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Research article

Melissopalynological analysis and floral spectra of *Apis mellifera scutellata* Lepeletier bees in different agroecologies of southwest Ethiopia

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ABSTRACT

The availability of bee forage limits honeybee productivity and is very important for beekeepers. Therefore, the current study aimed to identify the major botanical resources of honeybee, *A. mellifera scutellata,* in Southwest Ethiopia. Between October 2019 and October 2020, 69 group discussions (8–12 beekeepers), field observations, and pollen analysis were used to collect data. A total of 72 honey samples were collected from five districts at different seasons for pollen analysis. Most of the honey samples tested (93.06%) were multifloral, while 6.94% were monofloral. Melissopalynological analysis indicated that *Eucalyptus camaldulensis* (52.02%) was the predominant pollen type and is considered monofloral honey. *Terminalia* spp. (25.96%), *Guizotia* spp. (17.80%), and *Bidens* spp. (17.61%) were secondary pollen types and classified as multifloral honey. *Terminalia* spp., *Guizotia* spp., *Vernonia* spp., *Bidens* ssp., *Plantago* spp., and *E. camaldulensis* were pollen types recorded in honey samples in all agroecologies. Beekeepers ranked *Schefflera abyssinica*, *Vernonia amygdalina*, and *Cordia africana* as the first source of pollen and nectar for honeybees in highland, midland, and lowland, respectively. Additionally, *V. amygdalina*, *Coffea arabica*, *Croton macrostachyus*, and *C. africana* were commonly observed bee flora in all agroecologies. Honey bee management, such as bee forage shortages, the occurrence of brood and swarming, varied significantly ($P < 0.05$) among different agroecologies. In the present study, 53 honeybee plants were identified as pollen and nectar sources for honeybees. Various herbs (41.50%), trees (30.20%), and shrubs (28.30%) played a major role in honey production. Thus, beekeeping should be integrated with vegetation conservation for livelihood improvement and food security. Furthermore, existing bee flora should be cultivated in areas to increase the harvesting of honeybee products and improve the apiculture industry.

1. Introduction

The honeybee flora is the most important factor that influences the behavior or actions of honeybees and the quality of honey [1,2]. Pollen provides protein, vitamins, fatty acids and other nutrients for honeybees, whereas nectar provides carbohydrates [1,3].

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Adequate nectar and pollen resources are very important to maintain the health of honeybees. However, a shortage of both quantity and quality of pollen and nectar can lead to a decrease in the number of colonies that collect them [2,4]. The limited availability of floral resources for honeybees can affect their production and productivity, which is crucial for beekeepers [5,6]. Thus, honey pollen analysis helps to understand the distribution and abundance of foraging sources in the region, which allows assessing the potential of the area for honey production at the commercial level [7].

Ethiopia has a diverse agro-ecological and climatic conditions that are suitable for beekeeping [8]. The flowering plants known in Ethiopia are composed of six to seven thousand species spread across diverse agroecological zones [9]. This makes the country highly suitable for bees and beekeeping [10]. However, these variations in topography and the different climate zones complicate the development of flowering calendars in the country [8]. Therefore, the identification of nectar and pollen source plants is essential for the development of beekeeping. A calendar that displays the blooming sequence of different plants in a particular region serves the purpose of identifying the primary flowering periods and periods of scarcity. This information can be used to cultivate appropriate plants that can fill in the gaps during non flowering periods [11,12].

Melissopalynology is the analysis of pollen grains present in honey [7,13], which is important to determine the geographical and botanical origin of honey through a microscopic examination of honey sediments [14,15]. Every plant species has its genetic code of inheritance and a specific structural pattern that enable the pollen grain of one species to be differentiated from another [16,17]. Furthermore, the melissopalynological analysis of honey is more accurate than a visual survey for the study of honeybee forage, which is the most important tool for the development of regional apiculture [18]. It also provides information about the pollen and nectar sources used by honeybees in the region for honey production [19]. Honey can be monofloral or multifloral. Monofloral honey is a type of honey made predominantly from the pollen of a single plant species, whereas multifloral honey contains pollen from different plant species [13,17].

The identification of bee forage and their flowering period is important for beekeeping in Ethiopia to enhance honey production [20]. Therefore, it is essential to assess different agroecology to determine the availability of bee forage and establish a flowering period of honey plants that allows effective seasonal colony management. Agroecology can influence bee forage sources, temperature, and humidity in the study areas. Thus, the agroecology of a particular location may affect the availability, duration of flowering, flowering phenology, nectar production, and pollen production of various bee plants. This in turn has an impact on the production and seasonal growth of bee colonies [12,21]. The study areas are characterized by varied agroecologies that range from low to highlands and have diversified type of vegetation and various types of cultivated crops. Therefore, this study was carried out to determine the floral source of honey and identify the main bee forages that contribute to honey production in southwest Ethiopia for effective honeybee management.

2. Materials and methods

2.1. Study areas

The study was carried out in six selected districts of the Sheka, Bench-Sheko, and Majagn zones in southwest Ethiopia, namely Anderacha, Yeki, Guraferda, Sheko, Godare, and Megesh districts (Fig. 1a) for two consecutive years from October 2019 to October 2020. The agroecological zones of the study areas were classified into three categories, namely lowland (1500 m.a.s.l.), mid-altitude (1500–2300 m.a.s.l.) and highland (>2300 m.a.s.l.). The selected districts were classified as highland (Anderach, Sheko), midland (Yeki), and lowland (Guraferda, Godare and Mengesh) agroecological zones. The Bench-Sheko and Sheko zones are located southwest of Addis Ababa, the capital of Ethiopia, at 561 km and 694 km, respectively. Majagn is one of the Gambella Region administrative zones and borders southeast by the Southwest Region . The Majang zone is 628 km from Ethiopia's capital, Addis Ababa. The zone is

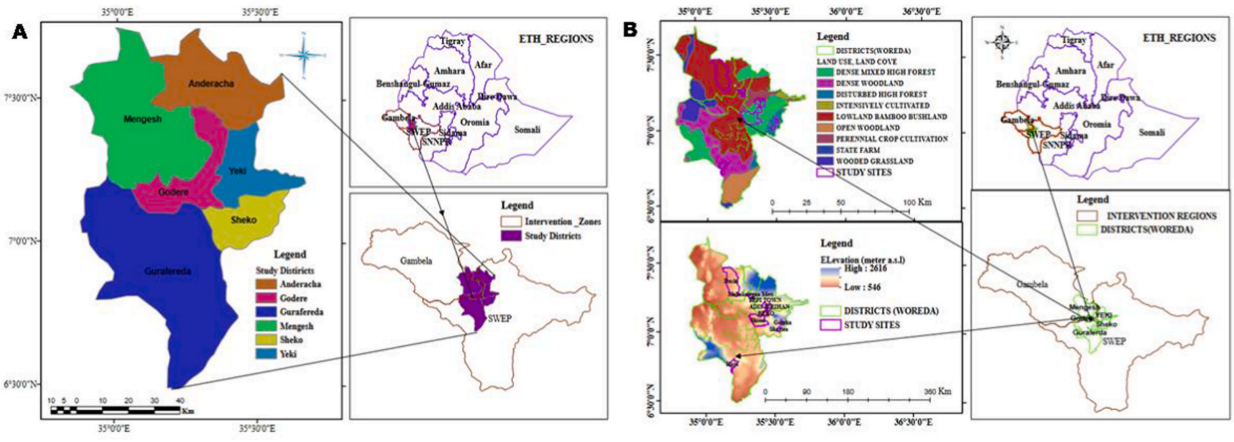

Fig. 1. Map showing the study areas (A) Map showing landscape structures of the study sites (B).

characterized by the production of forest coffee along with the spices that are collected from the forests for the market. The altitude, annual rainfall ranges, and average annual temperature of the selected zones are summarized in Table 1. The landscape structure of the study sites is shown in Fig. 1b. A total of three sites and 18 honey samples were taken from highland and midland, respectively. A total of 36 honey samples were collected from lowland areas at six different sites. Farmers in the Bench-Sheko, Sheka, and Majagn zones earn their livelihoods by the mixed crop-livestock production system and beekeeping.

2.2. Site selection and honey sample collection

In this study, the Bench-Sheko, Sheka and Majagn zones were selected purposively based on the potential of beekeeping practices. Five districts were randomly selected, namely Yeki, Guraferda, Sheko, Godare, and Megeshi. Volunteer beekeepers who managed honey colonies in apiaries were selected through the districts' apiculture departments in Guraferda (Kuja, Sega, and Chodit), Sheko (Gotika, Sheita, and Shimi), Yeki (Tepi Agricultural Research Center (TARC) at the station, Beko and Addis Berhan), Godare (Meti 02 and Mehal Meti) and Megeshi (Dush) as indicated in Fig. 1b. Then, a total of 12 sites were selected and honey bee colonies were established for honey samples. A total of 24 colonies of *Apis mellifera scutellata* honeybees were placed in Langstroth-type hives in the selected district of study zones. For each site, two colonies of honeybees were established for honey harvesting for melissopalynological analysis [22]. Fresh honey samples were collected from various districts, including Yeki, Guraferda, Sheko, Godare, and Mengesh, during both the major and minor harvest seasons, for laboratory analysis. A total of 72 honey samples were collected from the selected districts of the Sheka (18), Bench-Sheko (36), and Majagn (18) zones. These samples were taken using a simple random sampling method at the end of November, February, and April. The honey samples were stored at room temperature (25–30 °C) and then transported to the Holeta Bee Research Center for pollen analysis.

2.3. Melissopalynological analysis

Honey pollen analysis was carried out following the procedure adopted by Ref. [13] and [23] for the determination of the botanical composition and frequency of pollen types in honey. Approximately 10 g of each honey sample was mixed with 20 ml of warm water (40 °C). The solution was centrifuged at 2500 rpm for 10 min. The supernatant liquid was carefully sucked and decanted in a graduated centrifuge tube of the right size, to recover all the sediment. It is then centrifuged again for 10 min and the sediment volume reads in the graduated tube. After taking the complete suspension, it was available for use in the acetolysis method [24]. The sediment was mounted on slides in glycerin jelly (stained with safranine) and sealed with paraffin wax. The pollen grains thus prepared from each were examined under a light microscope with a 40× and 100× objective lens. Identification was done with the help of reference slides prepared from local flora, as well as published accounts [25]. The pollen grains obtained from the honey samples were identified and compared with the reference slides made from the identified plants. Pollen spectra were constructed on the basis of their percentages and hence the honey types of the area were determined. Pollen was categorized as predominant pollen (>45%), secondary pollen (16–45%), minor important minor pollen (3–15%) and minor pollen (<3%) according to Ref. [13].

2.4. Sampling techniques and sample size determination

Focus group discussions, key informant interviews, and personal observation were used to collect data on bee forage. Multistage purposive random sampling method was used to select Sheka, Bench-Sheko and Majegn zones based on the beekeeping potential. Six districts were randomly selected from the selected zone, namely Anderach, Yeki, Sheko, Guraferda, Godare and Mengesh. A total of 28 kebeles were randomly selected from these districts. Two focus group discussions were held in each kebele . The key informants were all beekeepers from different kebeles. A total of 69 focus groups with 8–12 beekeepers in each group were used in the discussion. Beekeepers were also asked to rank honeybee forage according to the importance and abundance of plants. In each district, five key informants were interviewed regarding the major bee flora with their flowering time, abundance, importance, seasonal forage availability and habits. Additionally, focus groups and key informant interviews were used to record data on honey harvesting seasons and honeybee management (Appendix A).

The absence of a colony is characterized as the whole colony abandoning the nest. In contrast to swarming, the entire colony leaves and likely searches for and locates a new nest location elsewhere, rather than the nest dividing into two or more parts. The process by which honeybee colonies reproduce and generate new colonies is known as natural swarming. It is the process by which the honey bee increases its chances of survival as a species [26]. Migration, on the other hand, refers to the movement of a honeybee colony across various biological zones [27]. The shortage of bee forage in this study is defined as the time when there is a shortage of plant flora in the areas. Colony dynamics determine whether the local honeybee population is growing or decreasing. The presence of male honey bees

Table 1
Annul temperature, rainfall range and altitude of selected zones in southwest Ethiopia.

Zones	Temperature (°C)	Rainfall range (mm)	Altitude (m.a.s.l.)
Bench-Sheko	20–40	1200–2000	850–3000
Sheka	15.1–27.5	1201–1800	1200–3000
Majagn	17.6–27.5	1401–1800	562–2444

m.a.s.l.: meters above seas level.

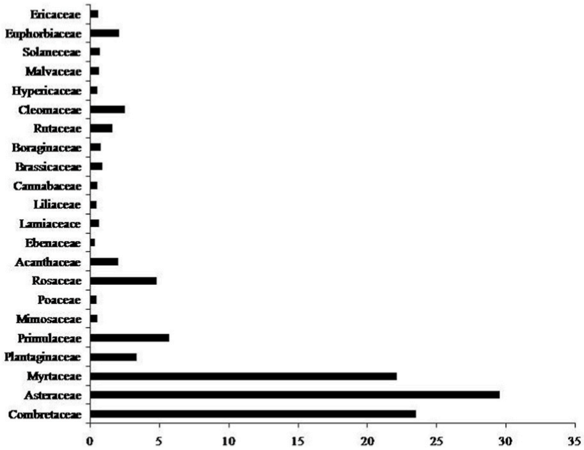

Fig. 2. Percentage of pollen grains of plant families for the honey of *Apis mellifera scutellata* from different plant sources in southwest Ethiopia.

in the colony indicates the availability of drones. Seasonal management of honey bee colonies includes manipulating the hive and hive space to provide room for the expanding brood-rearing area and the storage of surplus honey as needed. Poisonous plants are those that kill or paralyze honeybees when they come into contact with or ingest nectar or pollen from them [28].

2.5. Data analysis

All the collected data were analyzed using descriptive statistics and other related tools using SPSS software. The data were presented in frequency, table, and figure. The association between honeybee management and agro-ecology was tested using the χ^2-test. For all statistical analysis, 95% CI and a critical value of 0.05 was used.

3. Results and discussion

3.1. Melissopalynological analysis of honey

A total of 31 pollen types and 22 plant families were identified in 72 honey samples using melissopalynological analysis (Table 3, Figs. 2 and 3). Of all the honey samples that were tested, the majority (93.06%) were found to be multifloral, while the remaining 6.94% were monofloral (Table 2).The melissopalynological analysis of honey is crucial to determine both its geographical and botanical origin [15]. This method provides more accurate results compared to visual surveys, making it an essential tool for studying honeybee forage and the development of regional apiculture [18]. *Terminalia* species (Combretaceae) and *Guizotia* species (Asteraceae) were the type of secondary pollen observed in all agroecology honey, while *Eucalyptus camaldulensis* (Myrtaceae) was the type of secondary pollen in highland and midland agroecology honey. *Bidens* species were also secondary pollen types in lowland honey (Table 3). The diversity of important minor and minor honey source plant species was higher than the predominant and secondary pollen types.

This result showed that naturally occurring plants, eg, *Terminalia* spp., *Acacia* spp., *Croton* spp., and cultivated plants, eg *Zea mays*, *Eucalyptus camaldulensis*, and *Bidens* spp. were the floral source for honeybees. This is consistent with the findings of [29,30]; and [31]; who stated that honeybee foraging on multiple plant species from natural as well as agricultural ecosystems due to this different pollen spectrum was observed in honey. *Terminalia* spp., *Guizotia* spp., *Vernonia* spp., *Bidens* spp., *Plantago* spp. and *E. camaldulensis* were pollen types recorded in different agroecology (Table 3). *Acacia* spp., *Olea* spp., *Hypericm qurtinianm*, *Pavonia schimperiana*, *Celtis kraussiana* and *Cleome* spp. were the pollen types recorded in honey samples obtained in specific areas (Table 3). The occurrence of common and specific pollen types in honey samples can be attributed to the distribution and diversity of plants in a particular area depending on the agroecology of the area [32]. In the current study, pollen types that had no confirmed botanical affinity were called 'undetermined'.

The type of pollen *E. camaldulensis* (Myrtaceae) in lowland honey was identified as the predominant pollen type, which was considered as monofloral honey (Tables 2 and 3). Monofloral honey is usually produced from one plant species [33] and pollen amounts to more than 45% of the total pollen content. This may be due to the floral constancy behavior of honeybees that help to stay in a single species of plant reward food and continue until the flower ends the production of nectar or pollen [15,34]. Reviews by Ref. [8] showed that *E. camaldulensis* is one of the most important honeybee forage plants that provided monofloral honey in Ethiopia. Similarly to this finding [35], found that *E. camaldulensis* was a significant source of honey plants in the Wando district that produced monofloral honey. The honey samples collected from the three agroecology areas had several pollen types with low density and were therefore classified as multiflora honey (Tables 2 and 3). This may be due to honeybees preferring specific flora based on the availability of flora in a specific region and bees less frequently visiting flowering plant species in a particular region [31,32]. Consistent

Table 2
Number of pollen by origin area and honey type in study area.

Site	District	Total number of pollen per slide	Classification of honey
Kuja1 (K1)	Guraferda	211 (12.79)	Multifloral
Kuja2 (K2)	Guraferda	8289 (50.25)	Monofloral
Kuja3 (K3)	Guraferda	220 (1.33)	Multifloral
Kuja4 (K4)	Guraferda	570 (3.46)	Multifloral
Kuja5 (K5)	Guraferda	551 (3.34)	Multifloral
Kuja6 (K6)	Guraferda	660 (4.00)	Multifloral
Sega1 (S1)	Guraferda	125 (0.75)	Multifloral
Sega2 (S2)	Guraferda	857 (5.20)	Multifloral
Sega3 (S3)	Guraferda	335 (2.03)	Multifloral
Sega4 (S4)	Guraferda	1056 (6.40)	Multifloral
Sega5 (S5)	Guraferda	263 (1.59)	Multifloral
Sega6 (S6)	Guraferda	145 (0.88)	Multifloral
Chodit1 (CH1)	Guraferda	665 (4.03)	Multifloral
Chodit2 (CH2)	Guraferda	458 (2.78)	Multifloral
Chodit3 (CH3)	Guraferda	600 (3.64)	Multifloral
Chodit4 (CH4)	Guraferda	225 (1.36)	Multifloral
Chodit5 (CH5)	Guraferda	605 (3.67)	Multifloral
Chodit6 (CH6)	Guraferda	660 (4.00)	Multifloral
Gotika1(G1)	Sheko	737 (5.61)	Multifloral
Gotika1(G2)	Sheko	6307 (48.01)	Monofloral
Gotika1(G3)	Sheko	881 (6.71)	Multifloral
Gotika1(G4)	Sheko	742 (5.65)	Multifloral
Gotika1(G5)	Sheko	537 (4.09)	Multifloral
Gotika1(G6)	Sheko	2232(16.99)	Multifloral
Sheita1(SH1)	Sheko	1250 (9.52)	Multifloral
Sheita1(SH2)	Sheko	2501 (19.04)	Multifloral
Sheita1(SH3)	Sheko	716 (5.45)	Multifloral
Sheita1(SH4)	Sheko	1098 (8.36)	Multifloral
Sheita1(SH5)	Sheko	339 (2.58)	Multifloral
Sheita1(SH6)	Sheko	996 (7.58)	Multifloral
Shimi1 (SHI1)	Sheko	116 (0.88)	Multifloral
Shimi1 (SHI2)	Sheko	142 (1.08)	Multifloral
Shimi1 (SHI3)	Sheko	3385 (25.77)	Multifloral
Shimi1 (SHI4)	Sheko	118 (0.09)	Multifloral
Shimi1 (SHI5)	Sheko	440 (3.35)	Multifloral
Shimi1 (SHI6)	Sheko	600 (4.57)	Multifloral
TARC on station1 (TARC1)	Yeki	6222 (49.33)	Monofloral
TARC on station2 (TARC2)	Yeki	2354 (18.66)	Multifloral
TARC on station3 (TARC3)	Yeki	677 (5.37)	Mutifloral
TARC on station4 (TARC4)	Yeki	105 (0.83)	Multifloral
TARC on station5 (TARC5)	Yeki	2110 (16.73)	Multifloral
TARC on station6 (TARC6)	Yeki	202 (1.60)	Multifloral
Site	District	Total number of pollen per slide	Classification of honey
Beko1 (BE1)	Yeki	120 (0.95)	Multifloral
Beko2 (BE2)	Yeki	1038 (8.23)	Multifloral
Beko3 (BE3)	Yeki	118 (0.94)	Multifloral
Beko4 (BE4)	Yeki	225 (1.78)	Multifloral
Beko5 (BE5)	Yeki	225 (1.78)	Multifloral
Beko6 (BE6)	Yeki	108 (0.85)	Multifloral
Addis Berhan1 (AD1)	Yeki	330 (2.62)	Multifloral
Addis Berhan2 (AD2)	Yeki	225 (1.78)	Multifloral
Addis Berhan3 (AD3)	Yeki	330 (2.62)	Multifloral
Addis Berhan4 (AD4)	Yeki	225 (1.78)	Multifloral
Addis Berhan5 (AD5)	Yeki	338 (2.68)	Multifloral
Addis Berhan6 (AD6)	Yeki	660 (5.23)	Multifloral
Meti02-1 (M-02-1)	Godare	465 (6.61)	Multifloral
Meti02-2 (M-02-2)	Godare	997 (14.17)	Multifloral
Meti02-3 (M-02-3)	Godare	432 (6.14)	Multifloral
Meti02-4 (M-02-4)	Godare	3400 (48.32)	Monofloral
Meti02-5 (M-02-5)	Godare	158 (2.25)	Multifloral
Meti02-6 (M-02-6)	Godare	445 (6.32)	Multifloral
Mehal Meti 1 (MM1)	Godare	220 (3.13)	Multifloral
Mehal Meti 2 (MM2)	Godare	448 (6.37)	Multifloral
Mehal Meti 3 (MM3)	Godare	332 (4.72)	Multifloral
Mehal Meti 4 (MM4)	Godare	225 (3.20)	Multifloral
Mehal Meti 5 (MM5)	Godare	114 (1.62)	Multifloral
Mehal Meti 6 (MM6)	Godare	800 (11.37)	Multifloral

(*continued on next page*)

Table 2 (*continued*)

Site	District	Total number of pollen per slide	Classification of honey
Dush1 (DU1)	Mengesh	258 (4.15)	Multifloral
Dush2 (DU2)	Mengesh	660 (10.62)	Multifloral
Dush3 (DU3)	Mengesh	465 (7.49)	Multifloral
Dush4 (DU4)	Mengesh	997 (16.05)	Multifloral
Dush5 (DU5)	Mengesh	432 (6.95)	Multifloral
Dush6 (DU6)	Mengesh	3400 (54.73)	Monofloral

TARC: Tepi Agricultural Research Center.

Table 3
Honey pollen analysis categories of honey source plants in southwest Ethiopia.

Plant family	Pollen type	Honey sample/frequency classes (%)				
		Guraferda	Sheko	Yeki	Godare	Mengesh
Combretaceae	*Terminalia* spp	25.96	17.98	35.24	7.11	6.89
Mimosaceae	*Acacia* spp	2.39				
Asteraceae	*Bidens* spp	2.49	5.33	17.61	15.25	14.45
	Guizotia spp	17.80	16.04	17.01	6.61	7.03
	Vernonia spp	3.80	3.86	5.65	0.31	0.25
Myrtaceae	*Eucalyptus camaldulensis*	6.25	16.58	19.65	52.02	48.36
	Syzygium spp	0.68	0.58		2.42	3.06
Plantaginaceae	*Plantago* spp	4.82	5.30	0.88	1.56	0.89
Primulaceae	*Maesa lanceolata*	7.94	9.96	1.89		
Poaceae	*Zea mays*	0.03		0.03		
Rosaceae	*Pygeum africanum*	7.88	8.99			
	Rubus steudneri				0.15	0.21
Acanthaceae	*Justicia schimperiana*	0.51	5.09	0.15		
	Hypoe stestrifolia		0.06		0.31	0.45
Ebenaceae	*Euclea keniensis*	0.65	0.63			
Lamiaceae	*Ocimume bacilium*	0.74		1.00		
	Plectranthus spp	0.68		0.21		
	Ceanothus africanus				0.43	0.72
Liliaceae	*Olea* spp	0.09				
Rutaceae	*Clausena anisata*	10.21		0.21		
Cannabaceae	*Celtis kraussiana*	6.80				
Brassicaceae	*Lepidium sativum*	0.17	1.02	0.03		
Boraginaceae	*Trichodesma* spp	0.11	0.69			
Cleomaceae	*Cleome* spp		7.26			
Hypericaceae	*Hypericm qurtinianm*		0.02			
	Dombeya aethiopia				0.18	0.12
Malvaceae	*Pavonia schimperiana*		0.26			
Solaneceae	*Datura* spp		0.29	0.21	0.49	0.38
Euphorbiaceae	*Croton* spp		0.06		0.69	0.54
	Acalypha indica				12.24	9.56
Ericaceae	*Erica arborea*			0.25	0.23	0.43

Frequency classes: predominant pollen (>45%), secondary pollen (16–45%), important minor pollen (3–15%), minor pollen (<3%).

with the findings of [32]; the present result identified that several honey samples had a mixture of secondary pollen, important minor pollen, or minor pollen and could be categorize as multiflora honey. The existence of pollen types of cultivated plants in honey samples like *Zea mays* (Mytaceae) indicates that agro-ecosystems provide floral sources of bees. This plant is important for the survival and production of honeybees, particularly when natural flowering plants are not blooming. Similar findings were observed in Kenya by Refs. [32,36]. Cultivated crops produced unique honey, therefore management of the agro-ecosystem in the areas can help the survival of honeybees and increase honey yield. Most of the honey bee plants identified by pollen analysis from honey samples were similar to those of beekeepers response to honey bee flora in the study areas.

Melissopalynology, which is the study of pollen grains present in honey to identify plant species visited by bees while foraging for nectar, is essential to assess the quality, origin, and potential medicinal properties of honey samples [37]. In the case of African honey, pollen grains can be used to identify floral sources that contribute to the unique taste and aroma of honey. African honeys are known to contain a high diversity of pollen types, including some peculiar African pollen that cannot be found anywhere in the world [38].

Several studies have documented the pollen spectra of different African regions, including Ethiopia. Consistent with this finding [39], conducted a study on the pollen spectra of honeys from various regions of Ethiopia. The study identified several pollen types commonly found in African regions, such as Eucalyptus, Acacia, and Brassica. Furthermore, various pollen images atlases, such as the "Pollen Atlas of the Tropics of Africa" by Ref. [40] in West Africa [41] in South Africa, and [42] in East Africa, are available to compare and identify different pollen types.

A recent study by Refs. [32,43] on the characterization of Nigerian and Kenyan honey, respectively, using melissopalynology

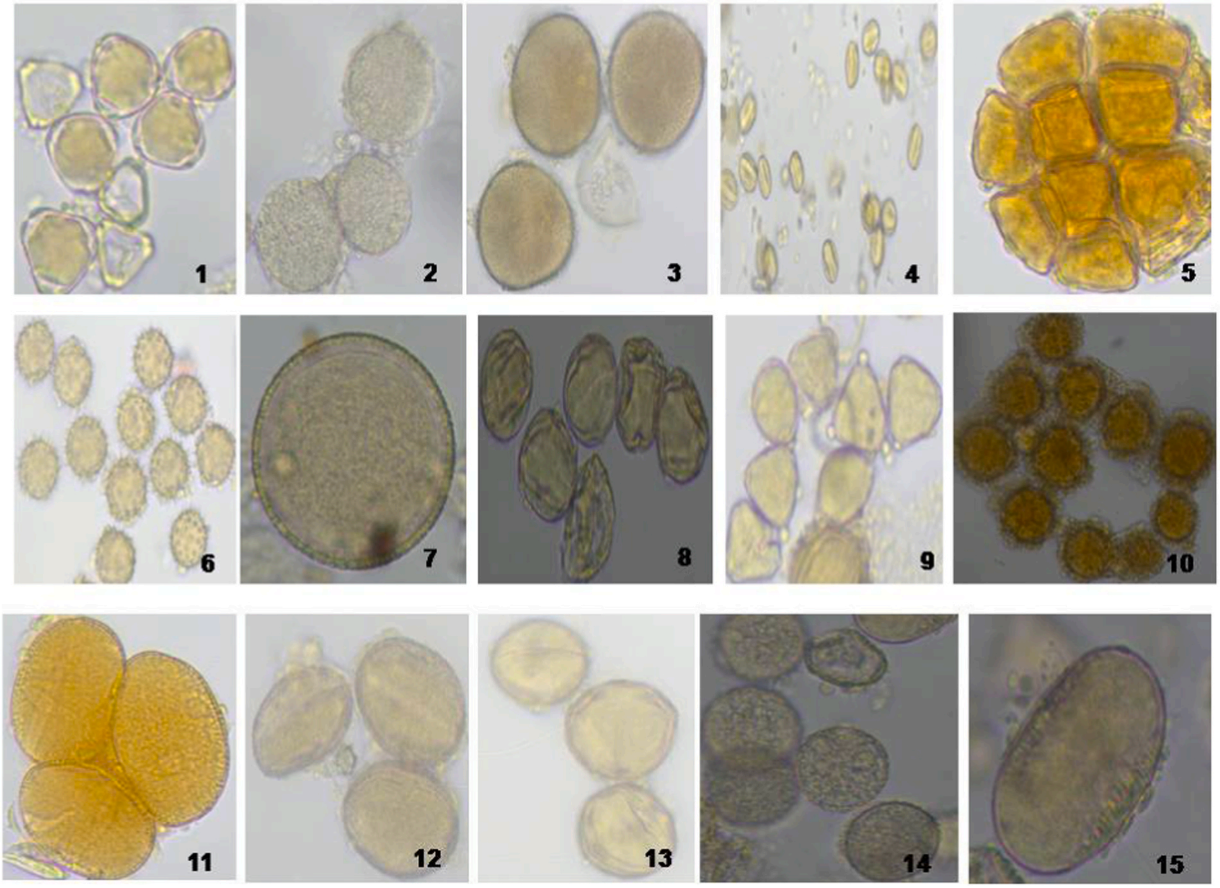

Fig. 3. Pollen grain shapes of some plant species mention in the study (1) *Eucalyptus camaldulensis* (2) *Plantago* spp. (3) *Zea mays* (4) *Terminalia* spp. (5) *Acacia* spp. (6) *Guizotia* spp. (7) *Croton* spp. (8) *Coffee arabica* (9) *Syzgium* spp. (10) *Vernonia* spp. (11) *Bidens* spp, (12) *Hypoes testrifolia* (13) Euclea keniensis (14) *Ocimume bacilium* (15) *Justicia schimperiana*.

included images of pollen grains in their report, which also supports the present study. These images provided visual aids for identifying the different types of pollen found in honey samples. It is crucial to authenticate honeys related to Ethiopia since honey adulteration is a common issue in the industry. Several studies have used melissopalynology to authenticate honey samples from different regions around the world [44,45]. Thus, discussing the results obtained in terms of the authenticity of Ethiopian honey can provide valuable information on the quality and purity of honey samples.

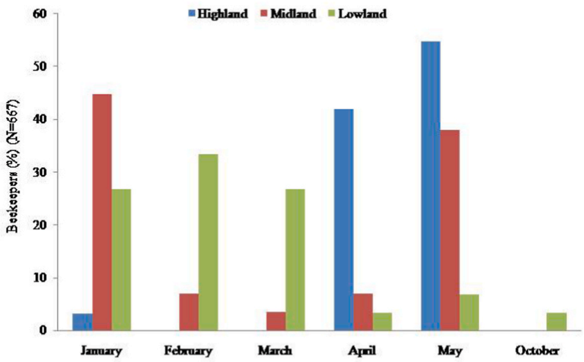

Fig. 4. Major honey harvesting season in different agro-ecology in southwest Ethiopia.

3.2. Honey harvesting seasons

A significant difference was observed in the honey harvesting seasons in the lowland, midland and highland agroecological zones. The majority (54.82%) of beekeepers harvested honey in May followed by April (41.89%) in the highlands (Fig. 4), while January (41.93%) and December (19.38%) were the minor honey flow months in the highlands (Fig. 5). February (33.33%) and January (26.71%) were the main honey flow months in lowland areas, with the minor honey flow in May (26.73%) as indicated in Figs. 3 and 4. Similarly, the major honey harvesting season was observed in January (44.81%) in midland areas, whereas a minor honey flow season was recorded in May (27.61%) in the spring season. This may be due to the fact that the distribution of natural vegetation and cultivated crops is different in agroecology. Additionally, the flowering season of the bee flora was different from place to place due to the diversity of plant habitats and environmental conditions [46]. Similarly to the present findings [47], reported that the honey harvesting seasons were different between different agroecology in the Sheka zone in the southwest part of the country. This finding also agrees with the previous study of [48] who reported that spring (April and May) is the major honey harvesting season and the end of autumn (November) and winter (January and February) is the minor harvesting season in selected zones of southwest Ethiopia. The current findings indicated that the honey harvesting cycle ranged from two to three times a year in southwest Ethiopia. This is in agreement with the previous findings [49–51], who observed that most beekeepers harvested honey 2–3 times a year in Ethiopia.

3.3. Abundance of bee forage in different agroecology

The abundance and preference ranking of the bee flora for honey production was carried out through group discussion and key informant interviews. The abundance and priority uses of bee forage varied across agroecology; this may be due to the difference in vegetation type among various agroecology. In the current study, *Schefflera abyssinica* was the first plant prioritized for honey source in highland agroecology (Table 4). The abundance of *S. abyssinica* was attributed to its widespread distribution in the highlands of the southwest part of Ethiopia [17]. Consistent with the present result [46], indicated that *S. abyssinica* was a more frequent honey source in a highland area of the Jimma zone. Additionally, a previous study conducted in highland agroecology also indicated *S. abyssinica* as the main honey source [50]. *Vernonia amygdalina*, *Coffea arabica*, *Croton macrostachys*, and *Cordia africana* were flora of bees frequently observed in all agroecology (Table 4). These findings indicated that the bee flora was the source of nectar and pollen at different months and days. *V. amygdalina* was ranked first in the bee flora in the lowlands and second in the midlands and highlands in the present study (Table 4). This result also indicated that *V. amygdalina* had a wider distribution and was the most important source of nectar and pollen in all agroecology. This result agrees with the finding of [17]; who stated that *V. amygdalina* is the most abundant bee forage in midland agroecology. In the current study, *C. africana* was the first prioritized tree and most abundant bee forage in lowland agroecology. The quantity and quality of honey yield were affected by the types of bee forage available in the areas [52].

3.4. Honey bee management in different agroecologies

The highest shortage of bee forage was observed during August in highland (76.89%), while the highest shortage of bee forages was recorded in October in lowland (63.48%) with a significant difference ($P < 0.05$) (Table 5). Refs. [53,54] reported that the shortage of honeybee forage was one of the major constraints to the development of beekeeping, which is consistent with the findings of this study. Seasonal colony management showed a significant difference ($P < 0.05$) among different agroecology with maximum management required in January in all agroecology and since the highest brood developed during this month (Table 5).

Natural swarming occurred in December in all agroecology with a significant difference ($P < 0.05$) among different agroecology (Table 5). Honeybees collected more pollen during the major flowering season, and the colony population increased with it [55]. Swarm cell usually occurs in very strong colonies and causes the honeybee colony to swarm. Moreover, large numbers of queens emerge during the major flowering season, and this causes honeybees to swarm [53]. These seasons provide an opportunity for the beekeeper to prepare their colony for colony multiplication purposes or to maximize their honey production.

The present study showed that a high absconding problem occurred in August in midland, resulting in significant differences ($P < 0.05$) among agroecology (Table 5). This may be due to a shortage of honeybee forage. Although swarming is a natural reproductive process in which a colony is split, absconding occurs when all bees leave the hive. Absconding is associated with low flowering plant

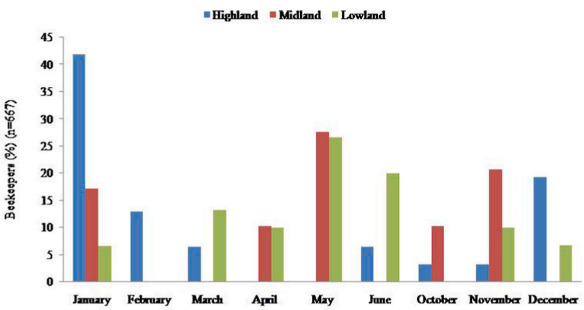

Fig. 5. Minor honey harvesting season in different agro-ecology in southwest Ethiopia.

Table 4
Abundance and priority in the importance of major honey bee forage species in southwest Ethiopia.

Agro-ecology	Scientific name	Local name	Abundance	Rank
Highland	*Schefflera abyssinica*	Geteme	More abundant	1
	Vernonia amygdalina	Grawa	Abundant	2
	Coffea arabica	Buna	Abundant	3
	Croton macrostachyus	Bisana	Abundant	4
	Persea americana	Avocado	Abundant	5
	Cordia africana	Wanza	Abundant	6
	Ficus sur	Shola	Medium	7
	Eucalyptus camaldulensis	Bahrzaf	Medium	8
	Opuntia ficus-indica	Qulkual	Medium	9
	Bidens macroptera	Adeyabeba	Abundant	10
Midland	*Vernonia amygdalina*	Grawa	More abundant	1
	Croton macrostachyus	Bsana	Abundant	2
	Schefflera abyssinica	Geteme	Abundant	3
	Zea mays	Bekolo	Abundant	4
	Cordia africana	Wanza	Abundant	5
	Mangifera indica	Mango	Abundant	6
	Carica papaya	Papaya	Medium	7
	Persea americana	Avocado	Medium	8
	Celosia argentea	Beklbelto	Abundant	9
	Coffea arabica	Buna	Abundant	10
Lowland	*Cordia africana*	Wanza	More abundant	1
	Vernonia amygdalina	Grawa	Abundant	2
	Combretaceae	Avalo	Abundant	3
	Albizia gummifera	Sesa	Abundant	4
	Croton macrostachyus	Bisana	Abundant	5
	Coffea arabica	Buna	Abundant	6
	Polyscias fulva	Yeznjerowenber	Abundant	7
	Bidens macroptera	Adeyabeba	Abundant	8
	Persea americana	Avocado	Abundant	9
	Ficu sur	Shola	Medium	10

Table 5
Honey bee management in different agro-ecology in southwest Ethiopia.

Variables	Categories	Study districts			Chi-square (χ^2)	
		Highland (%)	Lowland (%)	Midland (%)	Value	*P*-value
Shortage of bee forage	August	76.89	36.52	51.22	24.69	0.040
	October	23.12	63.48	48.81		
Seasonal colony management	January	57.61	66.73	90.00	7.84	0.020
	September	42.41	33.33	10.00		
Major colony dynamic	Yes	97.00	100.00	96.72	3.73	0.500
	No	3.00	0,00	3.33		
Occurrence of brood	January	72.13	73.14	87.00	36.44	0.010
	December	15.24	15.42	6.54		
	April	12.11	11.48	6.48		
Colony migration	August	57.48	69.68	10.33	28.53	0.200
	September	15.16	4.33	6.91		
	February	15.22	4.31	13.84		
	July	12.13	21.74	69.00		
Natural swarming of the colony	January	33.28	26.93	35.68	35.22	0.040
	December	51.49	68.91	53.63		
	February	15.21	4.22	10.72		
Absconding of colony	September	41.91	11.51	3.44	34.53	0.020
	July	25.87	23.11	31.00		
	August	32.28	34.57	65.64		
Drone availability	April	66.72	3.83	17.61	17.64	0.500
	January	16.67	21.41	23.47		
	December	16.72	74.79	58.85		
Poisonous plant	Yes	24.15	7.74	51.63	13.78	0.001
	No	75.82	92.33	48.44		

density, and a shortage of honeybee forage causes honeybee colonies to abscond [56]. In agreement with this result, absconding could also be caused by drought, overgrazing, deforestation, honeybee disease, pest, predatory, water shortage, poor bee manipulation, and lack of protection against bad weather conditions [57].This supports previous findings [54] that absconding could occur in both traditional and improved hives and result in a significant financial loss. Therefore, beekeepers must provide supplement feed and prevent colonies from natural enemies and pesticides during the shortage period.

The poisonous plants of honeybees were significantly ($P < 0.05$) higher in midland agroecology than in other agroecology (Table 5). These plants are causes of death or paralysis of honeybees when they come in contact with or ingest nectar or pollen from poisonous plants, and also honey produced from these plants is toxic to humans [28,6]. This may be due to the insecticidal property of these plants [58]. According to Refs. [46,48], *Euphorbia cotinifolia* and *Azadirachta indica* are poisonous plants for honeybees in southwest Ethiopia. This result also agrees with [59] who reported that these plants are poisonous to honeybees, and also honey produced from those plants could affect human health. In contrast to this finding [60], indicated that *Euphorbia cotinifolia* was nontoxic to honeybees. This difference may be due to variations in agroecology, the genotype of plants, stage, and parts of plants.

Results of the present study contribute to the beekeeper to manage their colonies by installing hives, re-queen colonies, harvesting honey, and honey bee products. The dearth period was long and short based on agroecology and knowledge of bee flora helping the beekeeper's effective management of bee colony [61]. The peak of the honey harvesting season varies depending on colony management practices, agroecology, and the flowering condition of honeybee flora [62].

3.5. Honey bee flora

Most of the bee forages identified in the study areas were dominated by herb (41.50%) followed by trees (30.20%) and shrubs (28.30%). According to the findings of [35]; herbaceous plants predominated as honeybee forage in the west Arsi and east Shewa zones. Similar findings were reported by Ref. [11] , who identified that *Schefflera abyssinica*, *Acacia* spp., and *Croton macrostachyus* were the three pollen types that honeybee foragers most favored. Beekeepers also reported that the flowering month and flowering period depend on the activity of honeybees related to the frequency, time of visits and duration of foraging for a single type of honeybee plant (Table 6, Appendix A). Knowledge about the identification of bee flora helps beekeepers to recognize the honey harvesting season and the management of beehives [63].

3.6. Limitations of the study

The study focused only on the main plants used by honeybees and did not examine other factors such as climate, disease, and beekeeping techniques. Additionally, it did not analyze the effects of pesticides or changes in land use on bee feed and honey production. Despite these limitations, the study provided valuable information on the primary plant resources of honeybees in the study area, highlighting the need to combine beekeeping with vegetation conservation to improve livelihoods and food security. However, more research is necessary to overcome these limitations and gain a more comprehensive understanding of the availability of bee feed in Ethiopia. Future studies could utilize molecular methods to identify and quantify the diversity and nectar composition of the plants used by honeybees in the area.

4. Conclusions

The present study provides basic information about the sources of honeybee flora in the study areas. The study showed that *Terminalia* spp, *Guizotia* spp, and *Bidens* spp. were the secondary important pollen sources in the areas. However, *E. camadulensis* was identified as the predominant pollen type in the study areas. *Terminalia* spp, *Guizotia* spp, *Vernonia* spp, *Bidens* spp, *Plantago* spp, and *E. scamaldulensis* were pollen types recorded in honey samples in all agroecologies. Bee forage shortages, the appearance of brood, swarming, absconding, poisonous plant, and seasonal management were significantly varied between different agroecology. Therefore, beekeeping should be integrated with the conservation of honeybee floral resources and the plantation of fast-growing honeybee plants around apiaries. Furthermore, existing bee flora should be cultivated in areas to increase the harvesting of honeybee products and improve the apiculture industry.

Author contribution statement

Dereje Tulu; Melkam Aleme; Gezahegn Mengistu; Ararsa Bogale: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Amsalu Bezabeh; Esayas Mendesil: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Data availability statement

Data will be made available on request.

Additional information

Supplementary content related to this article has been published online at [URL].

Declaration of competing interest

The authors declare no conflict of interest.

Table 6
Honeybee flora and their flowering month, period of flowering, and habit of plants in southwest Ethiopia.

Scientific name	Vernacular name	Flowering month	Flowering period (days)	Habit
Agave sisalana	Kacha	January	Thirty	Shrub
Mangifera indica	Mango	January	Twenty	Tree
Capsicum annuum	Berberea	January	Fifteen	Herb
Aningeria altissima	Qerero	January	Thirty	Tree
Rumex nervosus	Imbuacho	January	Thirty	Shrub
Nicandra physalodes	Atefaris	January	Thirty	Herb
Vernonia amygdalina	Grawa	January to February	Twenty	Shrub
Isodon schimperi	Yefyel gomen	February	Twenty	Shrub
Hydrophila auriculata	Amekiela	February	Twenty	Herb
Coffea arabica	Buna	March	Fifteen	Shrub
Schefflera abyssinica	Geteme	April	Thirty	Tree
Albizia gummifera	Sesa	April	Thirty	Tree
Catha edulis	Chat	April	Fifteen	Shrub
Ocimum lamiifolium	Damakesi	April	Fifteen	Herb
Phylolacca dodecandra	Endod	April	Twenty	Shrub
Rumex nepalensis	Tult	April	Thirty	Herb
Polyscias fulva	Yezinjero wenber	April	Twenty	Tree
Croton macrostachys	Bisana	May	Twenty	Tree
Eucalyptus camaldulensis	Bahirzaf	May	Thirty	Tree
Coriandrum sativem	Dimblal	May	Fifteen	Herb
Zantedeschia aethiopica	Yeturubaabeba	May	Twenty	Herb
Celosia argentea	Beklbelto	May	Fifteen	Herb
Carica papaya	Papaye	June	Fifteen	Shrub
Medicago polymorpha	Wajima	June	Fifteen	Herb
Cordia africana	Wanza	September	Twenty	Tree
Acanthaus sennii	Koshashila	September	Twenty	Herb
Lycopersicon esuculentum	Timatim	September	Twenty	Herb
Physalis peruviana	Aetii	September	Thirty	Herb
Schimus molle	Birbira	September	Thirty	Tree
Ficus sur	Shola	September	Thirty	Tree
Scientific name	Vernacular name	Flowering month	Flowering period (days)	Habit
Psidium guajava	Zeytuna	September	Twenty	Tree
Achyranthes aspera	Telej	September	Thirty	Herb
Rumex nepalensis	Tult	September	Thirty	Herb
Persea americana	Avocado	October	Fifteen	Tree
Polygala steudneri	Antid	October	Fifteen	Herb
Phoenix reclinata	Zembaba	October	Thirty	Tree
Ficus vasta	Warka	October	Twenty	Tree
Citrus aurantifolia	Lomi	October	Thirty	Tree
Dombeya torrida	Wulkfa	October	Thirty	Tree
Guizotia abyssinica	Nug	October	Fifteen	Herb
Kalanchoe densiflora	Endahulla	October	Thirty	Herb
Bidens macroptera	Adeyabeba	November	Twenty	Herbs
Ricinus communis	Gulo	November	Twenty	Shrub
Cucurbita pepo	Duba	November	Fifteen	Herb
Zea mays	Bekolo	November	Ten	Herb
Polyscias fulva	Yezinjerowenber	November	Twenty	Tree
Sorghum bicolor	Mashila	December	Fifteen	Herb
Combretaceae	Avalo	December	Twenty	Shrub
Brassica carinata	Gomen	December	Fifteen	Herb
Opuntia ficus-indica	Qulqual	December	Fifteen	Shrub
Musa x paradisiaca	Muzi	December	Twenty	Shrub
Maesa lanceolata	Kelewa	December	Twenty	Shrub
Detura arborea	Turubaabeba	December	Thirty	Shrub
Justitia schimperana	Sensel	December	Thirty	Shrub

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e16047.

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