper), rejecting the first 10 mL of the filtrate. Five mL of the solution was pipetted into each of the two test tubes (18 × 150 mm). Then five mL of water was added to one of the test tubes and mixed well (the sample solution) and five mL of sodium bisulphite solution (0.2%) was added to the second test tube and mixed well (the reference solution) using Vortex mixer. The absorbance of the sample solution against the reference solution at 284 and 336 nm, respectively was determined in 10 mm quartz cells within one hour of preparation.

The result was calculated as follows (Codex Alimentarius Commission, 1987):

$$\text{HMF in mg/kg} = (A284 - A336) \times 149.7 \times 5 \times D/W$$

Where: A284 = Absorbance at 284 nm, A336 = Absorbance at 336 nm, 149.7 = Constant, 5 = theoretical nominal sample weight, W = Weight in gram of the honey sample, D = Dilution factor.

5. Statistical analysis

Descriptive statistics was used to present the results of the survey study. Comparison of the physicochemical properties of honey samples was made between honey samples obtained from the forest and honey samples obtained from backyard hives. The data generated was analyzed using a T-test.

RESULTS AND DISCUSSION

1. Overview of beekeeping practices in the study area

The demographic characteristic of the respondents who took part in this study is indicated in Table 1. The study revealed that the age of majority (23 out of 25) of beekeepers was within the range of 20–50 years (Table 1). Kinati *et al.* (2012) and Gebremedhn (2015) reported that the mean age of beekeepers in Ethiopia were 40.5 and 40.1 years, respectively. The age of beekeepers is generally within the active working age. Regarding their experience in beekeeping, the respondents had several years of experience, with a range of 5–28 years of working practice with honeybees. The majority (52%) of the beekeepers in the study area were government employees. This shows that beekeepers have a good knowledge of apiary management and honey usage habits.

Backyard honey makes the major proportion (76%)

Table 1. Demographic characteristics of the interviewed beekeepers in Maun (n = 25)

Variables	Responses	Percentage (%) of total respondents
Age (years)	20–30	28
	31–40	16
	41–50	48
	50 and above	8
Occupation	Government employee	52
	Self employed	44
	Other (Student at tertiary school)	4

n = total number of respondents.

Table 2. Types of honey produced, hives used, sources of nectar, flowering season and honey harvest time (n = 25)

Variables	Responses	Percentage (%) of total respondents
Backyard honey	Modern hives	52
	Traditional hives	24
Forest honey	Modern hives	0
	Traditional hives	24
Trees/shrubs used as bee forage	Rosemary (*Salvia rosmarinus*)	8
	Lavender (*Lavendula angustifolia*)	4
	Fennel (*Foeniculum vulgare*)	4
	Peppermint (*Mentha piperita*)	4
	Strawberry (*Fragaria ananassa*)	8
	Watermelon (*Citrullus lanatus*)	16
	Marula tree (*Sclerocarya birrea*)	56
Flowering seasons	November to February	56
	January to February	44
Honey harvest time	February	28
	June	28
	December	44

n = total number of respondents.

of honey produced in the study area (Table 2). Most of the farmers (52%) in Maun use modern hives for honey production (Table 2) and most of the farmers in the area have a lot of knowledge and experience in bee management. A similar finding was reported by Gilbert *et al.* (2021) who indicated that honey is predominantly produced using the backyard production system (76%) in Pandamatenga area in north-eastern Botswana. According to Kiros and Tsegay (2017), majority of beekeepers in Jimma and Ellubabor Zones of western Ethiopia keep bees in their homestead (backyard) mainly to enable close supervision of colonies while other farmers keep bee colonies in forests so that they might attract wild swarms by hanging a number of traditional beehives on trees. In most parts of Ethiopia, backyard beekeeping with relatively better management is common (Adgaba, 2002). Bareki *et al.* (2019) reported that majority of the farmers in Lerala village of Botswana are small-scale farmers who use modern hives for beekeeping. Their use of modern hives (movable frame and top bar hives) makes hive inspection and management easier and minimizes damage and death of bees during harvesting of honey. Only 48% of the farmers in Lerala use traditional beehives, by using locally available materials such as logs (Bareki *et al.*, 2019). Similarly, a recent study conducted by Gilbert *et al.* (2021) indicated that the majority (60%) of farmers in Pandamatenga village in north-eastern Botswana use modern hives for honey production.

In Maun area, various honeybee floras mainly herbs such as rosemary (*Salvia rosmarinus*), lavender (*Lavendula angustifolia*), fennel (*Foeniculum vulgare*) and peppermint (*Mentha piperita*), strawberry (*Fragaria ananassa*), watermelon (*Citrullus lanatus*), and marula tree (*Sclerocarya birrea*) were identified as plants which are commonly used as a source of nectar by honeybees (Table 2). Most of the plants which farmers listed are herbs and they grow them in their backyards, whereas some are fruit bearing plants such as sstrawberry and watermelon while others are indigenous trees such as marula, which grow naturally in the forest and also in their backyards as well.

Plants that are used as bee forage flower between November–February and many of the respondents indicated that honey is harvested in the study area mainly in December (44%) (Table 2). According to Bareki *et al.* (2019), honey is harvested from November to May in Lerala village. Usually, honey is harvested prior to the harvest of major food and cash crops and hence sale of honey serves to satisfy farmers' immediate cash needs to cover items such as school fees, taxes and fertilizer loans (Bareki *et al*., 2019).

Honey has been utilized as a natural sweetener since ancient times as it has high level of fructose (Finola *et al*., 2007). Honey is said to be 25 times sweeter than table sugar (Finola *et al*., 2007) probably because if its high fructose content. Majority (48%) of the respondents indicated that they use honey as a source of energy, while 20% of the respondents mentioned that they use honey as a remedy for cold and flu (Table 3). Some respondents (16%) also indicated that honey is used as a remedy against acne (Table 3). Honey does have medicinal properties that are acknowledged increasingly by modern medicine (National Honey Board, 2002). On the other hand, 16% of the respondents said they use honey as a sweetener in beverages such as beer and soda.

Pests are the major problems associated with honey production in the study area. According to the respondent farmers, the major pests that affect honeybees in Maun include ants, wax moth and yellow jackets (Table 4). According to Phokedi (1985) and Bareki *et al*. (2019), ants (*Pheidole megaccephala*) and wax moth (*Galleria mellonella*), are the most disturbing pests of honeybees in Botswana. Yellow jackets are yellow and black predatory wasps belonging to the genera Vespula and Dolichovespula which sting and release toxin. The problem with these is that most people mistaken honeybees for yellow jackets and hence they attack and kill honeybees. 20% of the respondents stated that harsh weather conditions are not favorable to the bees as during heavy rains the honey tends to have a higher amount of moisture hence rapid fermentation of honey leading to income loss. During drought periods, there is no rainfall which means there will be poor vegetation for bees to forage leading to poor quality honey. According to NEPAD (2005), high inter-annual variability of rainfall and drought is a recurring element of Botswana's climate. Beekeeping is largely affected by climatic conditions such as long and short torrential rains, very cold and hot temperatures, inadequate rainfall and continuous rains for periods of two weeks which can reduce the livelihood of bee colonies (NEPAD, 2005).

Table 3. Uses of honey in Maun (n = 25)

Variables	Responses	Percentage (%) of total respondents
Uses of honey	Acne* remedy	16
	Source of energy	48
	Cold and flu remedy	20
	Used as a sweetener	16

n = total number of respondents; *acne is a skin condition where dead skin cells and hair follicles become plugged with oils, it causes whiteheads, blackheads or pimples.

Respondents mentioned that they do get help from extension officers (88%) (Table 4) from the Beekeeping Section of the Office of Agriculture in Maun. They get help such as consultations, handling of bees, harvesting of honey and marketing of honey. Respondents also mentioned that some individuals get funding from the Government (12%) through programmes such as CEDA (Citizen Entrepreneurship Development Agency). According to Bareki *et al*. (2019), the government of Botswana has established programmes aimed at supporting non-traditional agricultural activities such as horticulture and beekeeping. Government institutions that fund the beekeeping sector include CEDA and NDB (National Development Bank) and the funds are utilized by farmers who are in a position to practice beekeeping on a commercial scale (Turner and Makhaya, 2014). The support that the farmers get from the Government is a good opportunity to promote the apicultural sector in the study area.

Table 4. Challenges and opportunities for honey production in Maun (n = 25)

Variables	Responses	Percentage (%) of total respondents
Problems of honey production	Pests (wax moth, ants and yellow jackets)	68
	Harsh weather conditions (rainy seasons and drought)	20
	Pesticides harmful to bees	12
Opportunities for honey production	Support from extension workers	88
	Government funding	12

n = total number of respondents

Table 5. Physiochemical properties (mean ± SD) of honey samples collected from backyard hives and the forest in Maun (n = 3)

Parameters	Backyard honey	Forest honey
Moisture content (% by mass)	$18.03^{a} \pm 0.15$	$17.43^{b} \pm 0.21$
pH	$4.12^{a} \pm 0.02$	$6.45^{b} \pm 0.17$
Free acidity (meq/kg)	$21.6^{a} \pm 0.10$	$13.17^{b} \pm 0.06$
Total ash content (% by mass)	$0.14^{a} \pm 0.01$	$0.27^{b} \pm 0.02$
Reducing sugars content (% by mass)	$71.27^{a} \pm 0.13$	$60.38^{b} \pm 0.16$
Sucrose content (% by mass)	$1.63^{a} \pm 0.02$	$0.84^{b} \pm 0.04$
HMF (mg/kg)	$17.67^{a} \pm 0.21$	$20.63^{b} \pm 0.55$

SD = standard deviation; n = number of samples; HMF = Hydroxymethylfurfural; means followed by different superscript letters in a row are significantly different ($p \leq 0.05$).

2. Physiochemical properties of honey

The physicochemical properties of the honey samples analyzed in the present study are reported in Table 5. The moisture content of honey samples collected from backyard hives (18.03%) was significantly higher ($p \leq 0.05$) than honey samples collected from the forest (17.43%) (Table 5). The moisture content of honey observed in the present study is generally low as compared to the internationally set standards for honey (≤21%) (Bogdanov *et al.*, 1999). The low moisture content observed in the present study shows that the honey samples have been harvested after being mature. Moisture content is a complex function of many variables such as extraction and handling practices and hygroscopic nature, which in turn depends on climatic conditions, the time of the year, the initial moisture of the nectar, the degree of maturation, and its geographical origin (Finola *et al.*, 2007). The difference in moisture content of honey depends on harvesting season, the degree of maturity that honey reached in the hive, type of hive used, environmental temperature and moisture content of original plant (Finola *et al.*, 2007; Gobessa *et al.*, 2012). Moisture content is an important quality factor of honey. The Codex Alimentarius Commission (2001) standard sets a moisture content of honey to be no more than 20%. The moisture content of honey samples observed in the present study is in line with the moisture content (14.2–19%) of honey samples from Spain (Terrab *et al.*, 2004) and the moisture content of 14.64–19.04% reported by Ouchemoukh *et al.* (2007) for Algerian honey.

The acidity of honey is important because it influences the shelf life of the honey, its texture and is important in the extraction process (Terrab *et al.*, 2002, 2004). Honey is a naturally acidic product, which is attributed to the presence of organic acids that contribute to its flavor and its stability against microbial spoilage (Gobessa *et al.*, 2012). The pH of forest honey samples (6.45) was significantly higher ($p \leq 0.05$) than the pH of backyard honey (4.12) (Table 5). The high pH of forest honey samples corresponds to the low free acidity of the forest honey samples as indicated in Table 5 and thus the lower free acidity contributed to the higher pH of the forest honey samples as compared to those of backyard honey samples which had higher free acidity and a corresponding low pH. Serrano *et al.* (2004) and Ouchemoukh *et al.* (2007) reported pH of honey ranging from 3.72 to 4.64 with a mean value of 4.07. On the other hand, White *et al.* (1962) reported that honey pH ranged between 3.42 and 6.10. Bogdanov *et al.* (1999) reported that pH of honey should be between 3.2 and 4.5. Honey samples collected from backyard hives in the present study fall within this range. However, the pH of honey samples obtained from the forest in the current study is significantly higher than the recommended pH range for honey. High acidity of honey indicates that the honey samples have high contents of minerals (Mohammed and Babiker, 2009).

Free acidity of backyard honey evaluated in the present study was 21.6 meq/kg and that of forest honey was 13.17 meq/kg (Table 5). The free acidity of all the honey samples examined in the present study are within the permitted range of less than 50 meq/kg for free acidity of honey according to the Codex standard (Codex Alimentarius Commission, 2001). The free acidity of honey from backyard hives was significantly higher ($p \leq 0.05$) than forest honey (Table 5). Finola *et al.* (2007) reported a free acidity of honey ranging from 11.9 to 29.4 meq/

kg. High acidity can be indicative of the fermentation of sugars into organic acids. None of the samples assessed in the present study are more than the limit allowed, which may indicate freshness of all honey samples. Differences in honey acidity could also be caused by differences in geographical condition, harvesting procedure and storage conditions (Kahraman *et al*., 2010).

The ash content may be indicative of environmental pollution or geographical origin, but the primary determinant of ash content of honey is the type of soil on which the plant that is used as a source of nectar was grown (Pokhrel, 2008). The total ash content of forest honey (0.27%) was significantly higher ($p \leq 0.05$) than the ash content of backyard honey (0.14%) (Table 5). Codex Alimentarius Commission (2001) proposed total ash content to be not more than 0.6% and the two honey samples examined in the present study are within the recommended range. Ouchemoukh *et al*. (2007) reported ash content of honey to range between 0.06–0.54% while White *et al*. (1962) reported ash content ranging from 0.02 to 1.03% for honey. The ash content of honey observed in the present study is in line with the values reported by Ouchemoukh *et al*. (2007) and White *et al*. (1962). Similarly, the values observed in the present study are in the same range with the values of 0.05 to 0.60% reported by Kinati *et al*. (2011) for honey produced in Gomma District of south-western Ethiopia and 0.198–0.271% reported by Nyau *et al*. (2013) for Zambian honey. Gilbert *et al*. (2021) reported ash content of 0.13% and 0.35% for honey samples collected from backyard hives and the forest, respectively in Pandamatenga village in north-eastern Botswana, which agrees with the present result.

The sugars in honey are responsible for many of the physicochemical properties such as viscosity, hygroscopicity and degree of granulation of honey (Bareki *et al*., 2019). The reducing sugar content of backyard honey (71.27%) was significantly higher ($p \leq 0.05$) than that for forest honey (60.38%) (Table 5). According to the Codex Alimentarius Commission (2001) standard, a minimum reducing sugar content of 65% is required for honey which means the reducing sugar content of forest honey (60.38%) is less than the minimum amount set. The values observed in the present study are higher than those reported (42.8 to 60.6%) by Rane and Doke (2012). The values observed in the current study are within the range of 54.45% to 79.99% reported by Getachew *et al*. (2014) for Ethiopian honey. Gobessa *et al*. (2012) reported reducing sugar contents ranging from 62 to 71% for honey produced in the Homesha district of western Ethiopia. Gilbert *et al*. (2021) reported a reducing sugar content of 56% for honey samples collected from Pandamatenga village in north-eastern Botswana, which is less than the values observed in the present study.

The sucrose content of honey depends on botanical origin of the nectar (Gobessa *et al*., 2012). A high sucrose concentration in honey usually implies a premature harvest of honey as the sucrose has not been fully converted to glucose and fructose by the action of invertase enzyme (Ozcan *et al*., 2006). Sucrose content of backyard honey (1.63%) was significantly higher ($p \leq 0.05$) than that for forest honey (0.84%) (Table 5). A maximum limit of 5% is suggested for sucrose content of honey according to the Codex standard (Codex Alimentarius Commission, 2001). The observed sucrose content of the honey samples in the present study falls within this limit. Ouchemoukh *et al*. (2007) reported sucrose content of 0.08–5.31% for honey samples produced in Algeria while Serrano *et al*. (2004) reported sucrose content of 0.14–11.49% for Andalusian honey samples. On the other hand, Makhloufi *et al*. (2007) reported sucrose content of 0.18–3.09% for Australian honey. Honey samples collected from backyard hives and the forest in Pandamatenga village in north-eastern Botswana had sucrose contents of 1.54% and 1.17%, respectively (Gilbert *et al*., 2021), which are comparable to the values observed in the present study.

Hydroxymethylfurfural (HMF) is only present in trace amounts in fresh honey (Bareki *et al*., 2019), and its concentration has been reported to increase with storage and the prolonged heating of honey. HMF is an essential parameter used to indicate honey's freshness and purity. The amount of HMF present in honey is the reference used as a guide to the extent of heating that has taken place: the higher the HMF value, the lower the quality of the honey. The HMF of forest honey (20.63 mg/kg) was significantly higher ($p \leq 0.05$) than that of backyard honey (17.67 mg/kg) (Table 5). The HMF values observed in the current study are within the allowed maximum limit of 40 mg/kg according to the Codex standard (Codex Alimentarius Commission, 2001). The current study values are within the range of 15.5–37.0 mg/kg reported for Mozambique honey (Escriche *et al*., 2017). Adenekan *et al*. (2010) reported HMF content of honey samples collected from different areas of Ibadan Nigeria ranging from 14.08 to 38.02 mg/kg. The present values are also within the range of 1.02 to 35.60 mg/kg reported for Burkina Faso honey samples (Escriche *et al*., 2017). Gilbert *et al*. (2021) reported higher HMF values of 26 mg/kg and 33.17 mg/kg, respectively for honey samples collected from backyard hives and the forest in Pandamatenga village in north-eastern Botswana compared to the present results.

CONCLUSION

Honey produced in Maun village is of good quality and it complies with international standards. The physicochemical properties evaluated in this study showed that the honey samples were fresh and fall within recommended limits. Statistically significant differences were observed between honey samples collected from backyard hives and those collected from the forest for all the parameters considered. Most farmers in Maun produce honey in their backyards using modern hives. Farmers in the study area face problems such as pests and harsh weather conditions which are not favorable for bees. Extension officers and the Government provide help to farmers in the form of consultation and finances which is a good initiative, and this will help to develop the apiculture sector in the area. In addition to the existing initiative, farmers in the study area should be provided with appropriate training on how to use equipment, harvest and market their honey, and on modern honey processing technologies so as to increase honey yield and improve honey quality. More research needs to be conducted on beekeeping and characterization of honey in different parts of Botswana in order to create a large pool of information which could be used for the development of honey standards of the country as well as the development of the apicultural sector.

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