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Plants foraged by bees for honey production in northern India: The diverse flora of India and its implications for apiculture

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ABSTRACT. The plants foraged by bees for honey production vary from place to place in the diverse flora of India. This paper reports a palynological study of honey from eight sites of agriculture and urbanisation in the Gangetic Plain of Uttar Pradesh (UP), and presents data from similar studies done in India. Pollen grains of 55 species were recorded in the honey from south-western, central and eastern parts of Uttar Pradesh, where *Ageratum conyzoides*, a noxious invasive weed, is a very dominant plant taxon. The second plant community used for foraging by honeybees consists of *Syzygium cumini*, *Feronia limonia*, *Eucalyptus globulus*, *Prosopis spicigera*, *Prosopis juliflora*, *Brassica campestris*, *Pimpinella tomentosa*, *Xanthium strumarium*, and *Ziziphus* sp. The third plant community foraged by honeybees includes diverse plant species such as *Capparis* sp., *Ficus* sp., *Murraya koenigii*, *Aegle marmelos*, and *Tinospora cordifolia*, as well as Caryophyllaceae and nectarless families. The last group of plants foraged by honeybees comprises ca 37 species sparsely present in the vicinity. If honeybees have access to their preferred plant species they rarely visit non-preferred species, but in the urban and rural agricultural areas where the vegetation is sparse they are forced to forage several other plants including invasive species. The quality and character of honey, whether multifloral, monofloral, or bifloral, largely indicates the changing pattern of vegetation in a particular area, and can furnish decadal to century-scale information about the vegetational changes induced by climate or anthropopression. Palynological data also shed light on medicinally important or allergenic pollen protein present in honey (valuable information for consumers) and the details about plant taxa foraged by honeybees can be used for branding and marketing particular types of honey.

KEYWORDS: Melissopalynology, apiculture, pollen composition, India

INTRODUCTION

The plant communities used for honey production in the wild are indispensable to the apiary industry. Honeybees exploit the local flora for nectar and pollen, the main sources of their diet. Nectar is the source of proteins for broods, and pollen provides energy to the entire beehive colony (Freitas & Silva 2006). Knowledge of the local flora is the basis for ascertaining the bee foragers' preference. This can be done through melissopalynological study of the honey: that is, quantitative and qualitative analyses of its pollen content. The pollen composition of honey helps establish its botanical origin, the various plants visited by honeybees to glean the nectar and pollen, its geographical provenance (Moar 1985), and the season of nectar flux. In India, nectar collection is done largely by the Indian bees *Apis dorsata*, *A. cerana*, and *A. mellifera*. The presence or absence of pollen in honey attests to the authenticity of honey, whether it is natural or adulterated or artificial. The relative abundance of different pollen types indicates the main plant sources for nectar, knowledge of which may help local people conserve plant resources useful for honey production.

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During the last few decades, melissopalynological studies from the districts of Hyderabad (Kalpana et al. 1990, Jhansi et al. 1994), Cuddapah (Lakshmi & Suryanarayana 2004), Mahboobnagar (Ramanujam & Khatija 1992), Ranga Reddy (Ramanujam & Kalpana 1991), Medak (Chaya & Varma 2010), Adilabad (Ramakrishna & Swathi 2013), Visakhapatnam, and East Godavari (Ramanujam et al. 1992) have been reported. There are a few sketchy reports from Karnataka (Seethalakshmi 1980, Agashe & Rangaswamy 1997, Bhargava et al. 2009, Chauhan & Murthy 2011), West Bengal (Bera et al. 2004, Jana & Bera 2004), Assam (Dixit et al. 2012), Maharashtra (Deodikar et al. 1958, Chaubal & Kotmire 1985), Himachal Pradesh (Sharma 1970, Sharma & Raj 1985, Attri 2010), Kumaon (Chaturvedi 1983, Verma 1988, Garg & Nair 1994), Bihar (Suryanarayana et al. 1992), and Madhya Pradesh (Chauhan & Quamar 2010).

Uttar Pradesh (UP) is one of India's largest states. It shows high floral diversity across its diverse areas, ranging from agricultural to highly urbanised, yet it has not received due attention in this respect, except for some reports from Lucknow (Chaturvedi & Sharma 1973, Chaturvedi 1976, Chauhan & Trivedi 2011, Chauhan et al. 2013) and Unnao (Chauhan & Singh 2010). Recently, a brief account of the mellissopalynology study has been reported from different sites in UP (Chauhan et al. 2015). However, the plant preferences of foraging honey bees, choices related to climate and anthropopression in the areas they inhabit in different regions of India has not been reviewed with regard to multifloral, bifloral and monofloral type of honeys. Factors such as high floral diversity, its scarcity due to deforestation, invasive/introduced plants facilitating the honey production has been discussed here in context with the climate and varied flora in the Indian sub-continent. We identified the pollen in honey samples from the region and used those data to discuss the potential role of information about medicinally useful and allergenic honeys in the development of apiculture on a commercial scale.

STUDY SITES

Figure 1 shows the sites of honey collection. Jhansi (25°27′N, 78°37′E) and Girar (25°54′N, 78°69′E) in south-western Uttar Pradesh are areas of dry tropical deciduous mixed forest,

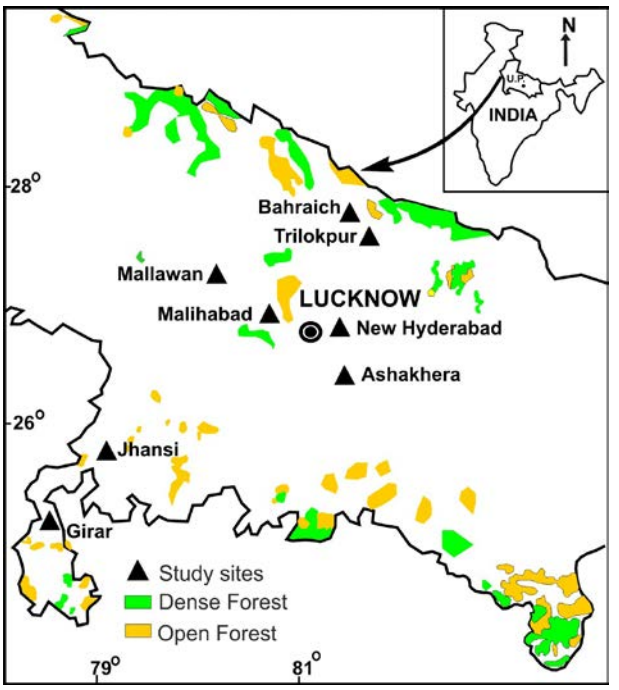


Fig. 1. Vegetation map of Uttar Pradesh, showing the study sites

with rugged and rocky landscape and without extensive agriculture due to the hilly terrain. Bahraich (27°34′N, 81°38′E) and Trilokpur (Lat. 26°55′N & Long. 80°59′E) lie in the eastern part of Uttar Pradesh and comprise moist and dry deciduous mixed forest along with adjoining cultivated land dominated by *Brassica* sp. crop, and with *Ageratum conyzoides* in wastelands. The topography of this region is flat plain.

We chose four sites in the central part of Uttar Pradesh: New Hyderabad (Lucknow city) and Ashakhera (outskirts of Lucknow (26°84′N, 80°94′E), Malihabad (26°91′N, 80°72′E) and Mallawan, Hardoi (26°51′42″N, 80°58′2″E); this area, the central Gangetic Plain, is characterised by extensive agriculture and urbanisation, with sparse moist and dry deciduous forest along with *Mangifera indica* orchards, *Syzygium* sp. and *Madhuca* sp. in patches. Tree avenues are common, along with herb and shrub plantings, including exotic plants. Malihabad is famous for its extensive mango orchards. All these sites are within 30 km of Lucknow city, except for Mallawan town which is ca 90 km from Lucknow city. Most of the area here is also under agriculture, with open vegetation and sparse trees.

CLIMATE

The climate in the study areas is humid subtropical (Fig. 2) and largely influenced by the

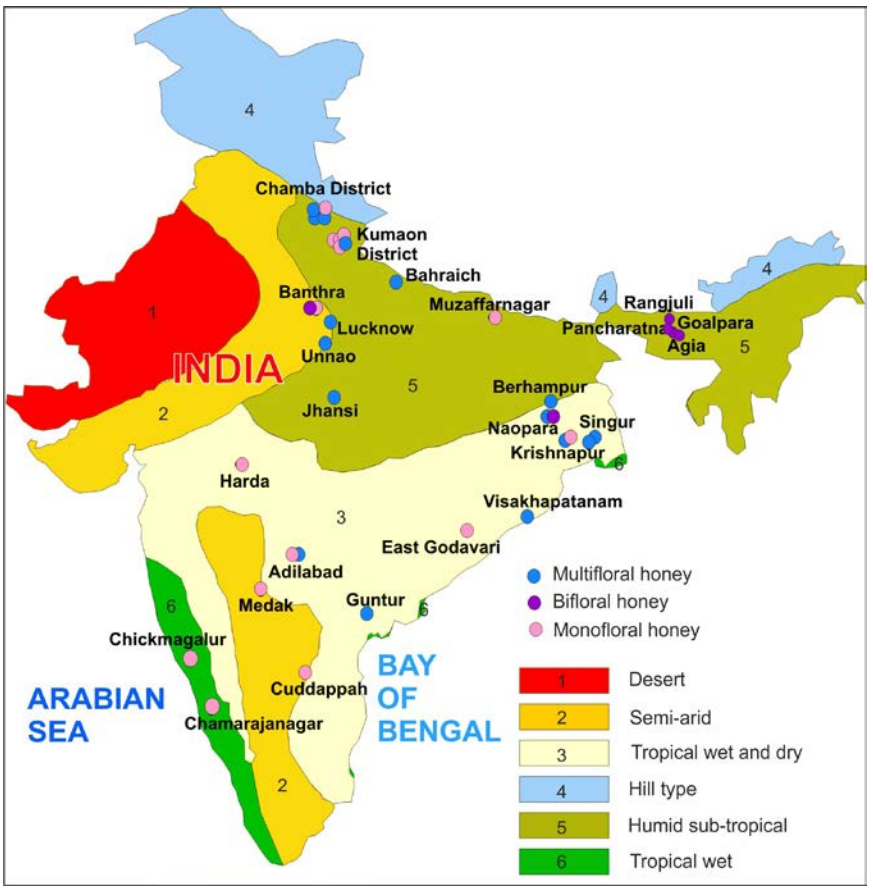


Fig. 2. Climatic boundaries of the Indian sub-continent, and type of honey in terms of pollen assemblage

south-west monsoon. Temperatures in winter (November to February) average 7.6°C minimum and 21°C maximum, and rarely go below 0°C during the coldest months (December, January). Summer (April to June) is marked by strong, dry, hot winds, with temperatures averaging 27°C minimum and 32.5°C maximum, reaching 48°C in June, particularly in Jhansi. The monsoon season begins in July and continues through mid-September. The weather becomes sultry from July to September. Average annual rainfall is 100–120 cm for central and eastern Uttar Pradesh, and ca 90 cm for south-western Uttar Pradesh. The south-west monsoon season accounts for 75% of the rainfall of the entire studied area. Most of the plant species flower during spring (February to April).

MATERIAL AND METHODS

Eight honey samples (Fig. 1) were collected from the beehives in April 2007 (fall winter), one each from Jhansi and Girar (south-western Uttar Pradesh), one each from Bahraich town and Trilokpur (east of Lucknow; eastern Uttar Pradesh), and one each from Mallawan (Hardoi District), Malihabad, Ashakhera and New Hyderabad (Lucknow District) in central Uttar Pradesh. Government permits were not required because the samples were collected from areas not under legal protection. Small honey samples were collected in plastic bottles with the help of local people, without disturbing the honeybees or any protected or endangered species in the vicinity of the study area. Honey samples (10 g each) were dissolved in distilled water and stirred gently to homogenise. The samples were sieved through 150 mesh (ca 100 µm) and the filtrate was acetolysed following Erdtman (1943). Permanent slides were prepared in glycerine gel and examined under an Olympus BX50 microscope. Micrographs of the pollen were taken under 400× magnification using an Olympus DP25 digital camera.

To identify the pollen recovered from the honey samples we consulted the sporothek in the herbarium of BSIP, and the published literature (Chauhan & Bera 1990, Nayar 1990). We used the following four pollen frequency classes (ICBB 1970, Louveaux et al. 1978): (1) predominant pollen (PP; >45%), (2) secondary pollen (SP; 16–45%), (3) important minor pollen (IMP; 3–15%), and (4) minor pollen (MP; <3%). Table 1 presents the diversity of pollen and the class and type of honey from different localities. Based on the pollen frequency range and the number of dominant and co-dominant plant species per unit volume of honey (10 g), three categories were identified (Wingenroth 2001): monofloral (>45% share of pollen of a single species), bifloral (22.25% shares of pollen of two species), and multifloral (<16% shares of pollen of more than three species).

Table 1. Types of honey from Uttar Pradesh, based on pollen class (ICBB 1978)

Locality	Type of honey	Class of pollen based on frequency			
		Predominant pollen (PP; >45%)	Secondary pollen (SP; 16–45%)	Important minor pollen (IMP; 3–15%)	Minor pollen (MP; <3%)
Jhansi	Multifloral		*Feronia limonia*	*Capparis* sp., *Ageratum conyzoides*, *Ficus* sp., *Murraya koenigii*	*Bombax ceiba*, *Brassica campestris*, *Delonix regia*, *Aegle marmelos*, *Symplocos racemosa*, *Mangifera indica*, *Adina cordifolia*, *Trewia nudiflora*, *Syzygium cumini*, *Strobilanthes angustifrons*, *Croton* sp., *Hygrophila auriculata*, *Peltophorum* sp., *Lagerstroemia speciosa*, *Aspidopterys* sp., *Barleria* sp., *Evolvulus* sp., Apiaceae, *Emblica officinalis*, Cucurbitaceae
Girar	Monofloral	*Syzygium cumini*	*Brassica campestris*	*Eucalyptus globulus*, *Ageratum conyzoides*	*Cannabis sativa*, *Pimpinella tomentosa*, *Xanthium strumarium*, *Holoptelea integrifolia*, Poaceae, *Solanum* sp., *Capparis* sp.
Bahraich	Multifloral		*Ageratum conyzoides*, *Syzygium cumini*, *Brassica campestris*	*Pimpinella tomentosa*, *Eucalyptus globulus*	*Aegle marmelos*, *Holoptelea integrifolia*, *Solanum* sp., *Ziziphus* sp., *Apium* sp., *Ficus* sp., *Feronia limonia*, Poaceae, *Pisum sativum*, *Amaranthus spinosus*, *Ricinus communis*
Trilokpur	Multifloral		*Syzygium cumini*, *Prosopis spicigera*, *P. juliflora*, *Moringa oleifera*	*Acacia* sp.	*Holoptelea integrifolia*, *Madhuca indica*, *Ziziphus* sp., *Tinospora cordifolia*, *Cannabis sativa*, *Eucalyptus globulus*, *Bombax ceiba*, *Chenopodium* sp., *Terminalia* sp., *Ailianthus excelsa*, *Ocimum* sp.
New Hyderabad (Lucknow)	Multifloral		*Prosopis spicigera*	*Syzygium cumini*, *Ageratum conyzoides*, *Bombax ceiba*, *Ailanthus excelsa*, *Tinospora cordifolia*, *Moringa oleifera*, *Eucalyptus globulus*, *Aegle marmelos*	*Brassica campestris*, *Pongamia pinnata*, *Melia azedarach*, *Holoptelea integrifolia*, *Cannabis sativa*, *Chenopodium* sp., Poaceae
Ashakhera	Bifloral		*Ageratum conyzoides*, *Prosopis spicigera*	*Prosopis juliflora*, *Syzygium cumini*, *Eucalyptus globulus*	*Tinospora cordifolia*, *Brassica campestris*, *Pimpinella tomentosa*, *Solanum nigrum*, *Terminalia* sp., *Ricinus communis*, *Pongamia pinnata*, *Ailanthus excelsa*, *Ranunculus* sp., Poaceae, *Cannabis sativa*, Cyperaceae
Malihabad	Multifloral		*Ageratum conyzoides*, *Syzygium cumini*, *Pimpinella tomentosa*	*Solanum nigrum*, *Brassica campestris*, *Eucalyptus globulus*	*Aegle marmelos*, *Holoptelea integrifolia*, *Feronia limonia*, *Apium* sp., *Ziziphus* sp.
Mallawan	Multifloral		*Ageratum conyzoides*, *Xanthium strumarium*, *Ziziphus*	Poaceae, *Acacia nilotica*, *Syzygium cumini*, *Holoptelea integrifolia*, *Blumea*, *Brassica campestris*, Caryophyllaceae	*Phoenix* sp., *Pimpinella tomentosa*, *Peltophorum* sp., *Emblica officinalis*, *Justicia simplex*, *Mimosa pudica*, *Eucalyptus globulus*, *Ricinus communis*, *Solanum* sp., *Tinospora cordifolia*, *Flacourtia indica*

Only entomophilous pollen is included in the pollen counts, and the relative shares are calculated as percentages. Anemophilous plant taxa such as *Holoptelea integrifolia*, *Solanum* sp., *Cannabis sativa*, *Amaranthus spinosus*, *Chenopodium album*, Poaceae, and Cyperaceae were excluded from the pollen counts because they are incidentally transported by wind or inadvertently transported by bees to the hives. Cluster analysis employed Statistica.

RESULTS

All the honey samples analysed from Uttar Pradesh were found very promising in terms of number and frequency of plant species and pollen types. The pollen counts per slide were ca >2000 for the samples from all the studied sites. Melissopalynological data from different parts of India are given in Figure 2. The percentage frequencies of the pollen recovered from the samples are given in Figure 3, and the dendrogram is presented in Figure 4. Figure 5 shows the flowering calendar of the recovered taxa. Figure 6 depicts the pollen grains recovered from the honey samples from all the studied sites. Below, the palynological results for the eight honey samples from

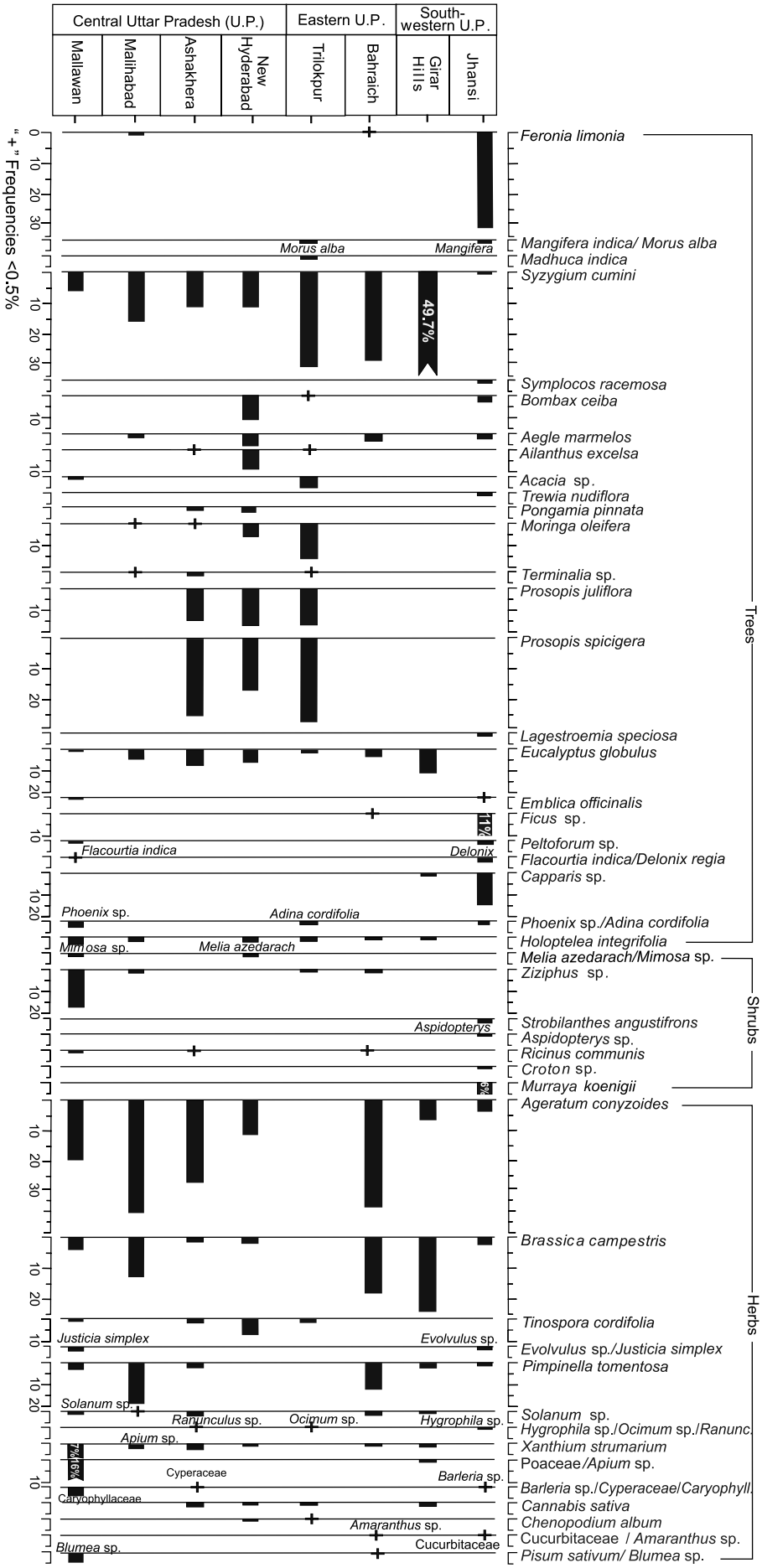


Fig. 3. Pollen spectra of honey samples from various locations of Uttar Pradesh, India

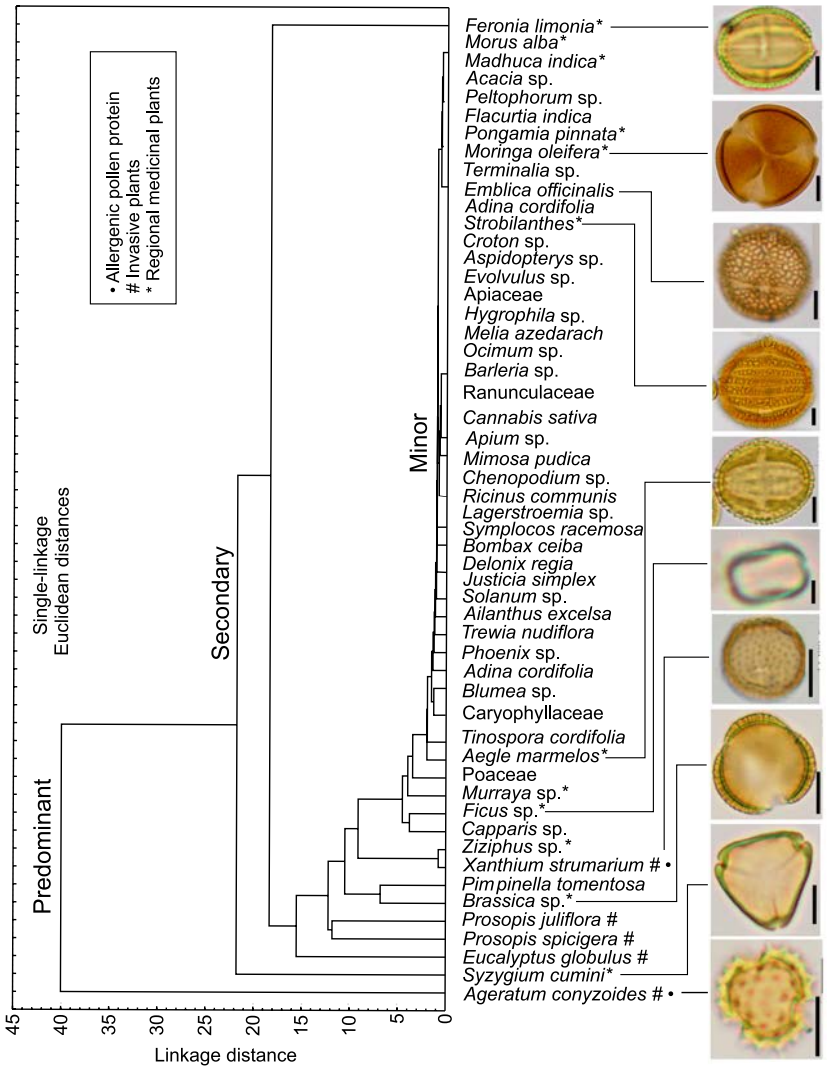


Fig. 4. Dendrogram for the different studied localities, showing the relative abundance of plant species recovered from the honey samples

three different regions of Uttar Pradesh (see also Fig. 3) show the content of predominant (PP), secondary (SP), important minor (IMP), and minor (MP) pollen.

SOUTH-WESTERN REGION (JHANSI)

Trees accounted for the largest number of species (14), contributing 82.5% of the total pollen in the honey, followed by 7 herb species (16.46% of total) and shrubby elements (4 species, 4.27%). The frequency of the SP *Feronia limonia* in the sample was 33.17%; it was the most dominant tree species. The IMPs *Ageratum conyzoides* (14.73%) and *Capparis* sp. (14.68%) were frequent, followed by *Ficus* sp. (10.9%) and *Murraya koenigii* (8.49%). The MPs included *Bombax ceiba* (2.65%), *Brassica campestris* (2.48%), *Delonix regia* (2.31%), and *Mangifera indica* (1.73%), *Aegle marmelos*, *Symplocos racemosa* (1.44% each), *Lagerstroemia speciosa* (1.27%), *Trewia nudiflora*, *Croton* sp. (1.15% each), *Adina cordifolia*, and *Strobilanthes angustifrons* (1.09% each). The rest of the MPs, contributing negligible amounts, were *Aspidopterys* sp. (0.98%), *Peltophorum* sp. (0.92%), *Syzygium cumini* (0.86%), *Hygrophila auriculata* (0.75%), Apiaceae, *Evolvulus* sp. (0.69% each), *Barleria* sp., *Emblica officinalis* (0.17% each), and Cucurbitaceae (0.058%). The absence of PPs and the presence of 25 SP, IMP, and MP species in the sample mark this honey as multifloral.

GIRAR

Eleven plant taxa comprising 4 trees and 7 herbaceous elements belonging to 9 families were recorded in the assemblage. The PP

Syzygium cumini showed the highest frequency (49.7%). *Brassica campestris*, the only SP in the sample, was also very frequent (23.37%). The IMPs *Eucalyptus globulus* (10.3%) and *Ageratum conyzoides* (7%) were frequent. The MP pollen were from *Cannabis sativa* (2.26%), *Pimpinella tomentosa* (2%), *Xanthium strumarium* (1.06%) and *Capparis* sp. (0.66%). Other nectarless plants were *Solanum* sp., Poaceae (0.79% each), and *Holoptelea integrifolia* (0.93%), with small shares in the pollen count. The dominance of herbaceous taxa is explained by the location of the sampling site in an expanse of agricultural land having only pockets of forest cover. These pollen data indicate that the honey is monofloral, with *Syzygium cumini* being the main source of nectar and with *Brassica campestris* preferred by the bees for nectar and foraging.

EASTERN REGION (BAHRAICH)

The honey sample from the outskirts of Bahraich, adjoining cultivated land, showed very low diversity of pollen as compared to the sample from Jhansi. We recorded 6 trees, 8 herbs and 2 shrubs belonging to 16 genera in 14 families. Pollen of the exotic weed *Ageratum conyzoides* had the highest share (35.9%), followed by *Syzygium cumini* (25.3%) and *Brassica campestris* (17.5%); these were all SPs. The IMPs were *Pimpinella tomentosa* (11.5%) and *Eucalyptus globulus* (3.45%). *Aegle marmelos* (2.02%), *Solanum* sp. (1.33%), *Ziziphus* sp.

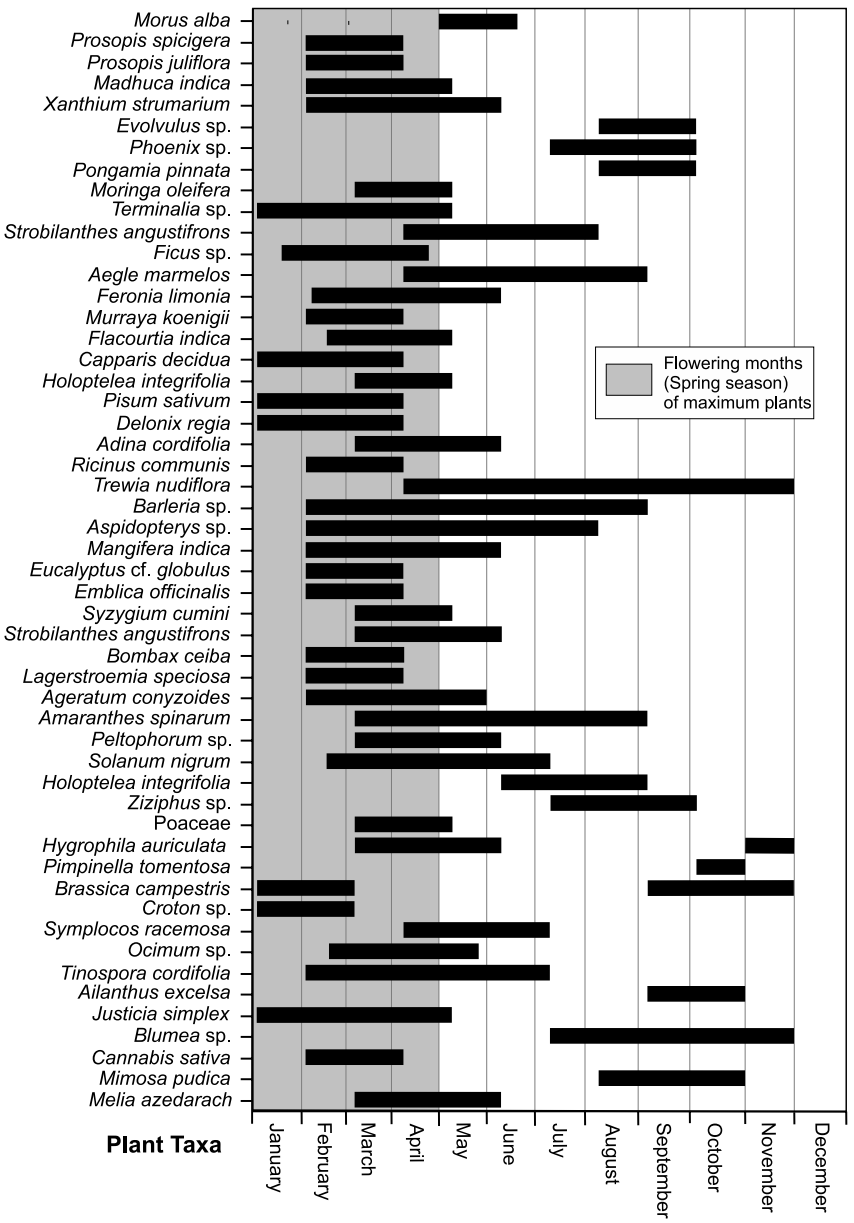
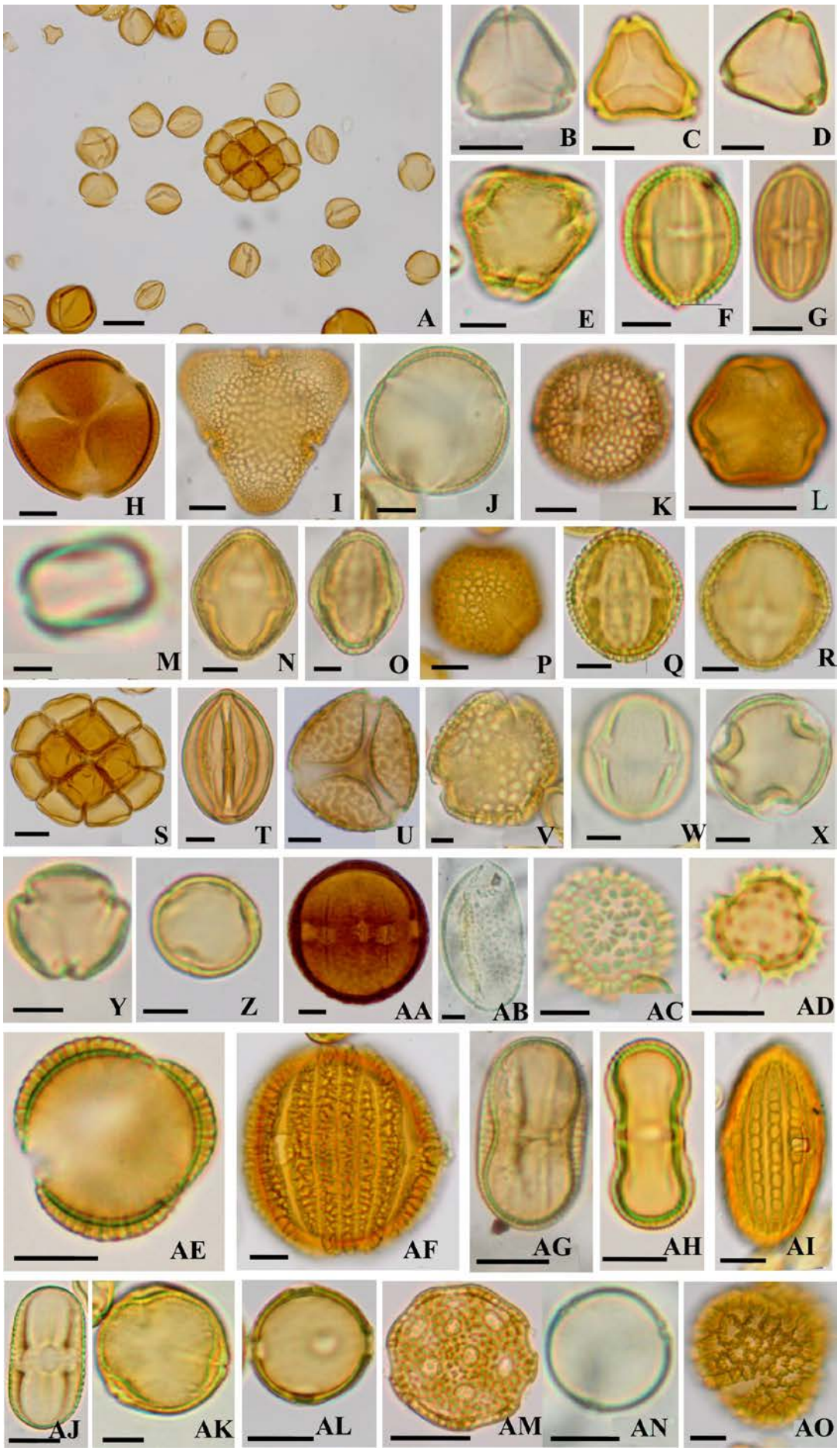


Fig. 5. Flowering calendar of the plant species recovered in the honey samples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(0.56%), and *Apium* sp. (0.73%) appeared sporadically, and the shares of *Pisum sativum*, *Ricinus communis*, *Feronia limonia* (0.092% each), and *Ficus* sp. (0.28%) were very low; all these taxa fall in the MP class. There were low shares of pollen of the anemophilous nectarless species *Holoptelea integrifolia* (1.02%), *Amaranthus spinosus* (0.092%), and Poaceae (0.87%). The overall pollen assemblage indicates that this honey is multifloral, with herbaceous plants contributing 65.6%, followed by trees (32.1%) and shrubs (0.69%).

TRILOKPUR

The pollen assemblage of the honey sample from Trilokpur, Bahraich (Fig. 3), contained 12 trees and 5 herbs and shrubs, belonging to 17 genera in 15 families. *Syzygium cumini* had the highest share (31.58%), followed by *Prosopis spicigera* (26.99%), *P. juliflora* (16.35%), and *Moringa oleifera* (16.35%); all of these fall in the SP class. Only *Acacia* sp. (4.48%) constitutes IMP. However, the MP included *Holoptelea integrifolia* (1.79%), *Madhuca indica* (1.12%) *Ziziphus* sp. (0.89%), *Tinospora cordifolia* (0.67%), *Cannabis sativa* (0.673%), *Eucalyptus globulus* (0.56%), *Bombax ceiba* (0.33%), *Chenopodium album* (0.332%), *Terminalia* sp. (0.22%), *Alianthus excelsa* (0.22%), and *Ocimum* sp. (0.22%). Overall, the pollen record from the honey indicates that it is multifloral, dominated by tree taxa (99.7%), followed by herbs and shrubs (1.89% each).

CENTRAL REGION (NEW HYDERABAD)

The honey sample from New Hyderabad, Lucknow (Fig. 3), contained 18 plant species (11 trees, 6 herbs, 1 shrub) belonging to 16 families. The SP *Prosopis spicigera* had the highest share (16.5%) in the pollen assemblage. The IMPs *Syzygium cumini* (11.96%), *Ageratum conyzoides* (12.37%), *Bombax ceiba* (10.72%), *Ailanthus excelsa* (9.24%), *Tinospora cordifolia* (7%), *Moringa oleifera* (6.18%), *Eucalyptus globulus* (4.2%), and *Aegle marmelos* (3.79%) showed moderate values. *Brassica campestris* (2.06%), *Pongamia pinnata* (1.5%), and *Melia azedarach* (0.82%) fall in the MP class. The pollen of nectarless *Holoptelea integrifolia* (1.65%), *Cannabis sativa* (1.15%), *Chenopodium album* (0.9%), and Poaceae (0.742%) also had low shares. In the overall assemblage, trees formed 73.81%, herbs 17.29%, and shrubs 1.73% of the pollen in this honey, which is multifloral.

ASHAKHERA

The honey contained pollen of 18 species: 8 trees, 1 shrub and 9 herbaceous taxa, belonging to 16 families. The SPs *Ageratum conyzoides* (26.9%) and *Prosopis spicigera* (25.7%) were dominant. They were followed by the IMPs *Prosopis juliflora* (14%), *Syzygium cumini* (12.4%), and *Eucalyptus globulus* (6.7%), and by the MPs *Tinospora cordifolia* (1.84%), *Brassica campestris* (1.59%), *Pimpinella tomentosa*, *Solanum* sp., *Terminalia* sp. (0.61% each), *Ricinus communis* (0.49%), *Pongamia pinnata* (0.78%), *Ailanthus excelsa* (0.26%), *Ranunculus* sp. (0.13%), nectarless Poaceae (1.59%), *Cannabis sativa* (0.98%), and Cyperaceae (0.49%). The overall pollen composition indicates that the honey is bifloral, with 60.41% tree pollen, 34.74% herb pollen, and 0.49% shrub pollen.

MALIHABAD

This pollen assemblage contained 17 plant taxa: 11 trees and 6 herbaceous species, belonging to 14 families. The exotic weed *Ageratum conyzoides* had the highest share (46%), placing it in the PP class, followed by the SPs *Eucalyptus globulus* (16.3%) and *Syzygium cumini* (16.5%). Only *Prosopis spicigera* (3.81%) was an IMP. The MPs in this assemblage were *P. juliflora* (2.28), *Trewia nudiflora* (2.54%), *Ailanthus excelsa* (1.8%) *Tinospora cordifolia* (2%), *Symplocos* sp. (1%), *Symplocos racemosa* (1%), *Terminalia* sp., *Emblica officinalis*, *Cannabis sativa* (0.63% each), *Moringa oleifera*, *Solanum* sp., *Pimpinella tomentosa*, *Holoptelea integrifolia* (0.38% each), *Peltophorum* sp. (0.48%), and nectarless Poaceae (1%). Trees

Fig. 6. Microphotographs of pollen (All scale bars: 10 μm). **A**. Cluster of pollen in honey sample. **B**. *Ziziphus* sp., **C**. *Eucalyptus globulus*, **D**. *Syzygium cumini*, **E**. *Symplocos racemosa*, **F**. *Feronia limonia*, **G**. *Capparis* sp., **H**. *Moringa oleifera*, **I**. *Bombax ceiba*, **J**. *Evolvulus*, **K**. *Emblica officinalis*, **L**. *Ailanthus excelsa*, **M**. Moraceae, **N** & **O**. *Lagerstroemia speciosa*, **P**. *Peltophorum* sp., **Q** & **R**. *Aegle marmelos*, **S**. *Acacia* sp., **T**. *Prosopis juliflora*, **U**. *P. specigera*, **V**. *Delonix regia*, **W** & **X**. *Mangifera indica*, **Y**. *Adina cordifolia*, **Z**. *Trewia nudiflora*, **AA**. *Madhuca indica*, **AB**. *Phoenix* sp., **AC**. *Croton* sp., **AD**. *Ageratum conyzoides*, **AE**. *Brassica campestris*, **AF**. *Hygrophila auriculata*, **AG**. *Justicia simplex*, **AH**. *Pimpinella tomentosa*, **AI**. *Strobilanthes angustifrons*, **AJ.** *Pisum sativum*, **AK**. *Ricinus communis*, **AL**. *Aspidopterys*, **AM**. *Xanthium strumarium*, **AN**. Caryophyllaceae, **AO**. *Barleria* sp.

and shrubs had almost equal shares: 47.16% and 48.43%, respectively. This honey is monofloral, in view of the high proportion of *Ageratum conyzoides* (46%).

MALLAWAN

This honey showed higher pollen diversity: 22 plant species (8 trees, 11 herbs, 3 shrubs) belonging to 18 families. The SPs *Ageratum conyzoides* (20.38%), *Xanthium strumarium* (16.74%), and *Ziziphus* sp. (16.2%) were followed by the IMPs nectarless Poaceae (7.29), *Syzygium cumini* (5.67). *Blumea* sp. (4.39%), Caryophyllaceae (4.18%), *Holoptelea integrifolia* (3.37%), and *Brassica campestris* (3.9%), and the MPs *Phoenix sylvestris* (2.8%), *Pimpinella tomentosa* (2.16%), *Justicia simplex* (2%) *Peltophorum* sp., *Chenopodium album* (0.95% each), *Emblica officinalis*, *Eucalyptus globulus*, *Ricinus communis*, *Mimosa pudica* (0.81% each), and *Solanum* sp. (0.67%). Trees contributed 16.04% of the pollen, followed by herbs (59.09%) and shrubs (17.82%). This honey is of the multifloral type.

DISCUSSION

Several factors related to climate, topography, and demography largely define the vegetation and flora of the studied region. The local floristic profile, which is affected by climate and anthropopression, is an important factor determining the type and class of honey, the pollen assemblage of which is an indicator of short-term vegetational changes. India is one of the largest producers and exporters of honey, with ca 300,000 beekeepers producing ca 60,000 tons of honey (55% domesticated, 45% wild) and earning ca 44 million USD (Sivaram et al. 1993, Sivaram & Anita 2000). The diversity of the flora of climatically varied India is a boon for honey production. *Apis dorsata*, *A. cerana*, and *A. mellifera* are the three main honey-producing bees in India. The hazards to beekeeping include deforestation, indiscriminate use of pesticides, insecticides, and weedicides, and unforeseen changes in climatic conditions.

The palynological record in the honey samples from the different studied sites showed *Syzygium cumini* pollen as predominant in Girar and appearing as secondary pollen in the samples from all other sites except New Hyderabad and Ashakhera (Lucknow) and Mallawan (Hardoi). The absence or low amounts of *S. cumini* pollen in these highly populated areas indicate its decline due to urbanisation or to the shrinking of agricultural land as a result of deforestation. *Syzygium cumini* is an evergreen tree bearing mildly fragrant flowers. It is widespread in both moist and dry climatic conditions. *S. cumini* is pollinated by honeybees, houseflies (*Musca domestica*), fruit flies, and wind. Throughout India, except for very cool regions, this tree is widely cultivated for its edible fruits and for medicinal uses. It is an important plant to conserve for beekeeping, as the flowers have abundant nectar and the honey produced is of very good quality.

The secondary pollen composition in the samples from the different studied sites showed almost equal shares of trees and herbs/shrubs. The trees are *Feronia limonia*, *Prosopis spicigera*, *P. juliflora*, and *Moringa oleifera*. The *Prosopis* species are invasives introduced about two centuries ago in India; they spread profusely in wastelands and are planted as avenue trees in urban areas. This accounts for their fairly high percentage (mean 22%) in the honey in and around urban areas such as Trilokpur, New Hyderabad, and Ashakhera. Pollen of the invasive weed *Ageratum conyzoides* had high shares in samples from rural, agricultural or arboricultural areas like Mallawan, Malihabad, Ashakhera, and Bahraich. Other herbs or shrubs noted as secondary contributors of nectar were *Brassica campestris*, *Pimpinella tomentosa*, *Xanthium strumarium*, and *Ziziphus* sp., having average 15–16% shares of the pollen in the honey. It is evident that the honeybees have adapted well to the presence of these invasive exotic trees or herbs, and that they largely depend on the vegetation available for forage within a short radius. Honeybees have a short range of flight from their beehive (700 m radius) if good forage is available (Orwa et al. 2009). Among the indigenous plants the only available plants for foraging are very limited as predominant and secondary pollen contributors (*Feronia limonia*, and *Syzygium cumini*). As a result, the honeybees have to depend on a variety of plants available in their vicinity as important minor pollen or minor pollen in the honey. This is part of the reason why most of the honey observed in the studied sites is multifloral. The secondary pollen of *Prosopis* spp. recorded in

the honey is a significant cause of allergy in humans. It is widely grown for greening desert and wastelands for reclamation. In research in the United Arab Emirates, ca 45% of patients tested sensitive to the protein present in pollen of *Prosopis* spp. (Naim & Phadke 1972, Ezeamuzie et al. 2000). *Ageratum conyzoides* pollen is also a common weed allergen and may cause asthma or rhinitis (Killian & McMichael 2004). The dendrogram (Fig. 4) plotted for the 55 plant species recorded in the honey from south-western, central and eastern Uttar Pradesh shows *Ageratum conyzoides* with the highest frequency, indicating its potential in apiculture but also the risk to those allergic to its pollen protein. The second plant community used for foraging by honeybees includes *Syzygium cumini*, *Feronia limonia*, *Eucalyptus globulus*, *Prosopis spicigera*, *P. juliflora*. *Brassica campestris*, *Pimpinella tomentosa*, *Xanthium strumarium*, and *Ziziphus* sp. The third plant community foraged by honeybees, in the important minor class, comprises diverse plant species such as *Capparis* sp., *Ficus* sp., *Murraya koenigii*, *Aegle marmelos*, *Tinospora cordifolia*, Caryophyllaceae, and nectarless Poaceae. The plant community in the minor class for foraging includes 45 species. Twenty-one of them are trees: *Adina cordifolia*, *Aegle marmelos*, *Ailanthus excelsa*, *Bombax ceiba*, *Delonix regia*, *Emblica officinalis*, *Eucalyptus globulus*, *Feronia limonia*, *Ficus* sp., *Holoptelea integrifolia*, *Phoenix* sp., *Trewia nudiflora*, *Symplocos racemosa*, *Mangifera indica*, *Lagerstroemia speciosa*, *Madhuca indica*, *Melia azedarach*, *Peltophorum* sp., *Pongamia pinnata*, *Syzygium cumini*, and *Terminalia* sp. Twenty-four of them are herbs or shrubs: *Amaranthus spinosus*, Apiaceae, *Apium* sp., *Aspidopterys* sp., *Barleria* sp., *Blumea* sp., *Brassica campestris*, *Cannabis sativa*, *Chenopodium* sp., *Croton* sp., Cucurbitaceae, *Evolvulus* sp., *Hygrophila auriculata*, *Justicia simplex*, *Ocimum* sp., *Pimpinella tomentosa*, *Pisum sativum*, Poaceae, *Solanum* sp., *Tinospora cordifolia*, *Xanthium strumarium*, *Ricinus communis*, *Strobilanthes angustifrons*, and *Ziziphus* sp.

All these plants generally flower from late winter and attain peak blooming from spring to early summer (Fig. 5) when nectar flow into the beehives mainly occurs. We infer from the prominent pollen constituents of the honey samples that honey production in Uttar Pradesh is mainly multifloral. Here we mention that *Bombax ceiba*, which is pollinated by bats, produces very low amounts of pollen even though it is a high nectar producer and is common in the region, particularly on forest margins, so its 2.68% pollen share, though seemingly low, attests to its frequent presence and profuse flowering from late winter to spring, when it serves as a good source of nectar (Fig. 5).

Plant height apparently does not present the bees with an obstacle to collecting nectar and pollen; we observed that both *Ageratum conyzoides* and *Syzygium cumini* pollen were major constituents of the honeys studied. However, at sites of scattered occurrence the same plant species also become minor pollen constituents in honeys. Honeybees forage the nectar-producing plants that occur within their range of flight. The pollen of anemophilous plants such as *Holoptelea integrifolia*, *Amaranthus spinosus*, and Poaceae were either incidentally trapped by wind or were inadvertently carried to the hive in the course of nectar collection.

The melissopalynological records from different parts of India (Fig. 2) show the dominant vegetation adapted to local climatic conditions. The data on pollen from honey are a source of knowledge about the region or area from which it is retrieved and can be used for forensic studies (Mildenhall 1990). In temperate Himachal Pradesh, the plant community foraged by bees includes *Pyrus communis*, *Plectranthus rugosus*, *Fagopyrum esculentum*, *Bauhinia variegata*, *Salvia* sp., Rosaceae, and Asteraceae (Attri 2010). The honey produced in natural conditions here is multifloral, and nectar flow occurs from spring to early summer. The common foraged plant species are acclimatised to cooler conditions. Among these species of fast-growing *Fagopyrum* is a high nectar producer which can be used as a crop for apiculture (Pendakur & Ramdas 2012) in temperate regions. Both *Plectranthus rugosus* and *Fagopyrum esculentum* are primary plants foraged by bees for honey, and can produce monofloral plant-specific honey for commercial use. Monofloral honeys have been recorded in other temperate areas such as Almora and Nainital districts in the Kumaon region (Chaturvedi 1983), where *Eucalyptus*, *Myrica*, *Brassica*, and Asteraceae – *Anaphalis* are the main source of nectar. Only a few honeys were multifloral, showing varied pollen percentages of *Alnus*, *Eucalyptus*, *Clematis*, Asteraceae – *Anaphalis*, and others (Verma 1988).

Monofloral honeys are very common in peninsular India. Studies from Andhra Pradesh revealed that the primary forage plants for honeybees in Cuddapah District are *Pterocarpus*, *Syzygium*, *Anogeissus latifolia*, *Flacourtia*, *Sapindus*, and *Zea mays* (Lakshmi & Suryanarayana 2004); in Medak District, *Prosopis julifera* and *Eucalyptus* (Chaya & Varma 2010); and in Godawari District, *Anogeissus latifolia* is the prominent source of nectar. In Adilabad District, monofloral honeys are common, with pollen of *Ageratum conyzoides*, *Pongamia pinnata*, *Borassus flabellifer*, *Coriandrum sativum*, and *Ocimum basilicum* as the most preferred plants except for one multifloral type with *Xanthium strumarium* and *Ageratum conyzoides* (Ramakrishna & Swathi 2013) which were visited for nectar. Honey samples analysed from Visakhapatanam and Guntur districts are multifloral, and *Lagerstroemia parviflora* and *Crotolaria juncea* and *Schleichera oleosa* are the major nectar-producing plants (Jhansi et al. 1994).

In southern Karnataka, research from Chamaraja Nagar and the BR Hills shows monofloral honeys with dominance of *Ageratum conyzoides* and *Pongamia* sp. pollen, respectively (Chauhan & Murthy 2011). Honey samples from coastal areas of Western Ghats (Chickmagalur) are also monofloral, with abundant *Cocos nucifera* (47%) and *Coffea arabica* (64%) pollen (Bhargava et al. 2009). Thus the pollen grains recorded in different climate-specific regions of India show equilibrium with the local vegetation, topography, and anthropogeny (agriculture or arboriculture).

Melissopalynological investigations in the central part of India in the high-seasonality zone of Harda District, Madhya Pradesh, show monofloral honeys marked by high frequency (>45%) of *Brassica campestris* and *Alternanthera sessilis*, reflecting the production of that honey in the spring during the blooming period of those species (Chauhan & Quamar 2010).

From Bihar there are few studies of honey. Only two samples were analysed from Muzuffarpur District, showing monofloral character, with *Zea mays* and *Phoenix sylvestris* as the predominant plant species in the respective samples (Suryanarayana et al. 1992). Studies from Assam in north-west India showed the honey to be bifloral, the dominant plant species being *Shorea robusta*, *Syzygium cumini*, *Mimusops elengi*, *Salmalia malabaricum*, *Brassica campestris*, and *Caesalpinia pulcherrima* (Dixit et al. 2012).

Most of the honeys analysed from Burdwan District, West Bengal, are multifloral, as indicated by the frequencies of *Cocos nucifera*, *Borassus flavellifer*, *Terminalia arjuna*, *Acacia auriculiformis*, *Lagerstroemia speciosa*, and *Xanthium strumarium* pollen, except for one monofloral honey sample from the coastal area with preponderance of *Cocos nucifera* pollen (Pal & Karmarkar 2013).

In the urban area of Lucknow the honeys are multifloral, comprised of plant species such as *Syzygium cumini*, *Prosopis juliflora*, *Ageratum conyzoides*, *Eucalyptus globulus*, and *Citrullus lanatus* (Chauhan & Trivedi 2011, Chauhan et al. 2013). Honeys from the semi-urban Banthara area were found to be both monofloral and bifloral, with *Cassia* type 1 and type 2 and *Asphodelus* sp. as the plants most preferred for nectar and pollen (Chaturvedi 1976). Our present study shows that the honeys collected/studied earlier from the same area (now urbanised) after a span of 30 to 40 years shows multifloral-type honey. The honey from the adjoining urban Unnao District is multifloral (Chauhan & Singh 2010), containing almost the same plant species as in the multifloral honeys from Lucknow. With changes in the vegetation of the area, the honeybees also change their preferences of plants for foraging. Periodic, long-term studies of the pollen in honeys from a given area should help in assessing changes in plant diversity related to natural or anthropogenic factors.

CONCLUSIONS

The utility of honey varies from person to person depending upon the allergenic properties of the protein present in it, which is related to the plants foraged by honey bees. On the Indian sub-continent the monofloral type of honey is found largely in the Himalayan and peninsular regions. Central and north-central parts of India show dominance of the multifloral type, and the eastern part is dominated by the bifloral type. This variation is attributed mainly to seasonality. Areas of high seasonality, such as our study area, show high diversity of the flora, and hence the multifloral type of honey is found.

Melissopalynological studies can help in patenting plant-specific honey, and can raise awareness of allergens present in the pollen from a particular plant. To aid consumer choice, it would be helpful to establish apiaries based on knowledge of the dominance of medicinally important plants preferred by honeybees in a given area. We recorded pollen grains of 55 species in the honey from south-western, central and eastern parts of Uttar Pradesh, India. We found that *Ageratum conyzoides*, a noxious invasive weed known worldwide for its allergenic properties, was a very dominant plant taxa foraged by honey bees in the absence of medicinally important regional flora having useful pollen protein. The pollen assemblage in honey, whether multifloral, monofloral or bifloral, provides information related to the changing pattern of vegetation in an area, including the annual, decadal, and century-scale changes induced by climate or anthropopression. Importantly, reforestation and conservation of medicinally important regional plant species can furnish useful nectar sources for honeybees.

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