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Seasonal variation and characterisation of pollen collected by honeybee *Apis mellifera scutellata* Lepeletier in southwest Ethiopia

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Abstract
The ability of honeybees to successfully grow, reproduce and build strong colonies and produce honey depends on their ability to obtain enough resources from flowering plants within appropriate seasons. However, little is known about seasonal variations and characterisation of honeybee pollen collected in Ethiopia. Therefore, to address this, a total of 2160 pollen samples were collected from five districts in different seasons for two years. The pollen samples were acetolysed and taxonomically identified. The pollen type was classified into frequency categories based on its relative abundance. Diversity indices and species richness were also calculated and compared between districts and seasons. The highest species richness was recorded in Guraferda district, while the lowest was recorded in Godare district. The spring season was considered the most suitable as it has the highest richness in all districts. The 'predominant' and 'secondary' pollen sources were identified from different plant genera in Asteraceae (62.23%), Mimosaceae (23.59%), Myrtaceae (43.76%), Poaceae (27.25%), Rubiaceae (36.64%), Combretaceae (28.14%), Euphorbiaceae (18.97%), Burseraceae (16.35%), Convolvulaceae (16.52%), Solanaceae (21.40%), Icacinaceae (17.86%), and Dichapetalaceae (16.35%). *Terminalia* spp. (Combretaceae) had the highest pollen counts and are common in the area. Other species with significant pollen counts included *Acacia* spp. (Mimosaceae), *Croton macrostachyus* (Euphorbiaceae), *Eucalyptus camaldulensis* (Myrtaceae), *Vernonia* spp. (Asteraceae) and *Iodes* spp. (Icacinaceae). This study indicated that southwest Ethiopia has great potential for honey production and beekeeping business based on the study of pollen collected. Thus, these results help as a guide to the optimal use of flora resources by a honeybee in the areas.

Keywords: *apiculture, bee flora, melissopalynology, pollination*

Honeybees (*Apis mellifera scutellata* Lepeletier) provide valuable ecosystem service through pollination resulting in significant crop production (Hung et al. 2018; Ochungo et al. 2021). This essential environment amenity occurs as pollinators forage and collect nectars and pollen that they require for their growth (Di Pasquale et al. 2013). Pollen grains are the main source of protein, providing honeybees with ten amino acids that are important for brood rearing and queen feeding (Brodschneider & Crailsheim 2010; Wright et al. 2018). Furthermore, it is the source of lipids, microelements, minerals, vitamins, and other microcomponents that are essential for the development of honeybee colonies (Ghosh et al. 2020; Al-Kahtani et al. 2021). However, a deficiency in the quantity and quality of pollen can cause a reduction in brood rearing and even cannibalism (Albuquerque et al. 2014; Lau et al. 2019).

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Information about pollen flow periods helps to decide when pollen substitutes or supplements should be provided in an apiary, resulting in improved colony development (Dimou & Thrasyvoulou 2007). The ability of honeybees as foragers to collect pollen grains was influenced by the number of larvae (brood), the number of pollen stored in the colony, the genotype of the forager and the available resources in the environment (Bilisik et al. 2008; Ghosh et al. 2020). The honeybee collects pollen from the stamens of flowers moistened with nectar by the saliva secreted by the honeybee and agglutinated on hind legs, called a pollen load (Garcia-Garcia et al. 2001). Honeybee colonies regulate pollen collection according to the requirements of each colony, and a colony of approximately 20,000 bees needs an average of 7 kg of pollen per year (Al-Kahtani et al. 2021).

Ethiopia is endowed with natural flora and has a diverse agroecological and climatic condition that is suitable for beekeeping in the local area. Specifically, the southwest part of the country has suitable climates that favour high population density of honeybees and forest beekeeping practices (Tulu et al. 2020; Tadesse et al. 2021). The availability of floral plants limits the production and productivity of honeybees and is a very important field for honey beekeepers (Chala et al. 2013; Teklu 2017; Tulu et al. 2020). In Ethiopia, flowering plants of six to seven thousand species are spread across various agroecological zones. This makes the country highly suitable for honeybees and beekeeping business; however, most traditional beekeepers have no information on the vegetation that shelters the plants used by honeybees (Gidey & Mekonen 2010). Therefore, melissopalynological findings are the most important techniques in beekeeping industries that provide important information about botanical and geographical origins (Brodschneider et al. 2019; Ara Begum et al. 2021). Furthermore, this method demonstrated that pollen grain analysis collected by honeybees provides the most important information on the sources of plants visited by honeybees in the areas. The pollen collection by honeybees was different between seasons and was affected by the availability of the main pollen sources (Tulu et al. 2023).

Southwest Ethiopia is endowed with a diversified type of vegetation and is expected to have potential for honey production however, so far there is limited information on pollen foraging preferences of colonies in the study areas. Thus, a seasonal study of pollen load could lead to the identification of the optimal season for the harvesting of pollen grains and honeybee management (Negrao & Orsi 2018; Shawer et al. 2021). This result contributes to the development of the beekeeping industry and commercial honey production in Ethiopia. In addition, knowledge of the abundance of honeybee plants helps to determine the carrying capacity of the colony. A limited study on seasonal variation and pollen characterisation collected by honeybees in Ethiopia, particularly in the southwest part of the country (Tulu et al. 2023), prompted this investigation into seasonal fluctuations and pollen grains collected by honeybees (*Apis mellifera scutellata*).

Materials and methods

Description of the study areas

The study was carried out in five districts of the Sheka, Bench-Sheko and Majagn zones in southwest Ethiopia, namely Yeki, Guraferda, Sheko, Godare and Megesh districts. The Bench-Sheko and Sheko zones are located southwest of Addis Ababa, the capital city of Ethiopia, at 561 and 694 km, respectively. These districts are divided into two agroecological zones: midland (Sheko) and lowland (Yeki, Guraferda, Godare, and Mengesh). The Bench-Sheko zone is located at an altitude ranging from 850 to 3000 m above sea level. The annual average temperature in the Bench-Sheko zone ranged from 20 °C to 40 °C and the annual rainfall ranges from 1200 to 2000 mm. The Sheka zone is located at an altitude ranging from 1200 to 3000 m above sea level. The annual average temperature in the Sheka zone ranges from 15.1 °C to 27.5 °C and the annual mean rainfall ranges from 1201 to 1800 mm. The Majagn zone is located between 7°19′ 60.00″ N latitude and 35° 09′ 60.00″ E longitudes. The altitude of the zone ranges from 550 to 1260 m above sea level and honey production is the main income of the inhabitants of the study area.

Site selection

In this study, the Bench-Sheko, Sheka and Majagn zones were selected purposively based on the potential of beekeeping practices. Five districts were selected, i.e. Yeki, Guraferda, Sheko, Godare, and Megeshi. Volunteer beekeepers who managed honey colonies in apiaries were selected through the district apiculture departments in Guraferda (Kuja, Sega and Chodit), Sheko (Gotika, Sheita and Shimi), Yeki (Selam, Beko and Addis Berhan), Godare (Meti 02 and Mehal Meti) and Megeshi (Dush). A total of 45 sites were then selected and honeybee colonies were established for pollen samples.

Pollen collection

A total of 90 honeybee colonies of *Apis mellifera scutellata* species were placed in ten-frame Langstroth-type hives in the selected district of study zones. For this study, a total of 45 sites were selected from five selected districts. For each site, two colonies of honeybees were established for pollen analysis (Delaplane et al. 2013). Honeybee colonies were fitted with pollen traps and pollen loads were collected at 7-day intervals (Bilisik et al. 2008) for two consecutive years in 2019 and 2020. From each site, a minimum of 1 g of pollen was collected at each 7-day interval for palynological analysis. A total of 2160 pollen samples were collected from the Yeki, Guraferda, Sheko, Godare, and Mengesh districts in different seasons. Samples were kept in the refrigerator at +4 °C and transported on dry ice to the Holeta Bee Research Centre, Ethiopia, for pollen analysis.

Pollen analysis

The collected pollen samples were first sorted based on the colour of the pollen pellets by visual observation, followed by identification using microscopic techniques. Palynological preparations of the samples were performed using a method recommended by Louveaux et al. (1978). Dehydrated bee pollen samples were analysed and each 5 g sample was dissolved in 25 ml of distilled water. After the complete suspension was taken, it was submitted to the acetolysis method. The sediment was mounted on slides in glycerin jelly and sealed with paraffin wax. The pollen grains thus prepared from the pollen pellets were examined under a light microscope with a 40× and 100× (oil) objective lens. Identification was carried out with the help of reference slides prepared from local flora and previous published literature. Pollen was categorised as predominant (> 45%), secondary (16–45%), important minor (3–15%) and minor (< 3%) of pollen grain per sample according to Louveaux et al. (1978). This classification helps in qualitative and quantity analyses of honeybee pollen loads.

Taxonomic diversity

The Shannon–Weaver index was implemented to determine the diversity of the flora collected from pollen in each location to determine the taxonomic richness and evenness of each area. Using the equation below, the Shannon–Weaver diversity index (H') was calculated.

$$H' = -\sum P_i \,(In\, P_i)$$

where P_i is the proportion of each pollen type (i) in the sample and ln is the natural logarithm. A greater H' value indicated greater taxonomic diversity (Shannon 2001). Shannon–Weaver diversity indices were calculated for each site in each district. To compare the biodiversity of various plant communities, the effective number of species (ENS), a measure of species richness, was also calculated from the Shannon–Weaver diversity index for each site. However, the ENS tends to emphasise abundant taxa and to downplay the contribution of relatively rare taxa (Hill 1973). To account for unknown pollen types, each was given an individual 'unknown identification code'.

Data analysis

The data collected were entered into Microsoft Excel and analysed with SPSS version 20. The Statistical Package for Social Sciences (SPSS) was used to analyse all data collected using descriptive statistics and other relevant tools. A one-way analysis of variance (ANOVA) was used to compare the ENS and Shannon–Weaver diversity indices between districts and seasons. For all statistical analyses, 95% confidence intervals and a critical value of 0.05 were used.

Results

In the present study, the highest Shannon–Weaver index value was recorded in the spring season in all districts with a significant difference ($P = 0.002$), as indicated in Figure 1. Similarly, the highest (2.63) and lowest (1.09) Shannon–Weaver index value was recorded in the Guraferda and Godare districts, respectively (Figure 2). A significant difference ($P = 0.019$) was also observed between districts.

The honeybee flora increased from September to November and then decreased from December to February until zero-pollen sources were obtained in January. These plants increased from March to May, with the highest count being 32 bee plants in May. Subsequently, the number of honeybee plants gradually decreased with a small source of pollen from June to July, but increased again in August (Figure 3). It is the most appropriate period for

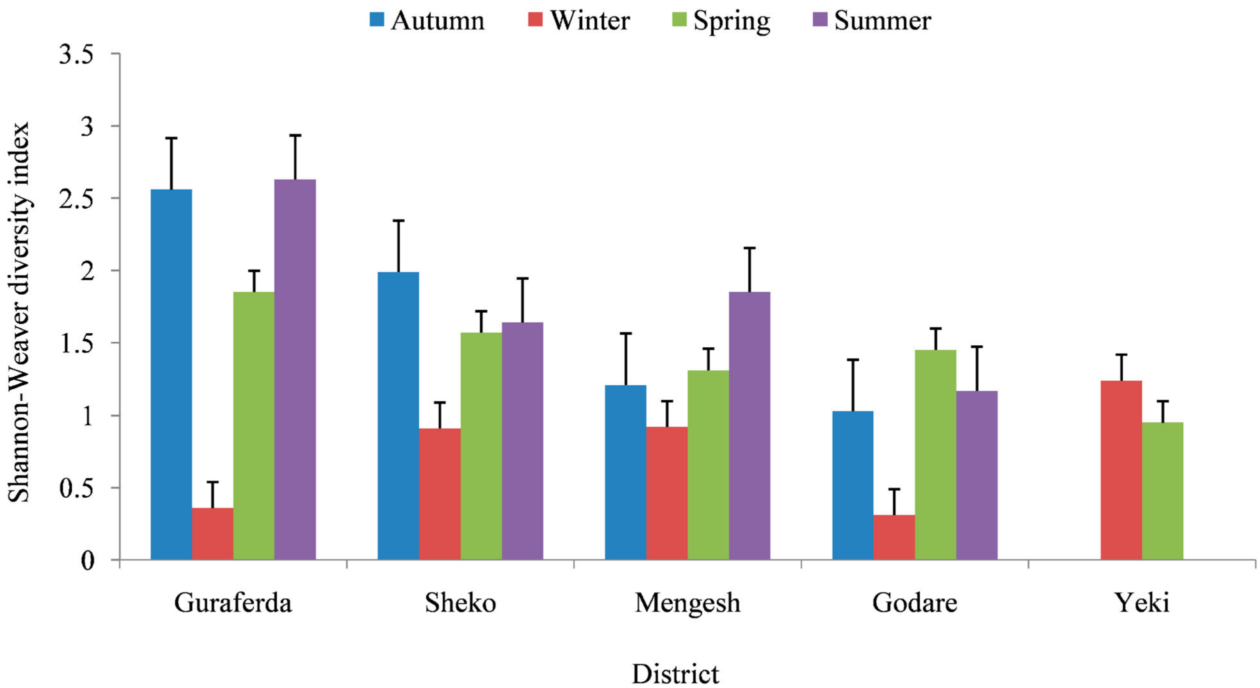

Figure 1. Shannon–Weaver diversity index value (mean ± standard deviation) for all sites in each district, categorised by season.

beekeepers to conduct honeybee management activities to better improve their colony strength. During this period, beekeepers install hives, requeen colonies, harvest honey and honeybee products.

In autumn (September–November), honeybees foraged pollen in the Guraferda district from 15 plant taxa belonging to 13 families. None of the pollen collected this season falls into the

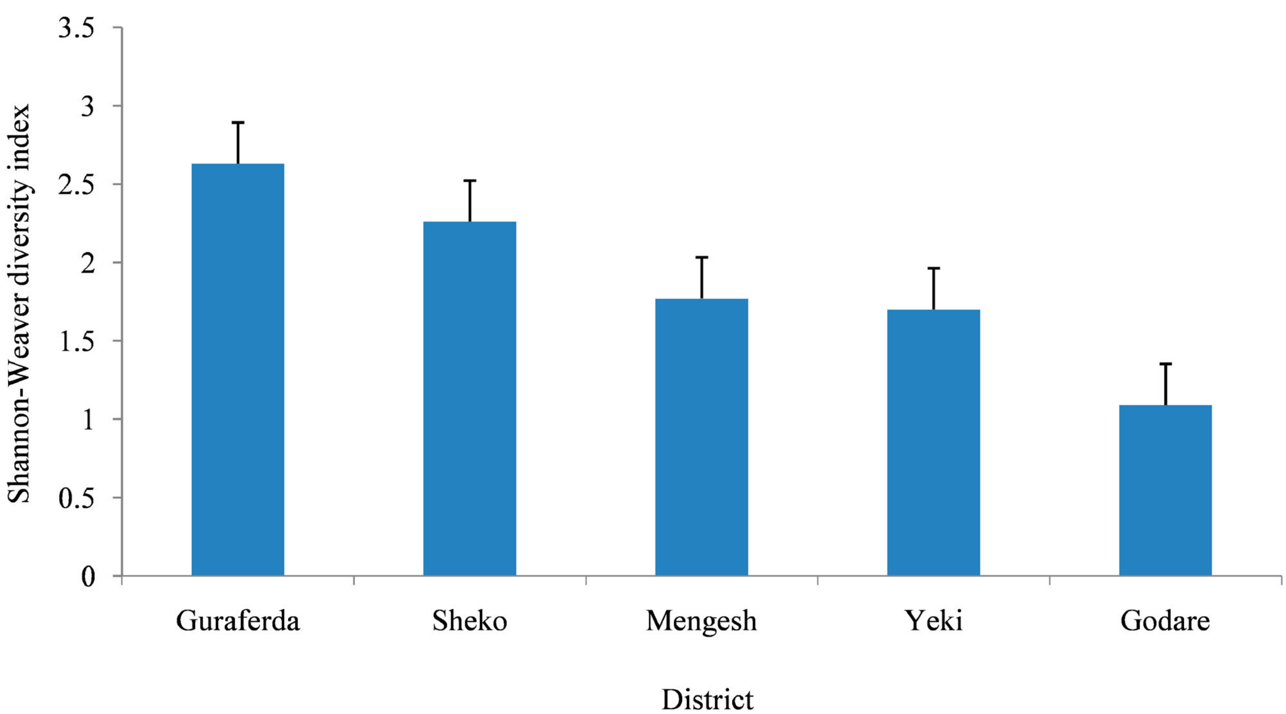

Figure 2. Overall, Shannon–Weaver diversity index value for all colonies sampled in each district.

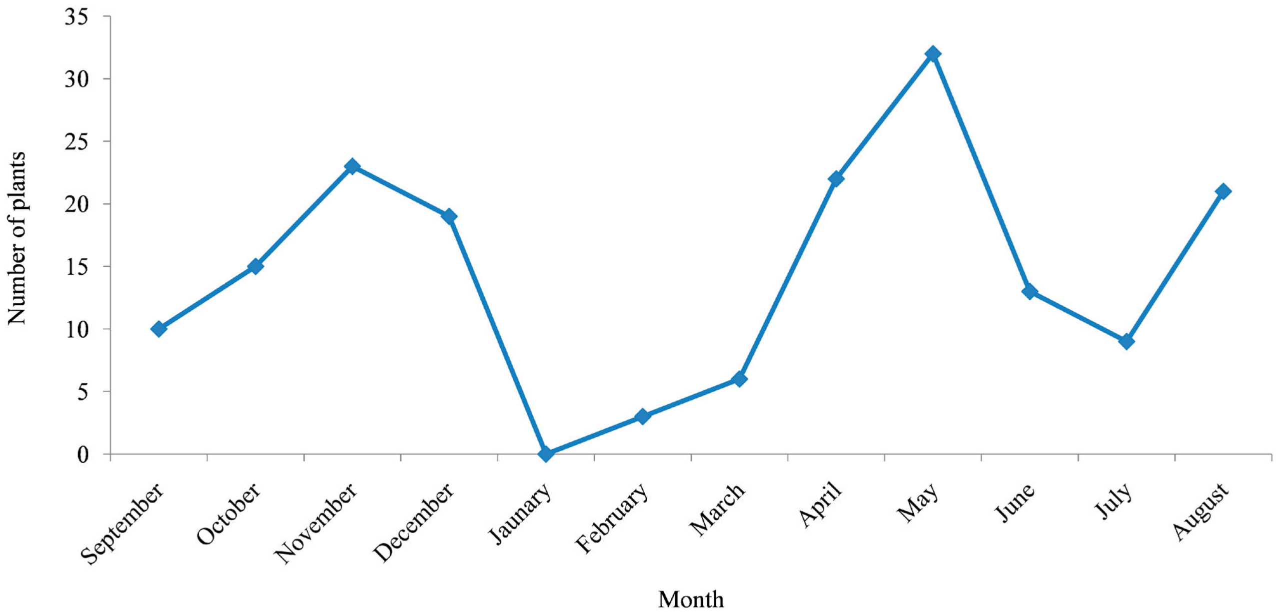

Figure 3. Number of plants identified in each month in study areas.

predominant category, which includes pollen grains that make up more than 45% of the sample. Pollen collected in this season has been indicated as secondary, important minor and minor pollen types (Figure 4A). The Shannon–Weaver diversity index in the autumn season was 2.56 and the ENS was 9.55 in the Guraferda district (Figure 1). In this study, honeybee colonies collected 40% of pollen from trees, while 33.3% and 26.7% of the pollen were collected from herbs and shrubs, respectively, during the autumn season (Supplementary Material I).

Three plant taxa belonging to three plant families were identified during the winter season (December–February) in the Guraferda district. In the winter season, one predominant and two important minor pollen types were identified (Figure 4B). During this season, most of the pollen (66.7%) was collected from herbs; however, 33.3% were from trees (Supplementary Material I). The Shannon–Weaver index for taxonomic diversity for each site in the winter season was 0.36 and the ENS was 1.43.

The current study also identified 17 plant taxa that belong to 11 families in the spring season (March–May), including two secondary pollen types, four important minor pollen types and five minor pollen types (Figure 4C). The Shannon–Weaver index for each site in spring was 1.85 and the ENS was 5.94 (Figure 1). The colonies collected 47.1% of the pollen from herbs, 29.4% of the pollen from trees, and 23.5% of the pollen from shrubs (Supplementary Material I). We identified pollen from ten plant taxa and families in summer (June–August), including secondary, important minor, and minor pollen types (Figure 4D). The Shannon–Weaver diversity index for each site in summer was 2.63 and the ENS was 6.37 (Figure 1). The colonies collected 40% of the pollen from herbs and 60% of the pollen from shrubs and trees (Supplementary Material I).

The foragers collected pollen from 13 plant taxa belonging to 12 families in the autumn season (September–November) in the Sheko district. Pollen collected in this season consisted of a predominant, a secondary, and ten minor pollen types (Figure 5A). The Shannon–Weaver diversity index for each site in the autumn season was 1.99 and the ENS was 7.28 (Figure 1).

In the autumn, 53.8%, 30.8% and 15.4% of pollen was collected from herbs, shrubs, and trees, respectively (Supplementary Material II). Six plant taxa of five plant families were recorded during winter (December–February). During this season, four major pollen types were identified: one predominant, one secondary, two important minors, and one minor (Figure 5B). Colonies collected in winter have 33.3% of pollen each from herbs, shrubs and trees, respectively (Supplementary Material II). Shannon–Weaver index for taxonomic diversity for each site in the winter season was 0.91 and the ENS was 2.49 (Figure 1). In this study, 13 plant taxa belonging to ten families were recorded in the spring season (March–May), which contained three secondary,

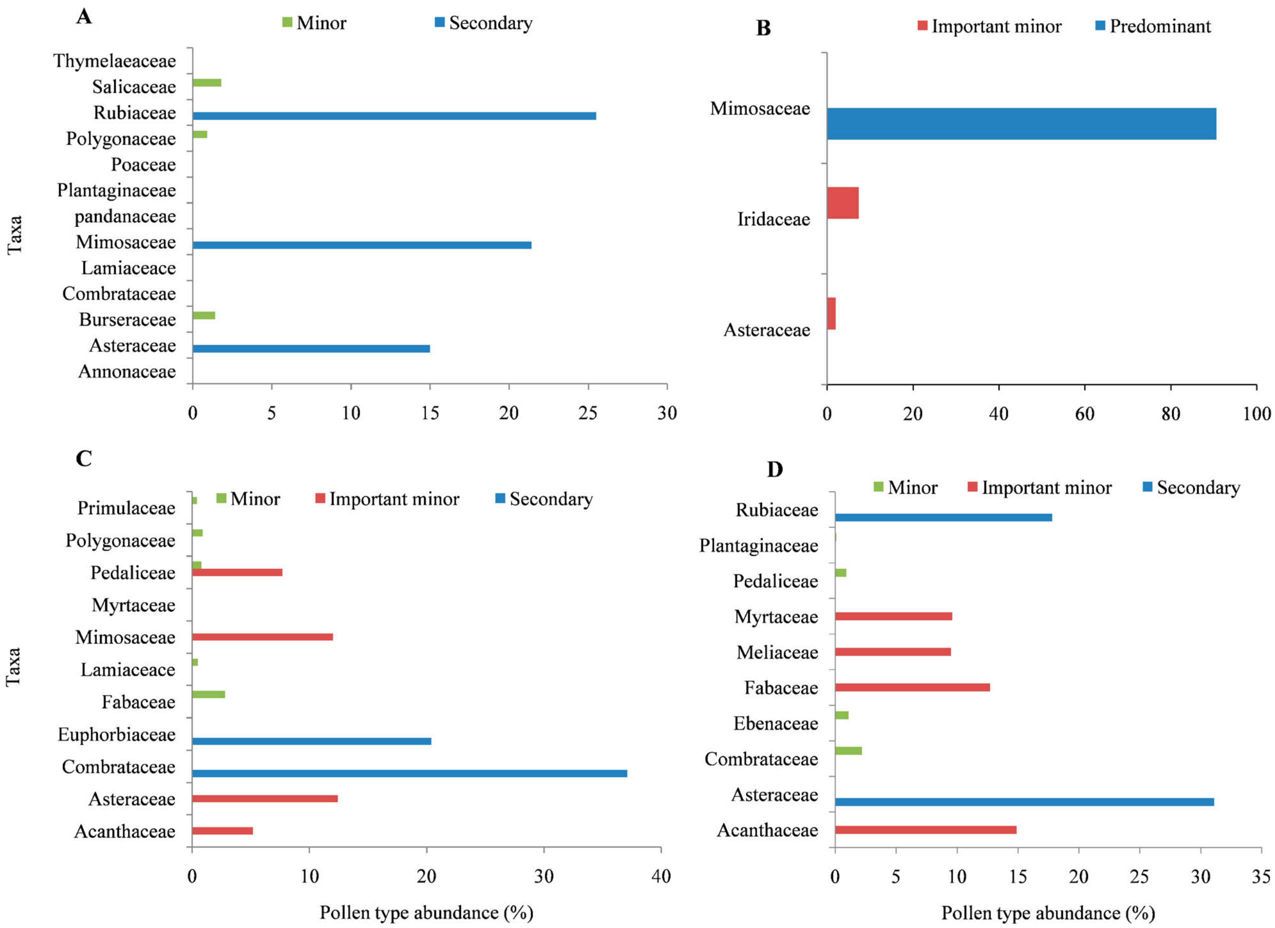

Figure 4. Relative pollen abundance of plant families in the Guraferda district through different seasons. **A.** Autumn. **B.** Winter. **C.** Spring. **D.** Summer.

two important minor and five minor pollen groups (Figure 5C). The Shannon–Weaver index for each site in spring was 1.57 and the ENS was 4.80 (Figure 1). The honeybee colonies collected 46.2% of the pollen from trees and 53.9% of the pollen from herbs and shrubs (Supplementary Material II). About ten plant taxa belonging to nine families were identified in the summer season (June–August). A predominant, three secondary, two important minor and three minor pollen categories were identified (Figure 5D). The Shannon–Weaver diversity index for each site in summer was 1.64 and the ENS was 5.16 (Figure 1). The majority (50%) of the pollen was collected from herbs, while 40% and 10% of the pollen were collected from shrubs and trees, respectively (Supplementary Material II).

The colonies collected pollen from seven plant taxa belonging to seven families in the winter season (December–February) in the Yeki district. The pollen collected contained one predominant, two secondary, one important minor and three minor pollen types (Figure 6A). The Shannon–Weaver diversity index at each site in winter was 1.24 and the ENS was 3.45 (Figure 1). Honeybees in the winter season collected 57.1% of the pollen from trees, while 28.6% and 14.3% of the pollen were collected from shrubs and herbs, respectively (Supplementary Material III). Three plant taxa belonging to three families were identified in the spring season (March–May). In this season, only one predominant, secondary, and important minor pollen group was found (Figure 6B). The colonies collected 33.3% of pollen each from trees, herbs, and shrubs (Supplementary Material III). Shannon–Weaver index for taxonomic diversity for each site in the spring season was 0.95 and the ENS was 2.59 (Figure 1). During the summer and autumn seasons, no records of pollen types were examined.

Four species of plants belonging to four families were identified in the autumn season (September–

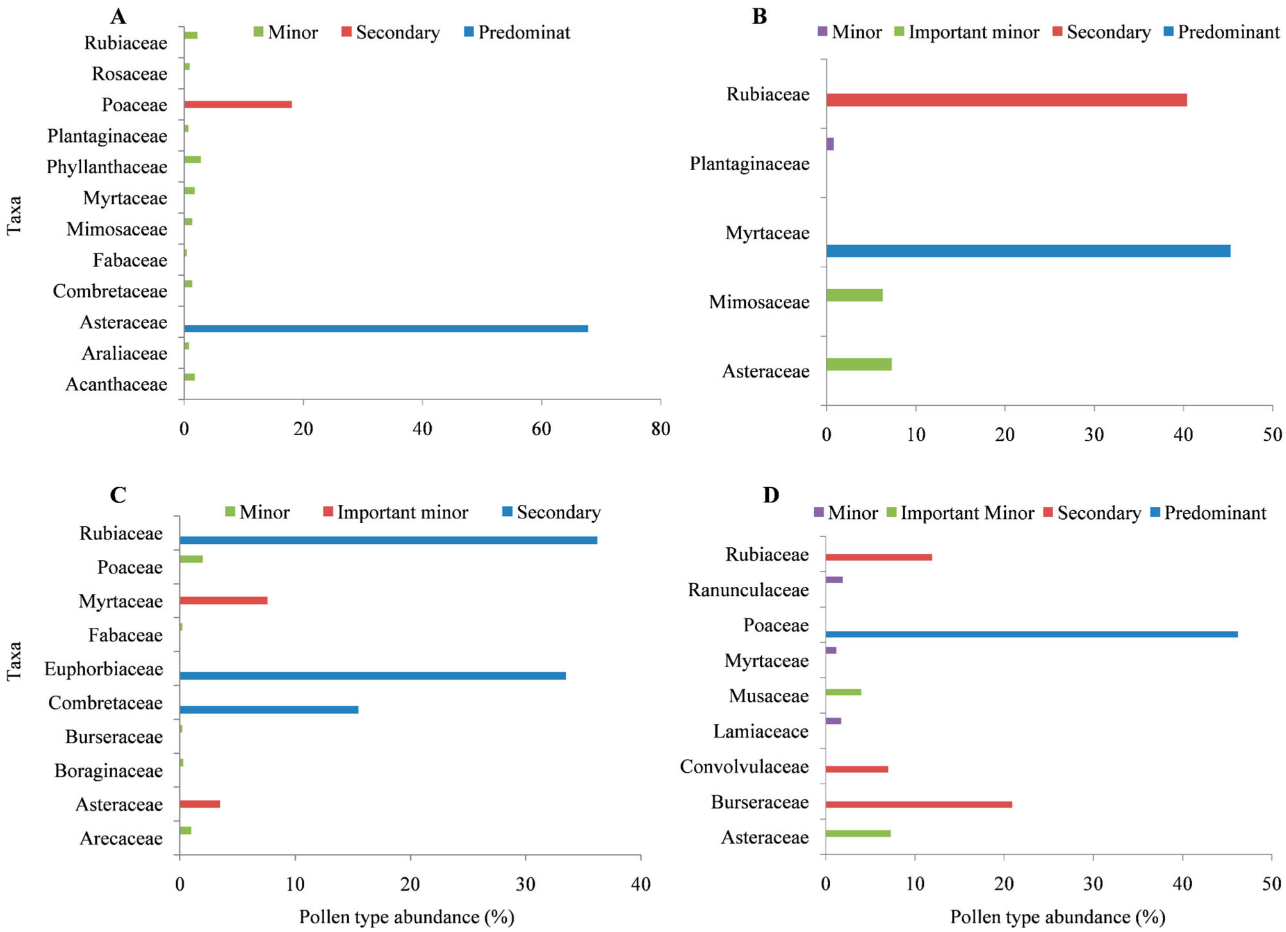

Figure 5. Relative pollen abundance of plant families in the Sheko district through different seasons. **A.** Autumn. **B.** Winter. **C.** Spring. **D.** Summer.

November) consisting of one predominant, one important minor, and two minor pollen types (Figure 7A) in the Godare district. The Shannon–Weaver diversity index of each site in the autumn season was 1.03 and the ENS was 2.81 (Figure 1). Half a percentage of pollen was collected from herbs, while 50% of the pollen was collected from trees and shrubs (Supplementary Material IV). During the winter season, only one plant taxa and family were identified (December–February). Five plants belonging to five families were identified in the spring season (March–May). Pollen categories were identified in this season, i.e. one predominant, one secondary, one important minor, and two minors (Figure 7B). The colonies collected 60% and 40% of the pollen from shrubs and trees, respectively (Supplementary Material IV). Shannon–Weaver index for taxonomic diversity for each site in the spring season was 1.45 and the ENS was 4.26 (Figure 1). Five plant taxa belonging to four families were identified in the summer season (June–August), including one predominant, one secondary, and two minor pollen types (Figure 7C). The study revealed that honeybees have foraged 40% of pollen grains from trees and shrubs, while 20% of the pollen was from herbs (Supplementary Material IV). The Shannon–Weaver index for each site in summer was 1.17 and the ENS was 3.22 (Figure 1).

Pollen collected from eight plant taxa belonging to seven families in the autumn season (September–November) in Mengesh district. The pollen collected in this season consisted of one predominant, one secondary, one important minor, and four minor pollen types (Figure 8A). The Shannon–Weaver diversity index of each site in the autumn season was 1.21 and ENS was 3.35 (Figure 1). In autumn, colonies collected 53.8%, 30.8% and 15.4% of pollen from herbs, shrubs, and trees, respectively (Supplementary Material V). Three species belonging to three families were

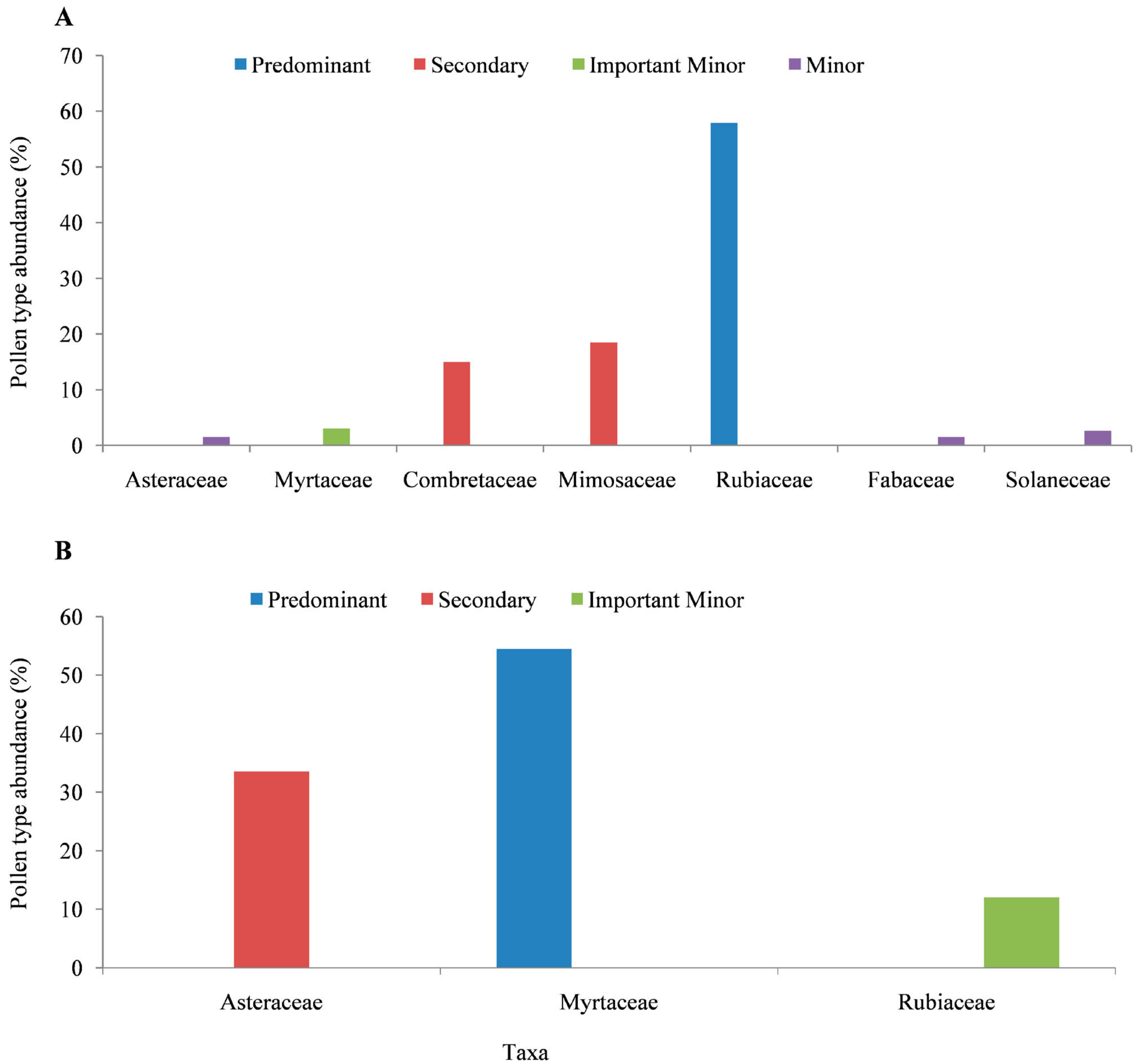

Figure 6. Relative pollen abundance of plant families in the Yeki district through different seasons. **A.** Winter. **B.** Spring.

identified in the winter season (December–February). During this season, a predominant and two important minor types were found in the current study (Figure 8B). The highest pollen (50%) was collected from herbs followed by trees (33.3%) and shrubs (16.7%), as indicated in Supplementary Material V. Shannon–Weaver index for taxonomic diversity for each site in the winter season was 0.92 and the ENS was 1.82 (Figure 1).

We found seven plants taxa belonging to five families in the spring season (March–May), which contained one predominant, one secondary and three minor pollen groups (Figure 8C). The Shannon–Weaver index for each site in spring was 1.31 and the ENS was 3.71 (Figure 1). The honeybee colonies collected 46.2% of the pollen from trees and 53.9% of the pollen from herbs and shrubs (Supplementary Material V). About six plant taxa belonging to six families were identified in the summer (June–August) season. Three secondary pollen categories, one important minor pollen category and two minor pollen categories were identified (Figure 8D). The Shannon–Weaver diversity index for each site in summer was 1.85 and the ENS was 6.36 (Figure 1). The majority (50%) of

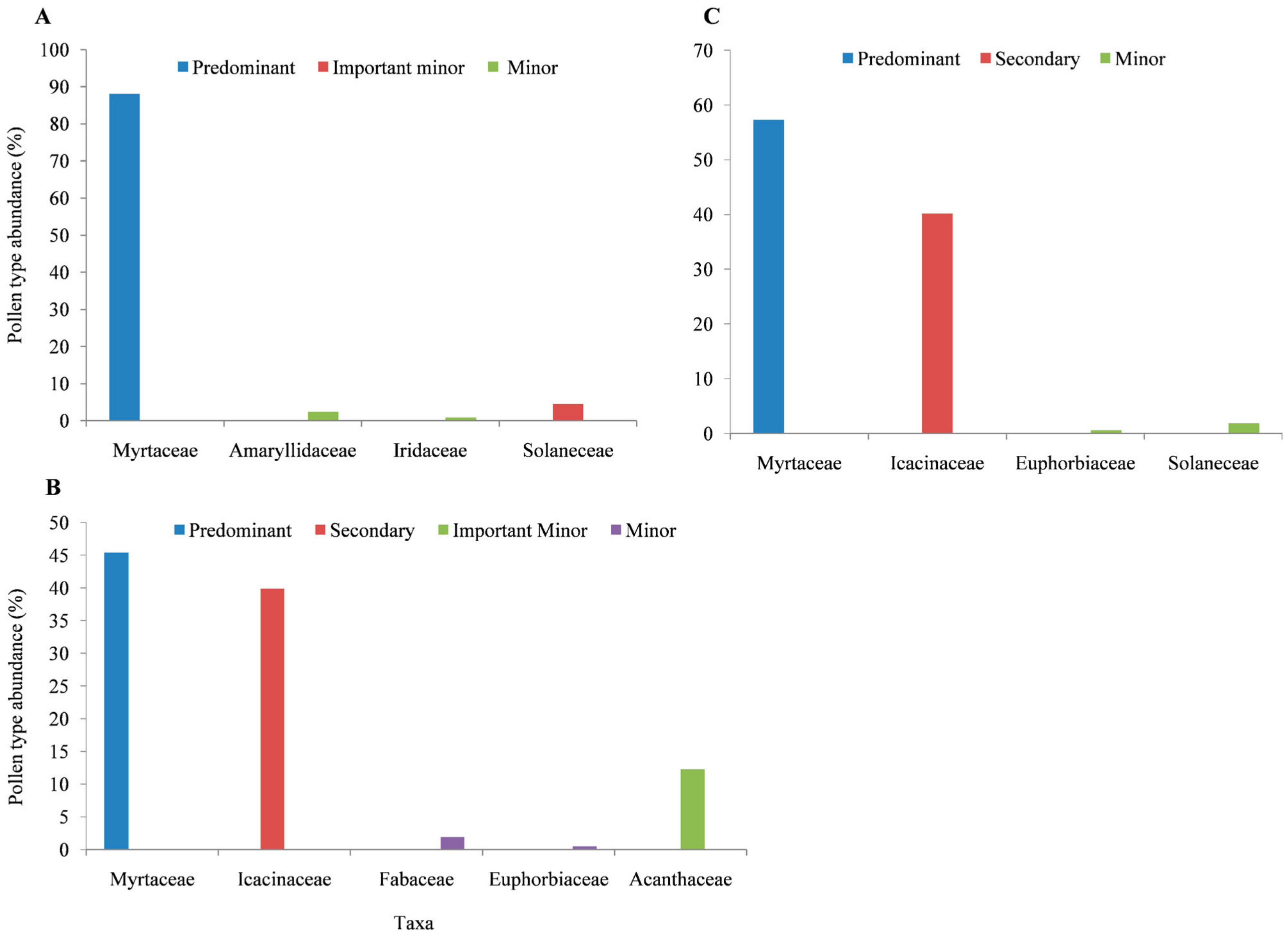

Figure 7. Relative pollen abundance of plant families in the Godare district through different seasons. **A.** Autumn. **B.** Spring. **C.** Summer.

pollen was collected from herbs, while 40% and 10% of pollen were collected from shrubs and trees, respectively (Supplementary Material V).

This study provided insights into the pollen grain shapes of various plant species. Notable pollen types observed in different study areas (Figure 9) included *Eucalyptus camaldulensis*, *Terminalia* spp., *Vernonia* spp., *Ocimum bacilium*, *Plantago* spp., *Guizotia* spp., *Coffea arabica*, *Bidens* spp., *Syzygium* spp., *Hypoestes trifolia*, *Acacia* spp., and *Zea mays*. The findings shed light on the diverse range of pollen shapes present in these species, contributing to a better understanding of their reproductive biology and ecological interactions.

Discussion

A two-year investigation was conducted on flora sources of pollen foraged by managed honeybee colonies in five selected districts in southwest Ethiopia. The pollen pellets foraged by honeybees were identified using standard palynological methods. In the current study, the 'predominant' and 'secondary' pollen sources were collected by foraging in all districts originating from different plant genera in the Asteraceae (62.23%), Mimosaceae (23.59%), Myrtaceae (43.76%), Poaceae (27.25%), Rubiaceae (36.64%), Combretaceae (28.14%), Euphorbiaceae (18.97%), Burseraceae (16.35%), Convolvulaceae (16.52%), Solanaceae (21.40%), Icacinaceae (17.86%) and Dichapetalaceae (16.35%) families (Figures 4–8). Consistent with the current finding, Shegaw and Giorgis (2021) found that these plants were the most preferred families by a honeybee in southwest Ethiopia. Similarly, to this finding, Ochungo et al. (2021) also found that Asteraceae and Combrataceae are the most abundant pollen source in Kenya. Furthermore, in agreement with the findings of Ara Begum et al. (2021), the current result also showed that Asteraceae, Rubiaceae, and Euphorbiaceae were the most common families with respect to melliferous plants. This underscores the ecological importance of these plant families as significant contributors to the foraging habits of

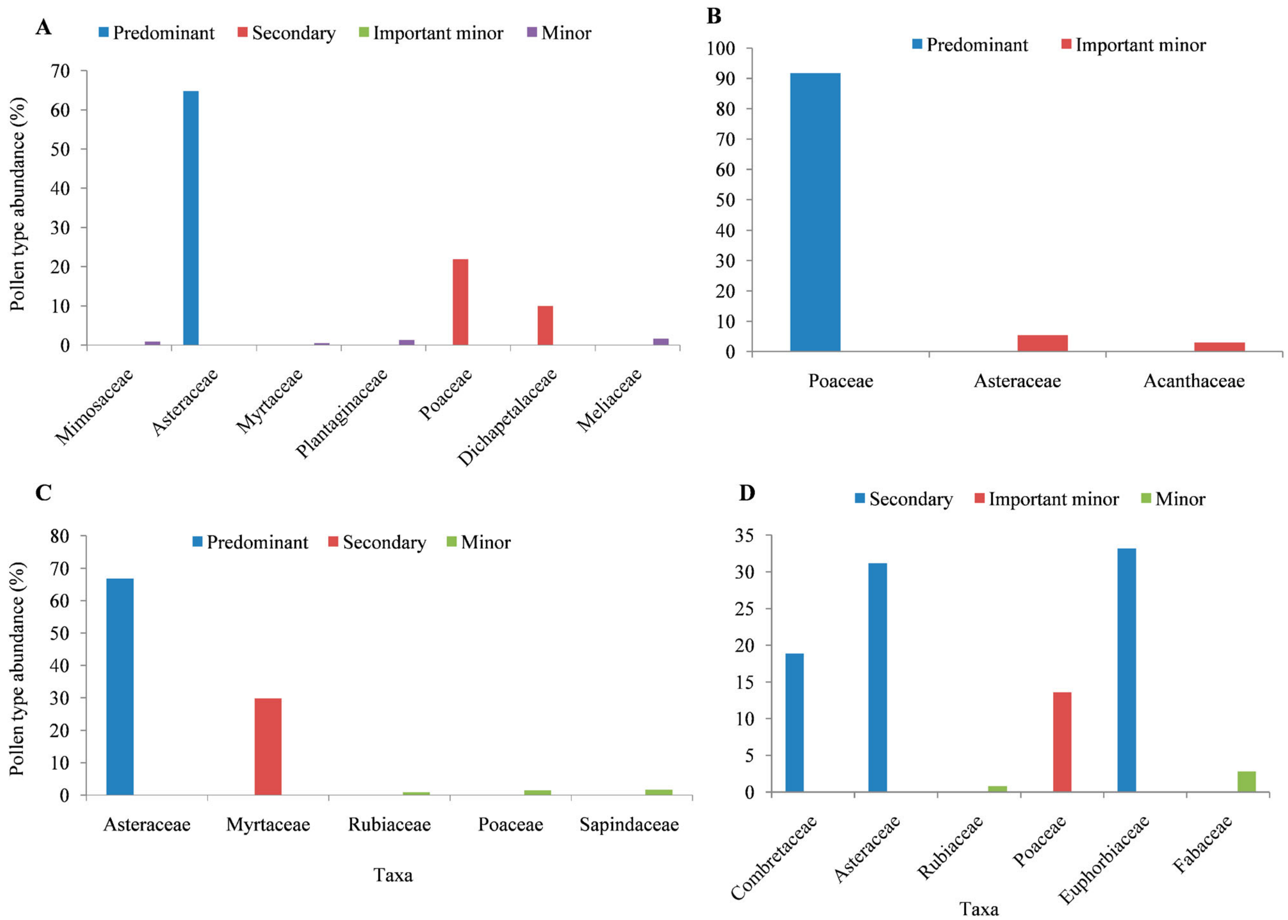

Figure 8. Relative pollen abundance of plant families in the Mengesh district through different seasons. **A.** Autumn. **B.** Winter. **C.** Spring. **D.** Summer.

bees and highlights their potential role in sustaining bee populations and honey production. By identifying these key pollen sources, our study provides valuable information for beekeeping practices, conservation efforts, and ecosystem management strategies in these areas (Ghosh et al. 2020; Al-Ghamdi & Al-Sagheer 2023).

Most of these pollen sources were collected from trees and herbs for colonies in five selected districts in southwest Ethiopia. However, the highest pollen was collected by foragers from herbs and shrubs in autumn and summer in the Sheko and Mengesh districts (Supplementary Material II and V). This showed that the herbaceous plant is the most important honeybee forage in southwest Ethiopia, which is consistent with the finding of Lau et al. (2019). The dominance of herbaceous plants in honeybee foraging suggests their importance in sustaining bee populations and supporting honey production in areas. These results have significant implications for beekeeping practices, conservation efforts, and ecosystem management strategies in southwest Ethiopia (Wakgari et al. 2021).

The highest number of taxa was identified in the Guraferda district during the spring season (March–May) ($n = 17$). Relatively, a low Shannon–Weaver diversity index (1.85) was also recorded in the spring season. This indicates that the foragers collected pollen evenly during a specific sampling period. The ENS ranged from 1.85 plant taxa in Mengesh district during the winter season (December–February), where pollen in the Poaceae was the 'predominant' type, to 9.55 plant taxa in Guraferda district during the autumn (September–October) season, where most of the pollen collected from the Rubiaceae, Mimosaceae, and Asteraceae. This finding was different from studies conducted in Europe and the United States which found the highest plant diversity in summer and spring, respectively (Dimou & Thrasyvoulou 2007; Coffey & Breen 2015; Lau et al. 2019). This variation may be due to differences in the season,

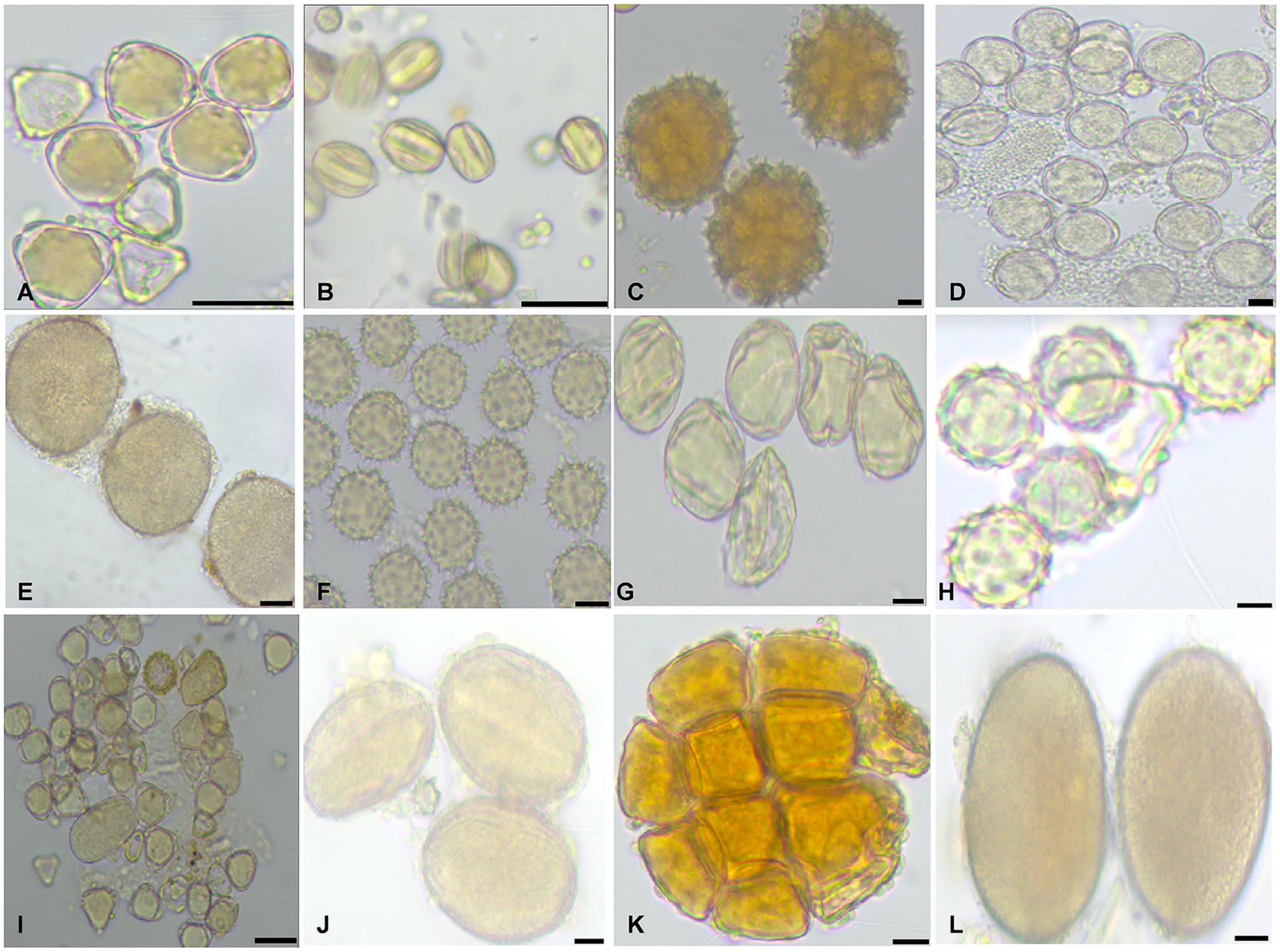

Figure 9. Main pollen grain shapes of some plant species. **A.** *Eucalyptus camaldulensis*. **B.** *Terminalia* spp. **C.** *Vernonia* spp. **D.** *Ocimum bacilium*. **E.** *Plantago* spp. **F.** *Guizotia* spp. **G.** *Coffea arabica*. **H.** *Bidens* spp. **I.** *Syzygium* spp. **J.** *Hypoes testrifolia*. **K.** *Acacia* spp. **L.** *Zea mays*. Scale bars – 10 μm.

landscape characteristics, and foraging activity of honeybee workers.

The highest taxonomic richness of pollen was collected by a forager in spring (March–May) in all districts with plants in the families Combrataceae, Rubiaceae and Asteraceae in the Guraferda, Sheko, and Mengesh districts, respectively. Similarly, to this result, the highest pollen types were collected during spring in Greece (Dimou & Thrasyvoulou 2007) since the brood population was growing over time, and pollen is needed as a protein source for growth (Dreller & Tappy 2000). The Myrtaceae represented by *Eucalyptus* were the only predominant pollen type in the Yeki and Godare districts in spring. Consistent with the current finding, the *Eucalyptus* genus frequently foraged honeybees in the West Indies and the United States (Sommeijer et al. 1983; Lau et al. 2019). The consistent attraction of honeybees to *Eucalyptus* flowers in different geographical locations highlights the widespread appeal and nutritional value of this plant genus for pollinators, underlining its ecological significance beyond specific areas. Asteraceae were recorded as the predominant pollen type in Mengesh district, representing the genera *Guizotia*, *Bidens*, and *Crossoce* during spring. This is consistent with the findings of Tura and Addi (2019), which showed that Asteraceae were highly foraged by honeybees in the Gera district in southwest Ethiopia. This highlights the widespread attractiveness of Asteraceae to honeybees in different areas, emphasising their ecological and economic importance in the local environment. The abundance of these plants contributes to the biodiversity of the areas and underscores their potential for honey production.

The colonies collected pollen in winter (December–February), mainly from trees and shrubs in Mimosaceae, Myrtaceae, Rubiaceae, and Acanthaceae, particularly species such as *Acacia* species, *Eucalyptus camaldulensis*, *Coffea arabica*, and *Justicia schimperiana*. Relatively, some plant groups provided pollen consistently throughout the year in all districts. Honeybees collected pollen from Myrtaceae (*Eucalyptus* spp.) throughout the year in all districts. *Eucalyptus* is known to be frequently foraged by honey and stingless bees in the United States, Oman and the West Indies (Sommeijer et al. 1983; Sajwani et al. 2014; Lau et al. 2019). Corroborated with the current result, Melin et al. (2018) showed that human-modified landscapes play an important role in supporting managed honeybees. However, *Eucalyptus* is generally considered pollen of poor nutrition, since it has a low lysine (an essential amino acid) content and omega-3 fatty acids, which are positively associated with improved honeybee learning and memory (Bell et al. 1983; Arien et al. 2015). These findings highlight the role of human-modified landscapes in supporting managed honeybees, while also highlighting the importance of considering the nutritional quality of pollen sources for honeybee health and performance.

The Poaceae and Myrtaceae with the species of *Zea mays* and *Eucalyptus camaldulensis,* respectively, were the predominant pollen types foraged by honeybee during the summer (June–August) in the Sheko and Godare districts, respectively. Our results have several similarities with the findings of Bilisik et al. (2008) and Sajwani et al. (2014) that indicated that *Z. mays* (Poaceae) were cultivated plants that were the pollen types of preference for foragers honeybees in August. It could suggest seasonal shifts in honeybee foraging behaviour influenced by factors such as floral abundance, nutrition, and the environment. Understanding these nuances is crucial for conservation and beekeeping, providing information on sustainable agriculture, biodiversity, and honeybee health. The prevalence of specific plant species reflects coevolutionary dynamics with honeybees (Ghosh et al. 2020; Jones et al. 2021).

In the autumn (September–October) season, honeybees frequently foraged pollen from Asteraceae and Myrtaceae, where Asteraceae was the predominant pollen type during autumn in the Sheko and Mengesh districts, and Myrtaceae was predominant in the Godare district. *Guizotia* spp., *Vernonia* spp., *Bidens* spp., *Girasol* spp., and *Crassocephalum* were the pollen type most preferred by honeybee foragers during autumn in the Asteraceae. Bilisik et al. (2008) reported similar results, who found Asteraceae as the most preferred pollen type by forager honeybees in autumn. This preference for specific plant families suggests a nuanced understanding of honeybee foraging behaviour in different ecological contexts. The prevalence of Asteraceae and Myrtaceae pollen in these areas during autumn underscores the importance of these plant families in sustaining honeybee populations during this season (Tulu et al. 2023).

The present study identified *Terminalia* spp. (Combretaceae), *Acacia* spp. (Mimosaceae), *Croton macrostachyus* (Euphorbiaceae), *Eucalyptus camaldulensis* (Myrtaceae), *Vernonia* spp. (Asteraceae) and *Iodes* spp. (Icacinaceae) as the major pollen source of honeybee pollen (Supplementary Material I–V) which agrees with the findings of Shegaw and Giorgis (2021) in the Kafa, Sheka, and Bench Maji zone of southwest Ethiopia. *Coffea arabica* (Rubiaceae) and *Zea mays* (Poaceae) were the major pollen source in agricultural crops, similar to the result of Ara Begum et al. (2021), who indicated that *Z. mays* (Poaceae) were the major pollen source for honeybees in Pakistan. This result partially agrees with the recommendation of Mehta et al. (2012), who recommended planting of trees such as *Eucalyptus* spp. (Myrtaceae), *Acacia* spp. (Mimosaceae) and *Croton* spp. (Euphorbiaceae) to improve the nectar and pollen source for the honeybee. This suggests regional variations in the preferred pollen sources for honeybees, highlighting the importance of considering local flora when designing bee-friendly environments. This study underscores the importance of specific plant species in sustaining honeybee populations in different geographical contexts (Ghosh et al. 2020).

The southwest part of the country has potential for honey production (Tulu et al. 2020); however, commercial beekeeping is underdeveloped as little is known about bee forage resources and their contribution to apicultural activities (Tarekegn et al. 2018). Since this study helps to increase colony strength in the areas, it results in increased honey production and other honeybee products for commercial purposes. Current findings are also important for the planning and establishment of honeybee forage to sustain honeybees and for the development of seasonal nutritional supplements fed to colonies when pollen is unavailable. These findings can help to understand the nutritional ecology of honeybees in southwest Ethiopia for the first time. The study also helps to promote the use of plants that provide appropriate pollen resources to honeybees in the country.

Conclusions

The present study has provided basic information on honeybees as a foraged source for the development of commercial beekeeping in the study areas. The variations observed in the qualitative and quantitative characteristics of pollen showed quite a variation to be considered useful markers for palynological analysis. This finding showed that Asteraceae (*Guizotia* spp., *Bidens* spp., *Vernonia* spp., *Girosol* spp., *Crassocephalum*) are a major pollen source in the autumn and spring seasons. Honeybees collected pollen sources from Myrtaceae (*Eucalyptus camaldulensis*) throughout the year in all districts, while Mimosaceae (*Acacia* spp.) and Rubiaceae (*Coffea arabica*) were only examined in winter. Furthermore, the Poaceae (*Zea mays)* was the most important pollen source in the winter and summer seasons. This study indicated that southwest Ethiopia has great potential for increased honey production from cultivated crops and natural forage from honeybees. These results help guide the optimal use of flora resources by a honeybee in the areas. Furthermore, existing bee flora must be cultivated in areas to increase the harvest of honeybee products and improve the apiculture industry.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Supplemental data

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