Hindawi
Journal of Food Quality
Volume 2022, Article ID 3841184, 10 pages
https://doi.org/10.1155/2022/3841184

Research Article

Physicochemical Properties and Floral Sources of Honey Produced in Marsabit Forest Reserve, Northern Kenya

Godwin Leslie Muhati[1] **and Mary Wanjiru Warui**[2]

[1]*Kenya Wildlife Service, P. O. Box 40241-00100, Nairobi, Kenya*
[2]*National Museums of Kenya, P. O. Box 40658-00100, Nairobi, Kenya*

Correspondence should be addressed to Mary Wanjiru Warui; waruimaryw@gmail.com

Received 17 September 2021; Revised 6 May 2022; Accepted 26 May 2022; Published 29 June 2022

Academic Editor: Massimo Lucarini

This study assessed the physicochemical properties and floral sources (botanical origin) of sixteen honey samples collected from beekeepers in five clusters surrounding the Marsabit Forest Reserve (MFR) in northern Kenya. Analysis of Variance (ANOVA) was used to determine the differences in physicochemical properties of honey, while relative frequencies of pollen types in each honey sample were calculated and expressed as percentages. The mean physicochemical parameter values were moisture, $18.09 \pm 0.86\%$; total reducing sugars, $73.03 \pm 1.00\%$; apparent sucrose, $2.43 \pm 0.66\%$; acidity, 20.25 ± 0.86 meq/kg; hydroxymethylfurfural (HMF), 11.01 ± 5.39 mg/kg. All parameter values were within limits set in the East African Standard, Codex Alimentarius, and the European Union directive standards for honey. Pollen analysis showed a total of 108 pollen types representing 55 families and 97 genera. The highest represented family in the honey samples was Euphorbiaceae. The study recommends the further uptake of apiculture and the training and facilitation of honey producers, processors, and traders on quality assurance and certification of honey to make them competitive in the markets beyond the local level.

1. Introduction

According to European Union (EU) directive for honey (2001/110/EC) [1], honey is a natural sweet substance produced by honeybees from the nectar of plants (blossom honey) or excretions of plant-sucking insects on the living part of plants or secretions of living parts of plants (honeydew honey).

Attributes (physical, chemical, and organoleptic properties) of honey are greatly influenced by climatic conditions, floral sources, and technical know-how of beekeepers in honey harvesting, handling, processing, and storage [2–7]. Therefore, the characteristics of honey can vary depending on the region of production [4].

In recent years, there has been a growing demand for original, authentic, exclusive, and value-added products in most countries [8]. Parameters that have influenced the demand for honey include moisture content, total reducing sugars, sucrose, acidity, hydroxymethylfurfural (HMF), diastase activity, electrical conductivity, and water-insoluble content. Together with nectar sources, these parameters determine honey flavor (taste), viscosity, and colour, which are what most consumers consider when purchasing honey.

Therefore, a quality check is essential in determining the suitability of honey for human consumption, premium prices, access, and competitiveness in the local, regional, and international markets [6]. Physicochemical, sensory, and melissopalynological [8–10] and microbial [11, 12] analysis are the methods used in determining honey characteristics.

According to Lengarite et al. [13] and Lengarite et al. [14], honey production in Kenya is expanding, but data on production trends, processing, and marketing are fragmented. Beekeeping contributes to Kenya's agricultural gross domestic product, income generation, employment creation, nutritional benefits, and improved livelihoods, especially in arid and semiarid areas [15, 16]. Marsabit

County is one of the arid and semiarid regions in Kenya, where beekeeping is practiced by small-scale farmers surrounding mountainous regions [13, 14].

In areas surrounding Marsabit Forest Reserve (MFR), beekeeping is practiced by a few farmer groups and individuals who have received technical support, knowledge, and infrastructure from governmental and nongovernmental actors to enhance honey production (personal communication, Kenya Forest Service, Kenya Wildlife Service, and Department of Agriculture representatives in Marsabit County). However, there is unexploited potential for creating market value from honey produced around the MFR. This is attributed to inadequate information on honey quality and limited market outlets and access [13]. This challenge can be addressed by expanding market opportunities through the production of quality and unique honey that complies with honey quality requirements [5, 6, 13] as well as demonstrating the linkages between product characteristics to its origin, namely, floral sources and production methods [4, 6].

Honey quality characteristics can enhance its recognition, consumer confidence, product traceability, and thus access to niche markets, increasing premium prices and profitability. Lengarite et al. [13], in a pilot study on honey production in the Ndoto and Nyiru Mountains and Mount Kulal in the Marsabit and Samburu Districts, established that strengthening local marketing systems by helping beekeepers and traders build technical capacity and better organise themselves for increased marketing efficiency is essential. Facilitating honey certification and quality assurance was also recommended to help locals compete more effectively in regional consumer markets.

As established by Cuni-Sanchez et al. [17] and Muhati et al. [18], the MFR is a dry tropical forest in northern Kenya harbouring a diverse range of ecosystems, providing ecosystem goods and services (ES) critical to the people of Marsabit town. Of these ES, stakeholders in the MFR identified honey production as an essential service, among other ES that merit continuous protection by local communities and the mandated government institutions. However, no study has been undertaken around the MFR to establish the linkages between bee floral resources and honey. Also, little is known about the quality (physicochemical properties) of honey produced in the area and the compliance levels with local and international honey standards. The specific objectives of the study were (i) to determine the quality (physicochemical properties) of honey produced from the areas surrounding MFR and assess their compliance with local and international honey standards (i.e., EAS, Codex Alimentarius (CODEX STAN 12–1981), and EU directive for honey (2001/110/EC)) and (ii) to document bee floral resources that can form a link between MFR honey characteristics with their origin.

2. Materials and Methods

2.1. Study Area. The study was conducted in Saku Subcounty, which surrounds the Marsabit Forest Reserve (MFR) in northern Kenya (Figure 1).

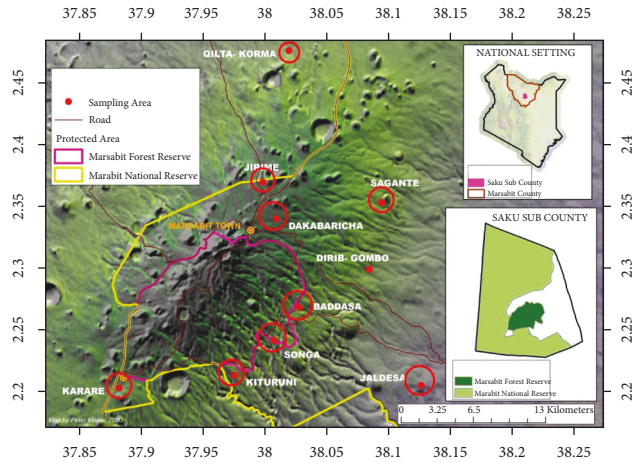

Figure 1: Map showing the study area and honey sampling areas.

MFR is a unique dry forest system in Eastern Africa unique for its ecological and socioeconomic functions and covers an area of approximately 157 square kilometres [19]. It is located 560 kilometres from Kenya's capital city, Nairobi, between latitudes 01°15′ North and 04°27′ North and longitudes 36°03′ East and 38°59′ East. It is the only government-gazetted forest in Marsabit County, established under Notice 936 in 1948 [20] by the Government of Kenya.

Villages in the study area are divided into five clusters, namely, MONAJIDA (Mountain, Nagayo, Jirime, and Dakabaricha villages); SOKI (Songa and Kituruni villages); QISA (Qilta-Korma and Sagante villages); JABADI (Jaldesa, Baddasa, Dirib-Gombo villages); and KAHU (Karare and Hula Hula villages) where beekeepers are distributed. The study area has a typical semiarid climate characterised by a bimodal rainfall pattern ranging from 600 to 1000 mm per annum, with a mean rainfall of 800 mm per year [18, 21]. The temperature ranges from 15°C to a high of 26°C, with an annual average of 20.5°C [18, 21].

The evergreen Marsabit forest is dominated by diverse indigenous flowering plant species, which include *Croton megalocarpus*, *Drypetes gerrardii*, *Ochna insculpta*, *Strychnos henningsii*, *Vangueria madagascariensis*, *Olea africana*, *Cordia africana*, *Acacia senegal*, *Grewia fallax*, *Acacia xanthophloea*, *Harrisonia abyssinica*, *Psydrax schimperiana*, *Dovyalis abyssinica*, *Euphorbia tirucalli*, *Teclea hanangensis*, *Rinorea convallarioides*, *Tarenna graveolens*, *Cassipourea malosana*, *Podocarpus gracilior*, and *Juniperus procera* tree species [18].

Marsabit forest provides ES, which includes provisioning services (e.g., food, water, fuelwood, pasture, and medicinal plants), regulating services (i.e., climate regulation, natural hazard regulation, carbon storage, water purification, air quality regulation, erosion regulation), and cultural services (i.e., spiritual enrichment, recreation, and aesthetic values). These services are critical to the livelihood and well-being of the people of Marsabit town and surrounding areas [19, 22].

2.2. Honey Sample Collection. A total of sixteen honey samples, 3 from MONAJIDA (Jirime and Dakabaricha villages), 3 from SOKI (Songa and Kituruni villages), 2 from

QISA (Qilta-Korma and Sagante villages), 6 from JABADI (Jaldesa, Baddasa, Dirib-Gombo villages), and 2 from KAHU (Karare village), were collected from beekeepers (Figure 1). The number of samples collected in each cluster was determined by the availability of honey from farmers who had harvested and processed the honey during the study period (December 2018-February 2019).

Each sample was placed in a fresh, sterile, firmly tightened food-grade clear Polyethylene Terephthalate (PET) plastic container manufactured by General Plastics Limited, Kenya. For ease of identification, each container was labelled with the date of collection, area of collection, name of the beekeeper, and contact details. The samples were stored at room temperature (25°C) and kept away from direct sunlight and moisture to ensure that the quality was maintained as per the time of collection. The physicochemical analysis was conducted at the National Beekeeping Institute, Kenya, while pollen analysis was undertaken at the Palynology Department, National Museums of Kenya.

2.3. Physicochemical Analysis. Physicochemical analysis for measurement of moisture content, total reducing sugars (TRS), apparent sucrose, acidity, and hydroxymethylfurfural (HMF) was done based on methods described by the Association of the Official Analytical Chemists [23] and harmonised methods of the International Honey Commission [24].

Honey moisture content was determined by use of a calibrated Abbe refractometer. Drops of honey were placed on a well-dried prism and covered with an illuminating mirror which was adjusted to reflect enough rays of light. The refractive index of honey was read and recorded.

Total reducing sugars (TRS) (glucose and fructose) and sucrose were determined using the High-Performance Liquid Chromatography (HPLC) technique. Proportions of sugar standards were prepared as follows: 2% fructose, 1.5% glucose, and 0.25% sucrose. The solutions were dissolved in 100 ml of distilled water and kept in the refrigerator for a night. Operational conditions of High-Performance Liquid Chromatography were optimised for sugars measurement as follows: flow rate, 0.6 ml/min; column temperature, 80°C; cell temperature, 40°C; mobile phase, water; analysis time per scale, 20 min; detection, RID-10A; Column-Shim-pack SPR-ca (250 mm L×7.8 mm I.D, 8 μm). The percentage sugar concentration was calculated using the area of the analyte in the sample, the area of the analyte in the standard, the concentration of the analyte in the standard, and the weight of the sample.

Acid levels were determined using a well-calibrated Benchtop model HI-2210, HAnna instruments, and a digital pH meter. 10 grams of honey was diluted in 75 ml of distilled water and stirred, and PH readings were recorded. The solution was titrated with 0.1 M sodium hydroxide (NaOH) to a pH of 8.3. NaOH volume was used in determining acidity.

HMF was determined by High-Pressure Liquid Chromatography (HPLC) [25] where 5 g of honey (weighed with a digital balance) was transferred to a volumetric flask and diluted into 100 ml of distilled water. The solution was filtered and the filtrate was injected into Shimadzu Prominence High-Performance Liquid Chromatography (HPLC) and run for 10 minutes. The process was repeated using more samples. HMF was determined using a Liquid Chromatography solution software.

Parameter values obtained were compared with the recommended levels as specified in the East African Standards (EAS) for honey (EAS 36 : 2000) [26], Codex Alimentarius honey standards (CODEX STAN 12–1981) [27], and the European Union (EU) directive for honey (2001/110/EC) [28].

2.4. Melissopalynological (Pollen) Analysis. The melissopalynological analysis was undertaken to determine the botanical origin (floral sources) of the honey based on pollen types. Identification of the pollen types in honey samples and determination of their relative frequencies in each sample were done using the methods described by [29–31].

Ten grams of honey were dissolved in 20 ml of distilled water and the mixture was centrifuged for 10 minutes. 20 ml of distilled water was added to the sediment and centrifuged for 5 minutes. A heating plate was heated to not more than 40°C and glycerine was liquefied. An area was marked on a microscope slide, and then the sediment was spread evenly on the marked area. This sediment was placed on the heating plate, and then the liquefied glycerine was applied to the cover slide that was used to cover the slide. Covering prevents contamination from foreign pollen coming from either previous honey preparations or the air. For an even dispersion of the glycerine jelly and uniform swelling of the pollen grains, the sediment was left on a heating plate for 5 minutes before the observation started. The sediment was examined under the microscope at a magnification that was most suitable for identifying the various elements in the sediment. Pollen grains were counted to determine their relative frequencies [32] with a check done to ascertain the main types and density.

Relative frequencies of identified pollen types were determined through grouping and counting pollen grains in the prepared sediment of each honey sample [10] with the help of a microscope. For each pollen type, the relative frequency was calculated as the respective percentage with respect to the total number of pollen grains counted. Only stabilised counts based on the total were expressed as percentages [32].

Confirmation of the geographical origin of honey was based on the identified pollen spectrum being consistent with the flora of the particular region from which honey samples were obtained [9, 24, 29]. Pollen from the different plant species was distinguished based on traits such as pollen grain size, shape/form, number, colour, and size of the apertures (pores or furrows).

2.5. Statistical Analysis. Data was captured in Microsoft Excel, where the mean and standard deviation of the physicochemical property values of the sampled honey were calculated. Analysis of Variance (ANOVA) was used to

determine the differences in physicochemical properties parameter values of honey obtained from the five clusters in the study area. Bonferroni test was used to reduce the chances of obtaining false-positive results. Relative frequencies of each pollen type in each honey sample were calculated and expressed as percentages based on the total number of pollen grains counted.

3. Results and Discussion

3.1. Physicochemical Properties of Sampled Honey. The mean physicochemical parameter values of the honey samples from the study and honey standard specifications as stipulated in EAS, Codex Alimentarius, and EU directive for honey are presented in Table 1.

The moisture content of the honey samples ranged between 16.70 and 19.60%, with an overall mean of 18.09 ± 0.86%. These values were below the maximum limit of levels recommended by EAS, Codex Alimentarius, and the EU directive for honey. These results suggested that the beekeepers in the study area harvested ripe and capped honey (mature honey) which was well handled and stored under suitable conditions, free from moisture. This further indicated that the honey was unlikely to ferment or get an unpleasant flavour and a shorter shelf life [24].

There was no significant difference in moisture content percentage between honey samples obtained from the five clusters. However, the moisture content of three honey samples from JABADI was higher (19.60%, 19.20%, and 19.20%) than that of other honey samples. The high-moisture content may be attributed to climatic conditions (high humidity, rainfall) during honey harvesting, storage conditions, or the botanical origin of the honey [33].

Total reducing sugars (TRS) (glucose and fructose) values of the honey analysed ranged within 71.06–74.40%, with an overall mean of 73.03 ± 1.00%. These values were above the minimum limits specified by EAS, Codex Alimentarius, and EU directive for honey. The results suggested the use of appropriate processing methods and favourable storage conditions (i.e., areas free from moisture and high temperatures). This also implied that the honey was not adulterated [34] and could remain in its original state for some time before rystallization [5].

The apparent sucrose of the honey samples ranged within 1.11–3.17%, with an overall mean of 2.43 ± 0.66. The apparent sucrose for all the samples was below 5%, which is the maximum limit according to EAS, Codex Alimentarius, and EU directive for honey. These results suggest that the honey samples studied were natural floral honey [9] and were not adulterated. There was no significant difference in the apparent sucrose between honey samples obtained from the five clusters. This observation could be attributed to similarity in some bee floral sources across the clusters, as was noted by Lengarite et al. [14].

The acidity of the honey ranged between 19.00 and 23.00 meq/kg with an overall mean of 20.25 ± 0.86 meq/kg. These values were below the maximum limit stipulated by EAS, Codex Alimentarius, and EU directive for honey. These results suggested that the honey was ripe during harvesting, of low water content, and thus not likely to ferment [35]. The similarity in free acidity in the different clusters may be attributed to the similarity of the nectar sugar concentration [36] from floral sources in the study area.

Hydroxymethylfurfural (HMF) in the honey samples analysed ranged within 1.13–20.60 mg/kg with an overall mean of 11.01 ± 5.39 mg/kg. These values were below the maximum limit value specified by EAS, Codex Alimentarius, and EU directive for honey. These results suggested that honey was not overheated and adulterated during processing [37], with the storage conditions also appropriate.

In summary, all 16 honey samples collected from the areas surrounding the MFR were of acceptable quality and fit for human consumption based on EAS, Codex Alimentarius, and EU directives for honey. Based on the results, it is thus plausible to conclude that producers and processors of honey around the MFR took appropriate measures to safeguard its quality.

To maintain the quality of honey produced in the study area, there is a need to continuously train beekeepers on best practices in honey harvesting and handling, processing, and quality assurance. This will enhance not only the quality of honey but also the volumes of production and value. The formation of beekeeper/honey producer groups would facilitate collective effort in the quality assurance of honey produced in a particular region. This would be useful in enhancing access to various markets for the maximisation of profits.

3.2. Botanical Origin of Sampled Honey. A total of 108 pollen types representing 55 families and 97 genera were identified from the 16 honey samples derived from farmers surrounding the MFR (Tables 2 and 3). These pollen types represented 46 species of trees and shrubs, 44 herbaceous species (including grasses and sedges), and 3 species of climbers and lianas.

The highest represented family was Euphorbiaceae with 8 genera followed by Asteraceae and Labiatae with 7 genera, Acanthaceae and Leguminosae both with 6 genera, and Rubiaceae, Capparaceae, Cucurbitaceae, and Malvaceae, with 4 genera. The rest of the families were represented by less than 4 genera. Some pollen grains/species identified in the honey samples analysed are shown in Figure 2.

The most commonly represented genera in most of the samples in order of abundance were the following ($N = 13{,}362$): *Leucas*, 23.5% ($n = 3{,}141$), *Leonotis*, 20.1% ($n = 2{,}686$), *Croton*, 7.8% ($n = 1{,}048$), *Eucalyptus*, 6.9% ($n = 918$), *Rhus*, 5.3% ($n = 713$), and *Asteraceae*, 5.3% ($n = 710$). The occurrence of the rest of the species was below 5% ($N \leq 500$). *Leucas* and *Phyllanthus* pollen types were noted in 15 honey samples, while *Croton* and *Leonotis* pollen types were represented in 14 samples. This is an indication of similarities of vegetation types in the different clusters of the study area based on climatic and edaphic factors [38]. Observation of 31.5% of the total pollen types represented once in specific honey samples is attributed to the distribution and diversity of plants in a particular area [39, 40] as well as honeybees foraging behaviour [41].

Table 1: Physicochemical parameter results of the honey samples obtained from beekeepers around Mt. Marsabit Forest.

Study area/cluster	Moisture content (%)	Total reducing sugars (%)	Apparent sucrose (%)	Acidity (meq/kg)	HMF (mg/kg)
JABADI ($n = 6$)	18.47 ± 0.99	72.86 ± 1.09	2.25 ± 0.81	20.50 ± 1.38	8.53 ± 3.21
KAHU ($n = 2$)	17.30 ± 0.71	72.84 ± 0.35	2.91 ± 0.28	20.50 ± 0.71	15.10 ± 2.12
MONAJIDA ($n = 3$)	18.10 ± 0.66	72.81 ± 1.52	2.48 ± 0.70	20.00 ± 0.00	12.08 ± 9.96
QISA ($n = 2$)	17.45 ± 1.06	74.21 ± 0.28	2.30 ± 0.44	20.00 ± 0.00	14.85 ± 8.13
SOKI ($n = 3$)	18.27 ± 0.61	72.96 ± 0.79	2.50 ± 0.81	20.00 ± 0.00	9.62 ± 1.75
Bonferroni p-value	0.441	0.589	0.849	0.888	0.487
Honey standards specifications					
EAS	≤22	≥60	≤5	≤40	≤80
Codex	≤20	≥60	≤5	≤50	≤40
EU directive	≤20	≥60	≤5	≤50	≤40

Table 2: Pollen types (>3%) in honey samples from study clusters.

Pollen type/area	Cluster				
	MONAJIDA	SOKI	QISA	JABADI	KAHU
Croton sp.	√	√	√	√	√
Leonotis sp.	√	√	√	√	√
Leucas sp.	√	√	√	√	√
Eucalyptus sp.	√	√	√	√	√
Solanum sp.		√			
Rhus natalensis			√	√	
Asteraceae	√	√	√	√	√
Heliotropium sp.	√				
Acalypha sp.	√	√			
Labiatae	√				
Alchornea sp.	√				
Indigofera sp.	√				
Olea sp.	√				
Myrica sp.	√				
Phyllanthus sp.	√	√		√	
Ageratum sp.	√	√	√	√	
Syzygium sp.	√	√	√		
Cadaba sp.	√				
Legume sp.	√				
Cucumis sp.	√	√			
Neubotonia sp.	√			√	
Epilobium sp.	√				
Salvadora sp.	√				√
Hypitis sp.		√			
Commiphora sp.		√			
Phyllanthus sp.		√	√	√	
Kedrostis sp.		√			
Cassia sp.		√		√	
Basilicum sp.		√			
Legume sp.		√	√		
Euphorbia sp.		√			
Heliotropium sp.		√			
Hyphaene sp.		√			
Rubiaceae		√			
Capparis sp.		√			
Cleome sp.		√			
Rutaceae		√			
Justicia sp.			√		
Loranthus sp.			√	√	√
Achyranthes sp.				√	
Lannea sp.				√	
Grewia sp.				√	
Ocimum sp.				√	√
Neubotonia sp.				√	
Abutilon sp.				√	
Acacia sp.				√	
Brucea sp.				√	

Table 3: Pollen types (<3% minor pollen) in honey samples from study clusters.

Pollen type/area	Cluster				
	MONAJIDA	SOKI	QISA	JABADI	KAHU
Abutilon sp.	√	√		√	
Acacia sp.	√	√		√	√
Acalypha sp.	√		√	√	
Acanthus sp.	√				
Adenia sp.		√			
Ageratum sp.		√		√	
Albizia sp.	√	√	√	√	
Alchornea sp.		√			√
Allophylus sp.	√		√		
Aloe sp.	√		√		√
Amaranthaceae	√	√	√		√
Anthospermum sp.			√		
Asclepiadaceae		√	√		
Asteraceae		√	√	√	
Bidens pilosa		√		√	
Boerhavia sp.		√			
Canthium sp.	√	√		√	√
Capitanya sp.	√				
Capparis sp.				√	√
Cardiospermum sp.			√		
Casuarina sp.	√				
Cissus sp.				√	
Cleome sp.	√		√	√	
Combretum sp.	√	√	√	√	√
Commelina sp.		√	√	√	√
Commicarpus sp.			√	√	
Commiphora sp.	√	√	√	√	
Corbichonia sp.			√	√	
Cordia sp.	√	√		√	
Croton sp.	√			√	
Cruceferae				√	
Cucumis sp.		√	√	√	
Cucurbitaceae		√			
Cyperaceae	√	√			
Diospyros sp.		√			
Dracena sp.			√		
Ecbolium sp.	√		√	√	
Elaeagnus sp.			√		
Epilobium sp.		√		√	
Eucalyptus sp.	√	√	√	√	
Euclea sp.					√
Euphorbia sp.	√	√		√	
Grewia sp.	√			√	
Gunneropsis sp.	√	√			
Heliotropium sp.	√	√		√	
Hibiscus sp.	√			√	√
Hildebrandtii sp.	√	√	√		
Hippocratea sp.	√				
Hyphaene sp.				√	
Hypitis sp.	√	√	√	√	
Hypoestes sp.	√			√	
Indigofera sp.	√	√			√
Ipomea sp.	√	√		√	
Jatropha sp.				√	
Justicia sp.	√	√		√	
Kedrostis sp.			√	√	
Kleinia sp.			√		
Lannea sp.				√	
Legume sp.	√	√	√	√	√

Table 3: Continued.

Pollen type/area	Cluster				
	MONAJIDA	SOKI	QISA	JABADI	KAHU
Leonotis sp.		√		√	
Leucas sp.				√	
Loranthus sp.	√	√	√	√	
Luffa sp.			√		
Maerua sp.	√			√	
Maesa sp.	√				
Malvaceae				√	
Mitracarpus sp.		√			
Myrica sp.	√				
Myriophyllum sp.	√			√	
Neubotonia sp.			√		
Nicotiana sp.				√	
Nymphea sp.		√		√	
Ocimum sp.	√	√		√	
Olea sp.		√		√	
Pavonia sp.				√	
Peristrophe sp.				√	
Phyllanthus sp.	√	√	√	√	√
Pluchea sp.	√				
Poaceae			√	√	√
Portulaca sp.			√		
Proteaceae	√				
Rhus natalensis	√	√		√	√
Rhynchosia sp.		√		√	
Ricinus sp.		√			
Rubiaceae	√	√			
Ruellia sp.			√		
Rumex sp.	√	√		√	√
Rutaceae	√	√	√	√	
Salvadora sp.	√	√	√	√	
Sesbania sp.	√				
Solanum sp.		√		√	
Sphaeranthus sp.		√			
Stemodia sp.		√			
Sueda sp.				√	
Syzygium sp.				√	
Tamarindus sp.			√	√	
Tribulus sp.	√			√	
Trichocladus sp.				√	
Vernonia sp.				√	
Ximenia sp.				√	
Ziziphus sp.		√		√	

According to the pollen types and assemblages observed, the diversity of plant species varied across the honey samples. A sample from Monajida had the highest species diversity, 39.8% ($n = 43$) of the total pollen types identified ($N = 108$), followed by two samples from Jabadi, with 38% ($n = 41$), and then two samples from Soki, with a 30.6% ($n = 33$) of the pollen types. Another sample from Jabadi had the lowest plant species diversity, with only eight pollen types (7.4% of the total identified). Finally, a sample from Monajida had the highest count of pollen assemblage (12.5%). In comparison, a sample from Soki had the lowest count of pollen assemblage (1.8%); however, it was among the samples with high species diversity of represented plants.

These results suggest the preference of honeybees to forage on more than one plant species across the five clusters depending on their availability (season of production) and floral reward (nectar or pollen), as noted by Fidalgo and Kleinert [42]. Bees visit flowers with promising floral rewards that can be foraged at minimal cost (time and energy) [43]. This further highlights the significance of the MFR and the surrounding agroecosystems as an important floral source for honeybees of diverse plant species.

Some of the pollen types identified belong to genera perceived to have medicinal value in the study area (e.g., *Grewia tenax* and *Commelina benghalensis*), as noted by Muhati et al. [18]. It is thus plausible that the honey produced from the nectar of these plants is likely to have some medicinal properties. The importance of the medicinal plant use in MFR and the island forests in Northern Kenya cannot be gainsaid [44–49]. During the study, most beekeepers

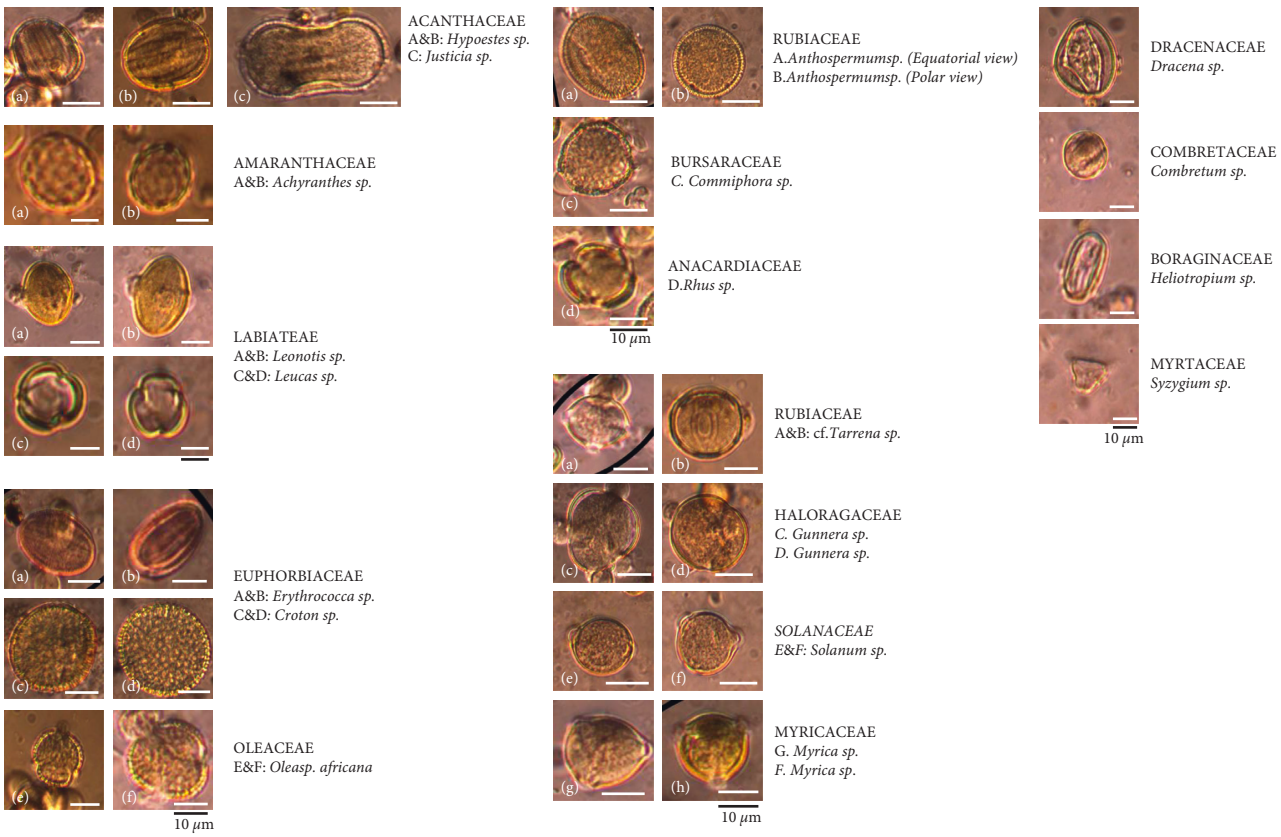

Figure 2: Some of the pollen grains/types identified in honey samples.

around the MFR acknowledged the use of honey produced within the region to treat diseases like colds, coughs, wounds, and stomach-related problems. These medicinal properties can enhance the reputation and market demand for honey produced around the MFR.

This has been possible for Manuka honey in New Zealand, whose demand and market access were associated with methylglyoxal, an antibacterial compound found in the Manuka tree (*Leptospermum scoparium*), which dominates the production area [50].

Pollen types identified from the honey samples analysed represented naturally occurring and introduced plant species in the MFR and its surroundings [44–51]. This presents an opportunity to link honey characteristics (physicochemical properties, taste, colour, and smell) with origin (floral source). On the other hand, honeybees are important pollinators of most plant species represented by identified pollen types [41]. Protection of the MFR and pollination of plant species in the forest can enhance the continued regeneration of floral sources and, thus, the survival of bees, translating to increased honey production. Furthermore, pollination also facilitates crop production and regeneration of nontimber forest products, e.g., forage and medicinal herbs that enhance community livelihoods.

Diverse floral sources contribute significantly to the characteristics/properties of honey [8]. Therefore, pollen analysis provides information that links pollen types with honey characteristics, which is useful in establishing the market. Given Kenya's current focus on the conservation and sustainable development of natural resources in the arid and semiarid areas [15], benefits derived from interactions between honeybees and plant species in the MFR present a good justification for the sustainable utilisation and conservation of the forest and its environments to maintain honey characteristics.

4. Conclusion and Recommendations

Our study examined the physicochemical properties of honey produced from the areas surrounding MFR, their compliance with honey standards, and the bee floral resources that could form a link between honey characteristics with their origin. The study established that the honey produced around the MFR was of good quality that meets the specifications of existing local and international honey standards. Pollen (melissopalynological) analysis showed that honey was produced from nectars of flowering plants originating from the MFR and its environments. Different pollen spectrum was noted across analysed honey samples based on existence, flowering seasons, and richness of floral sources in the different clusters of the study area. The composition and compliance of honey produced around the MFR with existing standards can influence its authentication and positive reputation, thereby facilitating its entry into the various niche markets. These results highlight the need for training honey processors and traders and facilitation on quality assurance and certification of honey to compete in the regional market. Encouraging beekeeping within/around

the MFR can facilitate the production of quality honey and conservation of the forest, thereby diversifying community livelihoods. Therefore, forest conservation initiatives in the MFR need to incorporate sustainable beekeeping activities. While our study determined the physicochemical properties of honey produced from the areas surrounding the MFR, and the bee floral resources that link honey characteristics to their origin, changes that occur in individual physicochemical parameters during storage were not undertaken. Conclusive studies to shed more light on the variability of the sucrose, reducing sugars, acidity, and hydroxymethylfurfural (HMF) content of honey samples in MFR over time relative to other jurisdictions may be necessary.

Data Availability

The data used in the development of this manuscript are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Both authors, M. W. Warui and G. L. Muhati, were involved in data collection, data analysis, manuscript writing, and proofreading. The authors have approved the publishing of this article.

Acknowledgments

This work was financially supported by the French Development Agency (AFD), under agreement no. CKE 1036, 01H.

References

[1] Council Directive, "Council directive 2001/110/EC relating to honey," *Official Journal of the European Communities*, vol. 10/47, pp. 47–52, 2002.

[2] M. Blakeney, T. Coulet, G. Mengistie, and M. T. Mahop, *Extending the Protection of Geographical Indications: Case Studies of Agricultural Products in Africa*, Earthscan, London, UK, 2012.

[3] S. Bogdanov, C. Lüllmann, P. Martin, W. von der Ohe, H. Russmann, and G Vorwohl, "Honey quality and international regulatory standards: review by the international honey commission," *Bee World*, vol. 80, no. 2, pp. 61–69, 2015.

[4] T. Coulet and M. T. Mahop, "Cameroon: oku white honey," in *Extending The Protection of Geographical Indications. Case studies of Agricultural Products in Africa*, M. Blakeney, T. Coulet, G. Mengistie, and M. T. Mahop, Eds., Routledge, London, UK, 2012.

[5] E. Muli, A. Munguti, and S. K. Raina, "Quality of honey harvested and processed using traditional methods in rural areas of kenya," *Acta Veterinaria Brno*, vol. 76, no. 2, pp. 315–320, 2007.

[6] WIPO, *Bees, Geographical Indications, and Development. Oku white Honey, Cameroon*, Case study by World Intellectual Property Organization, Geneva, Switzerland, 2014, https://www.wipo.int/ipadvantage/en/details.jsp?id=5554.

[7] Y. Yang, M.-J. Battesti, J. Costa, and J. Paolini, "Characterisation of botanical and geographical origin of corsican "spring" honeys by melissopalynological and volatile analysis," *Foods*, vol. 3, 2014.

[8] S. Stolzenbach, D. V. Byrne, and W. L. P. Bredie, "Food Research International," *Sensory Local Uniqueness of Danish Honeys*, vol. 44, pp. 2766–2774, 2011.

[9] G. D. Jones and V. M. Bryant, "Pollen studies of east texas honey," *Palynology*, vol. 38, no. 2, pp. 242–258, 2014.

[10] W. Von Der Ohe, L. P. Oddo, M. L. Piana, M. Morlot, and P. Martin, "Harmonised methods of melissopalynology," *Apidologie*, vol. 35, p. S18, 2004 –S25.

[11] P. Adadi and A. K Obeng, "Assessment of bacterial quality of honey produced in tamale metropolis (Ghana)," *Journal of Food and Drug Analysis*, vol. 25, no. 2, pp. 369–373, 2017.

[12] P. Pomastowski, M. Złoch, A. Rodzik, M. Ligor, M. Kostrzewa, and B. Buszewski, "Analysis of bacteria associated with honeys of different geographical and botanical origin using two different identification approaches: MALDI-TOF MS and 16S rDNA PCR technique," *PLoS One*, vol. 14, no. 5, Article ID e0217078, 2019.

[13] M. Lengarite, A. Kagunyu, and F. Wayua, *Honey Production, Processing, Quality, and Marketing in the Mountains of Northern Kenya*, University of California, Davis, CA, USA, 2007.

[14] M. Lengarite, F. Wayua, M. Shibia, and A. Kagunyu, "Quality of honey processed and stored by honey processors and in the mountains of northern kenya," in *The 8th AFMA Congress on Repositioning African Agriculture by Enhancing Productivity, Market Access, Policy Dialogue and Adapting To Climate Change"*African Farm Management Association (AFMA), Nairobi, Kenya, 2012.

[15] GoK, *Agricultural Sector Development Strategy 2010-2020*, 2010, https://www.gafspfund.org/sites/gafspfund.org/files/Documents/5. Kenya_strategy.pdf.

[16] GoK, *Sessional Paper No. 7 on National Beekeeping Policy. Enhancing the Contribution of the Beekeeping Sector to Food Security, Agribusiness, Employment Creation and Environmental Conservation Towards Vision 2030*, Ministry of Agriculture, Livestock and Fisheries State Department, Nairobi, Kenya, 2013.

[17] A. Cuni-Sanchez, M. Pfeifer, R. Marchant, and N. D. Burgess, "Ethnic and locational differences in ecosystem service values: insights from the communities in forest islands in the desert," *Ecosystem Services*, vol. 19, pp. 42–50, 2016.

[18] G. L. Muhati, D. Olago, and L. Olaka, "Participatory scenario development process in addressing potential impacts of anthropogenic activities on the ecosystem services of Mt. marsabit forest, kenya," *Global Ecology and Conservation*, vol. 14, Article ID e00402, 2018.

[19] Kenya Wildlife Service, *The Marsabit Forest Ecosystem Management Plan 2015-2025*, Kenya Wildlife Service, Nairobi, Kenya, 2016.

[20] T. J. Synott, *A Report on the Status, Importance and Protection of Montane Forests*, 1979, https://wedocs.unep.org/20.500.11822/29265.

[21] G. L. Muhati, D. Olago, and L. Olaka, "Past and projected rainfall and temperature trends in a sub-humid montane Forest in northern kenya based on the CMIP5 model ensemble," *Global Ecology and Conservation*, vol. 16, Article ID e00469, 2018.

[22] G. Muhati, D. Olago, and L. Olaka, "quantification of carbon stocks in mount marsabit forest reserve, a sub-humid montane forest in northern kenya under anthropogenic

disturbance," *Global Ecology and Conservation*, vol. 14, Article ID e00383, 2018.

[23] AOAC, *AOAC: Official Methods of Analysis*, Association of Official Analytical Chemists, Rockville, MD, USA, 15th edition, 1990.

[24] S. Bogdanov and P. Martin, "Honey authenticity: a review," *Mitteilungen aus dem Gebiete der Lebensmitteluntersuchung und Hygiene*, vol. 93, no. 3, pp. 232–254, 2002.

[25] J. Jeuring and F. Kuppers, "High performance liquid chromatography of furfural and hydroxymethylfurfural in spirits and honey," *Journal of Association of Official Analytical Chemists*, vol. 63, no. 6, pp. 1215–1218, 1980.

[26] EAC, *East African Standards Honey 36:2000-Specification*, 2000, https://members.wto.org/crnattachments/2020/TBT/RWA/20_0208_00_e.pdf.

[27] Codex, "Codex alimentarius standard for honey 12-1981. revised codex standard for honey. standards and standard methods," 2001, https://www.fao.org/fao-who-codexalimentarius/sh-roxy/es/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXS%2B12-1981%252FCXS_012e.pdf.

[28] A. Iglesias, "Council directive 2001/110/EC of 20 December 2001 relating honey," 2001, https://eur-lex.europa.eu/eli/dir/2001/110/oj.

[29] J. Louveaux, A. Maurizio, and G. Vorwohl, "Methods of melissopalynology," *Bee World*, vol. 59, pp. 139–157, 1978.

[30] X. Sanchez, J. Pires, L. Estevinho, A. Iglesias, and J. P. Araujo, "Palynological and physicochemical data characterisation of honeys produced in the entre-douro e minho region of portugal," *International Journal of Food Science and Technology*, vol. 45, pp. 1255–1262, 2010.

[31] Y. Yang, M.-J. Battesti, J. Paolini, A. Muselli, P. Tomi, and J. Costa, "Melissopalynological origin determination and volatile composition analysis of corsican "erica arborea spring maquis" honeys," *Food Chemistry*, vol. 134, no. 1, pp. 37–47, 2012.

[32] F. Behm, K. Von der Ohe, and W. Henrich, "Zuverlässigkeit der pollenanalyse von honig. bestimmung der pollenhäufigkeit," *Deutsche Lebensmittel Rundschaum*, vol. 92, pp. 183–187, 1996.

[33] Y. Yücel and P. Sultanoğlu, "Characterisation of honeys from hatay region by their physicochemical properties combined with chemometrics," *Food Bioscience*, vol. 1, pp. 16–25, 2013.

[34] B. Tesfaye, D. Begna, and M. Eshetu, "Evaluation of physicochemical properties of honey produced in bale natural forest, southeastern Ethiopia," *International Journal of Agricultural Science and Food Technology*, 2016.

[35] T. Gomes, X. Sanchez, A. Iglesias, and L. Estevinho, "Study of organic honey from the northeast of Portugal," *Molecules*, vol. 16, pp. 5374–5386, 2011.

[36] T. Ruiz-Argueso and A. Rodriquez-Navarra, "Gluconic acid-producing bacteria from honey bees and ripening honey," *Journal of General Microbiology*, vol. 76, pp. 211–216, 1973.

[37] J. White, "The role of HMF and diastase assays in honey quality evaluation," *Bee World*, vol. 75, pp. 104–117, 2015.

[38] M. W. Warui, M. Gikungu, A. Bosselmann, and L. Hansted, "Pollination of Acacia woodlands and honey production by honey bees in Kitui, Kenya," *Future of Food: Journal on Food, Agriculture and Society*, vol. 6, no. 1, pp. 41–50, 2018, https://futureoffoodjournal.org/index.php/FOFJ/article/view/9.

[39] H. Beentje, J. Adamson, and D. Bhanderi, *Kenya Trees, Shrubs, and Lianas*, National Museums of Kenya, Nairobi, Kenya, 1994.

[40] P. Maundu and B. Tengnas, "Useful trees and shrubs for kenya. (N. (Kenya) world agroforestry centre (ICRAF)," *Technical Handbook*, 2005, https://www.worldagroforestry.org/downloads/Publications/PDFs/B13601.PDF.

[41] M. W. Gikungu, *Bee Diversity and Some Aspects of Their Ecological Interactions with Plants in a Successional Tropical Community*, Bonn University, Bonn, Germany, 2006.

[42] A. O. Fidalgo and A. M. P. Kleinert, "Floral preferences and climate influence in nectar and pollen foraging by melipona rufiventris lepeletier (*Hymenoptera: meliponini*) in Ubatuba, São Paulo State, Brazil," *Neotropical Entomology*, vol. 39, no. 6, pp. 879–884, 2010.

[43] M. J. Couvillon, F. C. R. Pearce, E. L. Harris-Jones et al., "Intra-dance variation among waggle runs and the design of efficient protocols for honey bee dance decoding," *Biology Open*, vol. 1, pp. 467–472, 2012.

[44] R. W. Bussmann, "Islands in the desert—forest vegetation of Kenya'S smaller mountains and highland areas (Nyiru, Ndoto, kulal, Marsabit, loroghi, ndare, mukogodo, porror, mathews, gakoe, imenti, ngaia, nyambeni, loita, nguruman, Nairobi)," *Journal of East African Natural History*, vol. 91, pp. 27–79, 2002.

[45] T. Y. Watkins and M. Imbumi, "Forests of mount kulal, Kenya: source of water and support to local livelihoods," *Unasylva (English ed.)*, vol. 58, no. 229, pp. 33–37, 2007.

[46] M. E. Dan, L. A. Olaka, M. B. Mamo, D. M. Chalo, and A. Cuni-Sanchez, "Desert landscape services: insights from pastoralist communities in northern kenya," *Ecosystem Services*, vol. 48, Article ID 101243, 2021.

[47] A. Delbanco, N. D. Burgess, and A. Cuni-Sanchez, "Medicinal plant trade in northern kenya: economic importance, uses, and origin," *Economic Botany*, vol. 71, no. 1, pp. 13–31, 2017.

[48] A. Jusu and A. C. Sanchez, "Economic importance of the medicinal plant trade in sierra leone 1," *Economic Botany*, vol. 67, no. 4, pp. 299–312, 2013.

[49] G. L. Muhati, "Ecosystem services of hurri hills, a montane woodland ecosystem in the arid lands of northern kenya," *Global Ecology and Conservation*, vol. 33, Article ID e01951, 2022.

[50] J. Atrott and T Henle, "Methylglyoxal in manuka honey - correlation with antibacterial properties," *Czech Journal of Food Sciences*, vol. 27, pp. S163–S165, 2009.

[51] E. W. Githae, C. K. K. Gachene, and D. W. Odee, "implication for in situ conservation of indigenous species with special reference to wild coffea arabica l. population in mount marsabit forest, kenya," *Tropical and Subtropical Agroecosystems*, vol. 14, pp. 715–722, 2011.