Acta Palaeobotanica 61(1), 20–31, 2021
https://doi.org/10.35535/acpa-2021-0002

e-ISSN 2082-0259
ISSN 0001-6594

Pollen analysis of summer honeys from Prayagraj District, Uttar Pradesh, India

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Received 1 December 2020; accepted for publication 21 May 2021

ABSTRACT. Eighteen *Apis dorsata* Fabricius summer honey samples collected from Prayagraj District (Uttar Pradesh) during the summer season were analysed for pollen content. A total of 43 pollen types belonging to 26 plant families were found in these samples. Five of the 18 honey samples were found to be unifloral; 13 were multifloral. In terms of frequency, pollen of *Syzygium cumini*, *Azadirachta indica* and *Coriandrum sativum* were recorded as predominant pollen types, 11 pollen types as secondary pollen types, 23 as important minor pollen types, and 38 as minor pollen types. The Asteraceae family showed the highest frequency of occurrence. Four pollen types were recorded in more than 50% of the honey samples: *Ageratum conyzoides*, *Bombax ceiba*, *Azadirachta indica* and *Syzygium cumini*. Absolute pollen type counts per 10 g of honey samples ranged from group II to group V. The aim of determining and evaluating the pollen data was to infer the flora visited by the honeybees during the summer season in Prayagraj District. The findings were correlated with the pattern of vegetation in the vicinity of the bee hive sites during honey production. The study indicates that Prayagraj District has good potential for beekeeping ventures, due to the high diversity of nectar- and pollen- producing taxa during the summer season.

KEYWORDS: *Apis dorsata*, Honey, Pollen analysis, Prayagraj District

INTRODUCTION

Pollen analysis of honey is used to provide reliable information regarding the floral types that serve as major or minor nectar and pollen sources for the honeybees. It is also used to the determine the geographical and botanical origin of honey (Louveaux et al., 1978; Barth, 2004; Von Der Ohe et al., 2004). Significant pollen analyses of summer honey samples have been done by a number of pioneer workers from time to time in various areas of India: Andhra Pradesh (Jhansi et al., 1991; Ramanujam and Kalpana, 1992; Ramanujam and Khatija, 1992; Ramanujam, 1994; Lakshmi and Suryanarayana, 2004), Assam (Bera et al., 2007; Dixit et al., 2012), Karnataka (Bhusari et al., 2005; Bhargava et al., 2009; Chauhan and Murthy, 2010; Sivaram et al., 2012; Ponnuchamy et al., 2014), Himachal Pradesh (Attri, 2010), Maharashtra (Ghugal et al., 2015; Mate, 2015; Laxmikant and Mate, 2014, 2016), Sikkim (Bera et al., 1997), Sundarbans (Jana and Bera, 2004), Madhya Pradesh (Chauhan and Quamar, 2010; Harugade et al., 2016), Uttarakhand (Dixit et al., 2013) West Bengal (Layek et al., 2015) and Uttar Pradesh (Chauhan and Singh, 2010; Chauhan and Trivedi, 2011).

Melissopalynological accounts of winter honey samples of Prayagraj District, Uttar Pradesh, have been given by Sahney et al. (2018) and Shukla and Kumar (2020), but no information on pollen analyses of summer honey samples of Prayagraj District is available. The aim of the present study was to determine and evaluate the pollen sources for honeybees in Prayagraj District during the summer season, to help beekeepers properly manage their bee colonies. We also correlated the findings with the pattern of vegetation in the vicinity of the bee hive sites.

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MATERIALS AND METHODS

STUDY AREA

Prayagraj is a district of Uttar Pradesh which lies at 24°47′N to 25°45′N and 81°84′E to 82°30′E at about 98 m above sea level (Fig. 1). The plain area of the district is situated at the confluence of the Ganga and Yamuna, the two main rivers of the district, so these rivers play a very pivotal role in agriculture there. The climate of Prayagraj District is typical humid subtropical, with three seasons: hot dry summer, warm humid monsoon and cold dry winter. The summer season lasts from April to June, with maximum temperatures ranging from 40°C to 45°C. The monsoon lasts from early July to late September, and the winter season lasts from December to March (District Census Handbook Allahabad, India 2011). Prayagraj District is mainly agricultural, the main crops being wheat (*Triticum aestivum*) during winter and rice (*Oryza sativa*) during autumn. Most cultivated areas are planted with *Brassica campestris*, *Coriandrum sativum*, *Sesamum indicum*, *Solanum melongena* and *Solanum tuberosum*. In cropland and uncultivated areas, a number of weeds (*Ageratum conyzoides* and *Parthenium hysterophorus*) and trees (*Azadirachta indica*, *Butea monosperma*, *Ziziphus glaberrima*, *Phyllanthus emblica*, *Terminalia arjuna*, *Ziziphus numilaria*, *Holoptelea integrifolia*, *Madhuca longifolia*, *Mangifera indica*, *Psidium guajava*, *Salmalia malabarica*, *Boswellia serrata*, *Acacia catechu* and *Vachellia nilotica*) are the chief taxa of Prayagraj District. Some other tree species including *Eucalyptus* sp. and *Callistemon* sp., planted for forestry programs, are also heavily used as pollen and nectar sources by honeybees in Prayagraj District (Mishra and Verma, 1992).

SAMPLE COLLECTION

Eighteen squeezed raw honey samples were collected from eight different localities of Prayagraj District during the summer season (April – June) in 2017–2018 by professionals under our supervision. The localities are as follows: near Sirsa road (Sample numbers: PR1, PR8, PR17), Bara (PR15, PR18), Sevaith (PR2, PR11), Saidabad (PR3, PR16), Handia (PR4, PR7, PR12), Phoolpur (PR5, PR13), Koraon (PR6, PR9) and Naini (PR10, PR14). All honey samples were collected from summer *Apis dorsata* hives, then were stored in airtight plastic bottles and labelled. Field surveys were done to document the vegetation growing around the honey collection sites. Floral materials were collected during the field survey for preparation of pollen reference slides.

PALYNOLOGICAL ANALYSIS

The honey samples for microscopic pollen analysis were prepared in the laboratory as follows: one gram of honey was dissolved in 10 ml of distilled water and centrifuged. The supernatant was disposed of and the residue washed again with 10 ml of distilled water. The recovered sediment was treated with 5 ml of glacial acetic acid and the mixture was subjected to

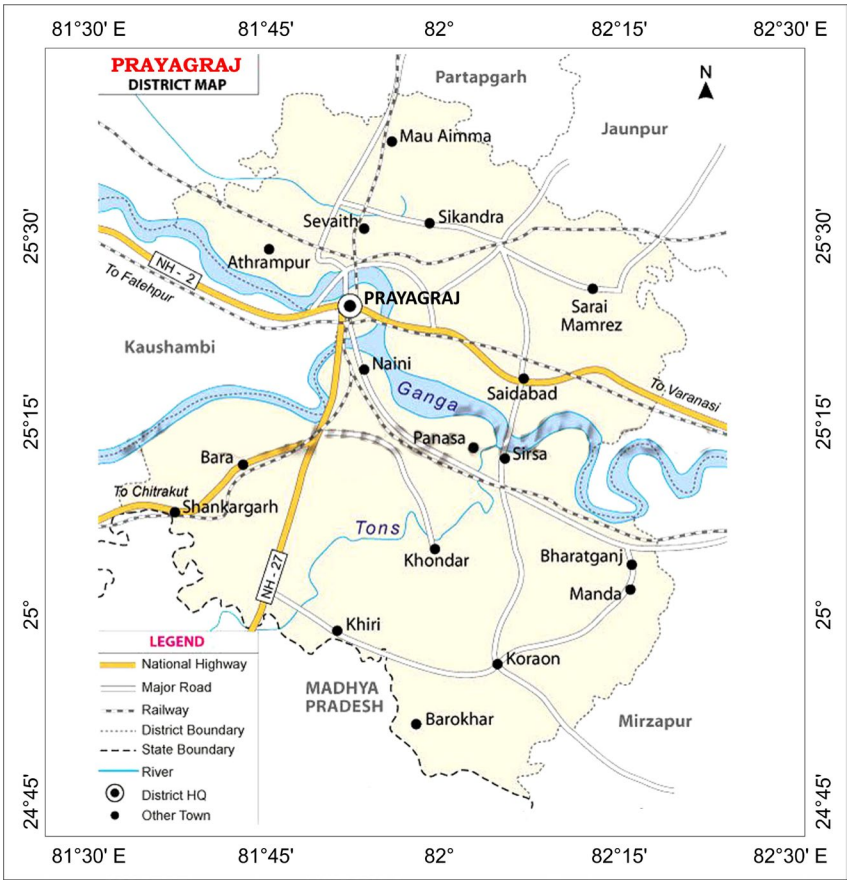

Fig. 1. Map showing the study area in Prayagraj District, Uttar Pradesh

acetolysis (Erdtman, 1960). Permanent pollen slides were prepared with safranin glycerine jelly. Four pollen slides of each honey sample were prepared. Three hundred or more pollen grains were counted per slide, for a total of 1200 or more pollen grains counted from each sample. Qualitative pollen analyses employed the methods recommended by the International Commission for Bee Botany (Louveaux et al., 1978). Pollen grains retrieved from the honey samples were identified by comparing them with the reference pollen slides and the relevant literature. The reference slides were prepared following the methods of Wodehouse (1935).

FREQUENCY CLASSES, FREQUENCY OF OCCURRENCE, RELATIVE FREQUENCY AND ABSOLUTE POLLEN COUNT

Pollen frequency was calculated as the percentage share of pollen grains of a particular taxon in the total number of grains counted. Once identified and counted, the pollen grains were assigned to one of the following frequency classes: predominant pollen type (above 45%), secondary pollen type (16–45%), important minor pollen type (3–15%) and minor pollen type (below 3%) (Louveaux et al., 1978). On the basis of the frequency classes, honey samples were categorized as unifloral or multifloral, depending on the presence of a predominant pollen type. Multifloral honey was further divided into bifloral and polyfloral honey. In bifloral honey, two secondary pollen types were recorded; in polyfloral honey, three or more secondary pollen types were recorded (Ramirez et al., 2011).

Frequency of occurrence, the relative percentage share of samples in which a certain pollen type was encountered, was calculated by dividing the number of samples in which a pollen type occurred by the total number of samples and then multiplying the quotient by 100. On the basis of frequency of occurrence, pollen types were classified as very frequent (>50%), frequent (20–50%), infrequent (10–20%) and rare (<10%) (Feller-Demalsy et al., 1987).

Relative frequency was calculated by dividing the number of samples in which a taxon occurred by the total number of taxa, then multiplying by 100 to obtain a percentage.

The absolute pollen counts (APCs) of honey samples (i.e. the number of pollen grains per 10 g honey) were obtained using a haemocytometer (Suryanarayana et al., 1981). The squeezed honeys showed more pollen grains than centrifugated honey (Von Der Ohe et al., 2004). The honey samples were assigned to the following APC groups: Gp I (APC < 20,000), Gp II (APC 20,000–100,000), Gp III (APC 100,000–500,000), Gp IV (APC 500,000–1,000,000), Gp V (APC > 1,000,000) (Louveaux et al., 1978). These pollen count groups respectively correspond to extremely poor, poor, rich, very rich and extremely rich pollen content in honey (Jose et al., 1989).

PHOTOGRAPHY

Photomicrographs of pollen grains were taken using a Leica DM 2500 light microscope fitted with a Leica DFC295 camera. Scanning electron micrographs were taken with a JSM–6610LV scanning electron microscope.

RESULTS

Forty-three pollen morphotypes belonging to 26 plant families were recorded from the 18 summer honey samples collected from the Prayagraj District, Uttar Pradesh, during 2017–18. Thirty-nine of the 43 pollen morphotypes were recorded as entemophilous/amphiphilous and two as anemophilous pollen taxa (Tab. 1). Pollen grains of *Amaranthus* sp. and Poaceae members were considered to be anemophilous plant taxa and were encountered in both the important pollen type and minor pollen type frequency classes. Table 2 presents the obtained pollen analysis data (including frequency) for the summer honey samples. The major nectarifeous and polleniferous plant taxa retrieved from the samples were *Ageratum conyzoides*, *Azadirachta indica*, *Bombax ceiba*, *Butea monosperma*, *Cassia fistula*, *Citrus* sp., *Dalbergia sissoo*, *Moringa oleifera*, *Syzygium cumini* and *Terminalia* sp. The main nectarless plant taxa were *Cassia fistula*, *Amaranthus* sp. and *Mimosa pudica* (Tab. 1; Fig. 3).

The number of pollen types found in each sample ranged from 8 to 22. The families with the greatest diversity of pollen types were Fabaceae (10 pollen types), Asteraceae (8), and Myrtaceae (2) (Tab. 2). Unidentified pollen taxa were recorded in 12 samples (PR2, PR3, PR5, PR6, PR7, PR8, PR9, PR10, PR11, PR14, PR16, PR17) at low frequency (0.55–1.55%) (Tab. 2).

Five of the 18 honey samples qualified as unifloral (27.78%, n = 5) due to the presence of predominant pollen types (>45%) and 13 honey samples were multifloral (72.22%, n = 13). *Syzygium cumini* (11.11%, n = 2), *Azadirachta indica* (11.11%, n = 2) and *Coriandrum sativum* (5.56%, n = 1) were recorded as predominant pollen types in those five samples. In the 13 samples that were multifloral, three were bifloral (16.67%) due to the presence of two secondary pollen types, and ten were polyfloral (55.56%), having three or more secondary pollen types. Eleven plant taxa were registered as secondary pollen types in the bifloral and polyfloral honey: *Acacia* sp., *Ageratum conyzoides*, *Azadirachta indica*, *Bombax ceiba*, *Butea monosperma*, *Cassia fistula*, *Citrus* sp., *Coriandrum sativum*, *Dalbergia sissoo*, *Moringa oleifera* and *Syzygium cumini* (Tab. 2; Figs 2, 4). In terms of frequency class, 23 pollen types were important minor types (3–15%) and 38 pollen types were minor types (<3%).

Table 1. Habit, flowering period, common name, mode of pollination and sources of plant species of Prayagraj District Uttar Pradesh

Plant species	Common name	Family	Habit	Mode of pollination	Sources
Acacia sp.	Acacia	Fabaceae	Tree	EN	N^2P^2
Ageratum conyzoides L.	Chickweed	Asteraceae	Herb	EN	N^3P^3
Amaranthus sp.	Amaranth	Amaranthaceae	Herb	AN	P^2
Argemone mexicana L.	Prickly poppy	Papaveraeceae	Herb	AM	P^3
Azadirachta indica A. Juss.	Margosa	Meliaceae	Tree	EN	N^2P^3
Bauhinia variegate L.	Kachnar	Fabaceae	Tree	EN	N^2P^1
Bombax ceiba L.	Silk cotton tree	Bombacaceae	Tree	EN	N^1P^1
Butea monosperma (Lam.) Kuntze	Palas	Fabaceae	Tree	EN	N^3P^3
Cassia fistula L.	Golden shower	Fabaceae	Tree	AM	P^2
Catharanthus sp.	Periwinkle	Apocynaceae	Herb	EN	N^2P^2
Chrysanthemum sp.	Chrysanths	Asteraceae	Herb	EN	N^3P^3
Citrus sp.	Lemon	Rutaceae	Shrub	EN	N^1P^1
Combretum indicum L.	Chinese honeysuckle	Combretaceae	Climber	EN	P^2
Coriandrum sativum L.	Coriander	Apiaceae	Herb	EN	N^3P^3
Cucurbita maxima Duchesne	Pumpkin	Cucurbitaceae	Climber	EN	N^1P^1
Cyperaceae	Sedge family	Cyperaceae	Herb	AN	P^1
Dalbergia sissoo Roxb.	Sissoo	Fabaceae	Tree	EN	N^1P^1
Delonix regia Raf.	Flame tree	Fabaceae	Tree	EN	N^2P^2
Dianthus sp.	Carnation	Caryophyllaceae	Herb	EN	N^3P^3
Eucalyptus sp.	Eucalyptus tree	Myrtaceae	Tree	AM	N^1P^1
Helianthus annuus L.	Sunflower	Asteraceae	Herb	EN	N^1P^1
Justicia adhatoda L.	Adhatoda	Acanthaceae	Weed	EN	N^1P^1
Lycopersicon esculentum Mill.	Tomato	Solanaceae	Herb	EN	P^3
Madhuca longifolia (J. Konig.) J.F. Macbr.	Mahua	Sapotaceae	Tree	EN	N^1P^1
Mangifera indica L.	Mango	Anacardiaceae	Tree	EN	N^3P^3
Mimosa pudica L.	Touch-me-not	Fabaceae	Herb	EN	P^1
Moringa oleifera Lam.	Moringa tree	Moringaceae	Tree	EN	N^1P^1
Morus alba L.	White mulberry	Moraceae	Tree	AM	P^2
Ocimum sanctum L.	Basil	Lamiaceae	Herb	EN	N^3P^2
Parthenium hysterophorus L.	Carrot grass	Asteraceae	Herb	EN	N^1P^1
Phaseolus sp.	Bean	Fabaceae	Climber	EN	N^1P^1
Phyllanthus emblica L.	Indian gooseberry	Phyllanthaceae	Tree	EN	N^2P^2
Prosopis juliflora (Sw.) DC.	Kikar	Fabaceae	Tree	EN	N^1P^1
Poaceae	Grass family	Poaceae	Herb	AN	P^1
Sesamum indicum L.	Sesamum	Pedaliaceae	Herb	EN	N^1P^1
Spilanthus sp.	Spilanthus	Asteraceae	Herb	EN	N^3P^1
Sonchus arvensis L.	Sow thistle	Asteraceae	Herb	EN	N^3P^3
Stellaria sp.	Starwort	Asteraceae	Herb	EN	N^1P^1
Syzygium cumini (L.) Skeels.	Blackberry	Myrtaceae	Tree	EN	N^1P^1
Tagetes erecta L.	Marigold	Asteraceae	Herb	EN	N^3P^3
Tamarindus indica L.	Tamarind	Fabaceae	Tree	EN	N^3P^3
Tecoma stans L.	Yellow trumpetbush	Bignoniaceae	Tree	EN	N^2P^3
Terminalia sp.	Terminalia tree	Combretaceae	Tree	EN	N^1P^1
Vernonia sp.	Iron weed	Asteraceae	Herb	EN	N^1P^1

AN – Anemophilous taxa; AM – Amphiphilous taxa; EN – Entomophilous taxa; N – nectar; P – Pollen; N^1 = Major nectar source; P^1 = Major pollen source; N^2 = Medium nectar source; P^2 = Medium pollen source; N^3 = Minor nectar source; P^3 = Minor pollen source

The important minor and minor pollen types were *Amaranthus* sp., *Bauhinia varigata*, *Butea monosperma*, *Delonix regia*, *Dalbergia sissoo*, *Madhuca longifolia*, *Mangifera indica*, *Mimosa pudica*, *Morus alba*, *Phyllanthus emblica, Prosopis juliflora, Parthenium hysterophorus* and *Terminalia* sp.

Members of Asteraceae had the highest frequency of occurrence 72.22% (n = 13) and relative frequency (4.80) (Tab. 3), followed by Fabaceae (n = 11, FC 61.11%, RF 4.06), Myrtaceae (n = 9, FC 38.89%, RF 2.58), Solanaceae (n = 9, FC 38.89%, RF 2.58) and Poaceae (n = 8, FC 44.44%, RF 2.95). Four pollen types were found in more than 50% of the samples: *Ageratum conyzoides* (n = 13, FC 72.22%, RF 4.80), *Bombax ceiba* (n = 10, FC 50.00%, RF 3.32), *Azadirachta indica* (n = 9, FC 55.56%, RF 3.39) and *Syzygium cumini* (n = 10, FC 50.00%, RF 3.32) (Tab. 3).

Based on absolute counts of the pollen types per 10 g of summer honey samples, 22.22%

Table 2. Pollen grains recovered from summer honey, and their frequency (U – unifloral, P – polyfloral, B – bifloral)

Pollen type	PR1	PR2	PR3	PR4	PR5	PR6	PR7	PR8	PR9	PR10	PR11	PR12	PR13	PR14	PR15	PR16	PR17	PR18
Acacia sp.		23.5		8		19.25		6.5			21						27	
Ageratum conyzoides	15.8	16	19.55	1		12.65	22.5			23	29.75	39.22	6.95	7.22		33		2.42
Amaranthus sp.							8.6			2.86				5.75				0.92
Argemone mexicana	1.85							2.98			5				1			
Asteraceae		1	0.55			1	21.26	3.50	3.25		1.65	0.65	2.98	2.15	2		3.50	5.75
Azadirachta indica	2.25	1		53		5		57.67		17			2.44	29		1		0.92
Bauhinia variegata			1.15												5		1	
Bombax ceiba		27.5	21.72		2		1.15		33.85		1		29.45	2.35	29.22			
Butea monosperma		8	6.2	17.5			17		8.98						6.55			
Cassia fistula		7.5	17.6		9.65			12.7					16.45			19.55		
Catharanthus sp.			1.73												0.65		1.65	
Chrysanthemum sp.			5								1.15		1.66					7.8
Citrus sp.						32.55			23	5.35		27.55	17.75	17				
Combretum indicum			2						1				2.82					
Coriandrum sativum								2.62				0.55			17.55		18	47.28
Cucurbita maxima			2				2				7				1			
Cyperaceae				7		3			9							2.45	2.55	
Dalbergia sissoo					6.4			8.2			2	11			16.98			
Delonix regia							2								2.85			
Dianthus sp.										1			1		1			
Eucalyptus sp.		1									2.66	5				5	22	
Fabaceae		5	1			9	4		1.82	23.55	2	1.70	1.55				5.5	5.8
Helianthus annuus		3.5		3					7.2					2		1.57		
Justicia adhatoda		1				0.75				2.33					1.15			
Lycopersicon esculentum						1		2.85		5.45		1				1		
Madhuca longifolia						4.15				2		1.78		1				
Mangifera indica			1						1			1.7	1				2.15	
Mimosa pudica	2					3								1	2.15			2.65
Moringa oleifera				5				1.43		1		2.15		16.8			5	
Morus alba					13.2					2	1.85					1.15		
Myrtaceae			1				2				4.26		2.55	0.68	2.4			9.22
Ocimum sanctum	1.15		3.25						1.55			2.4				5.4	2.4	
Parthenium hysterophorus	2									1		1.30	2			2.55		2
Phaseolus sp.		1					1							2	1.65			
Phyllanthus emblica							1		5						2.35			
Prosopis juliflora				5.5				2					2.25	2			1.78	
Poaceae	3.75		5.45							7		2	5	1		2	2	
Sesamum indicum					2		2							1				
Spilanthus sp.		0.50					1.98								1			
Solanaceae			2.8		1				1	2	16.33					1.65	1	
Sonchus arvensis			2								1			1.9	1			
Stellaria sp.			2								0.85			1		1.7		
Syzygium cumini	71.2		1		63.75		5.5	1.55		0.63			2.15			17.98	1.7	
Tagetes erecta		1							1.35				1	2				2.65
Tamarindus indica							2				1				1.5			12.35
Tecoma stans					1							1				1	1	
Terminalia sp			1				1.72		1	1	0.85							
Vernonia sp.							1.22			1			1	2.15				1.15
Type A		0.50			1		1.68											
Type B		1	1						1	0.85				1				
Type C			1			1.5		1			0.65						0.55	
Type D		1					1			0.98						1	1	
Honey type	U	P	P	U	U	B	P	U	B	P	P	B	P	P	P	P	P	U
Total pollen types	8	17	22	8	9	15	19	11	14	19	18	15	18	20	19	17	18	12
No. of unidentified pollen types	0	3	2	0	1	2	2	1	1	3	1	0	0	1	0	1	2	0

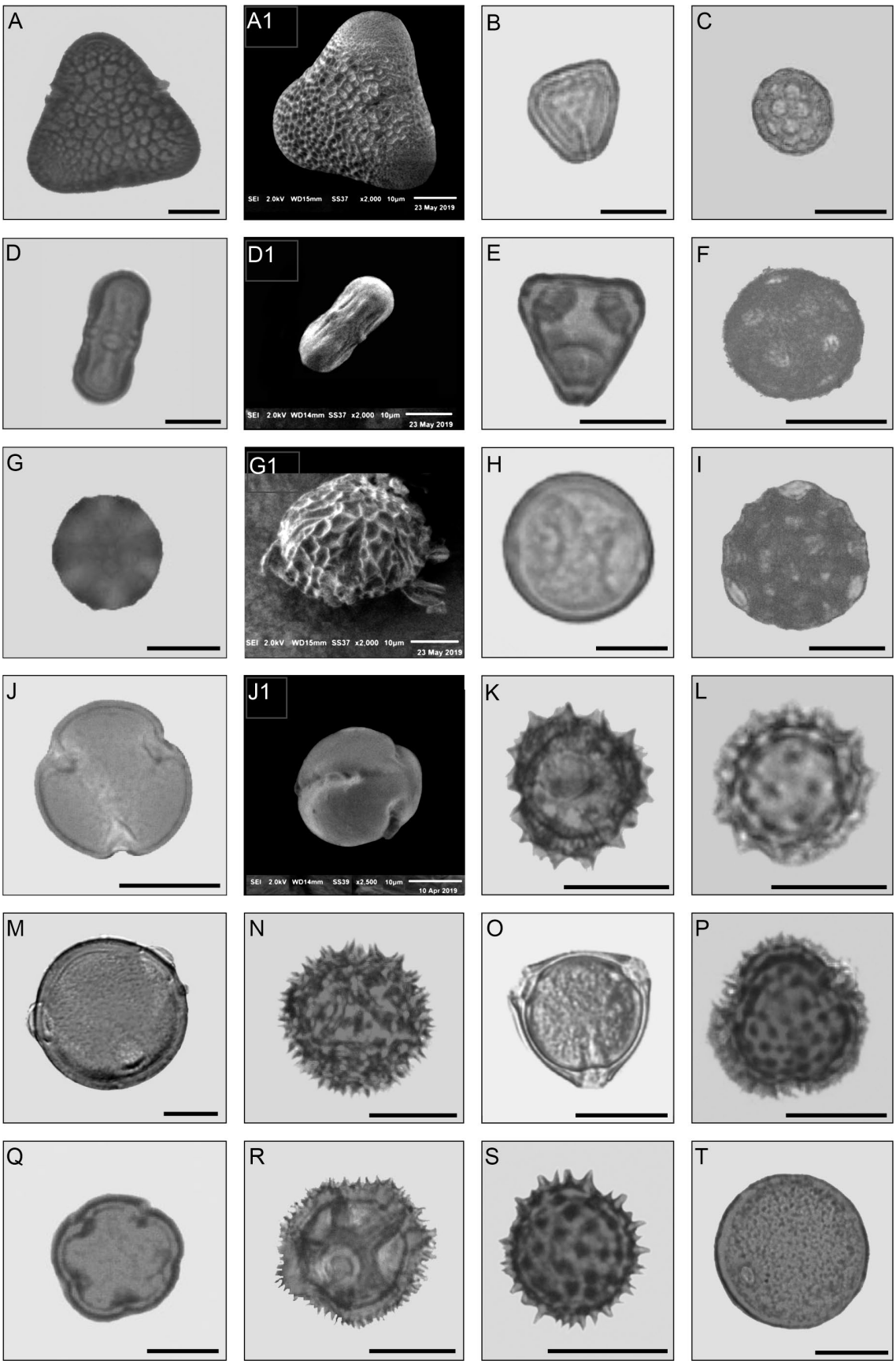

Fig. 2. Scanning electron micrographs and photomicrographs of selected pollen grains recovered from summer honey samples from Prayagraj District. **A**, **A1**. *Bombax ceiba*; **B**. *Syzygium cumini*; **C**. *Amaranthus* sp.; **D**, **D1**. *Coriandrum sativum*; **E**. *Eucalyptus* sp.; **F**. *Stellaria* sp.; **G**, **G1**. *Ocimum sanctum*; **H**. *Morus alba*; **I**. *Vernonia* sp.; **J**, **J1**. *Moringa oleifera*; **K**. *Chrysathemum* sp.; **L**. *Parthenium hysterophorus*; **M**. *Phaseolus* sp.; **N**. *Tagetes erecta*; **O**. Solanaceae; **P**. *Ageratum conyzoides*; **Q**. *Phyllanthus emblica*.; **R**. *Sonchus arvensis*; **S**. *Spilanthus* sp.; **T**. Poaceae. Scale bar = 20 µm

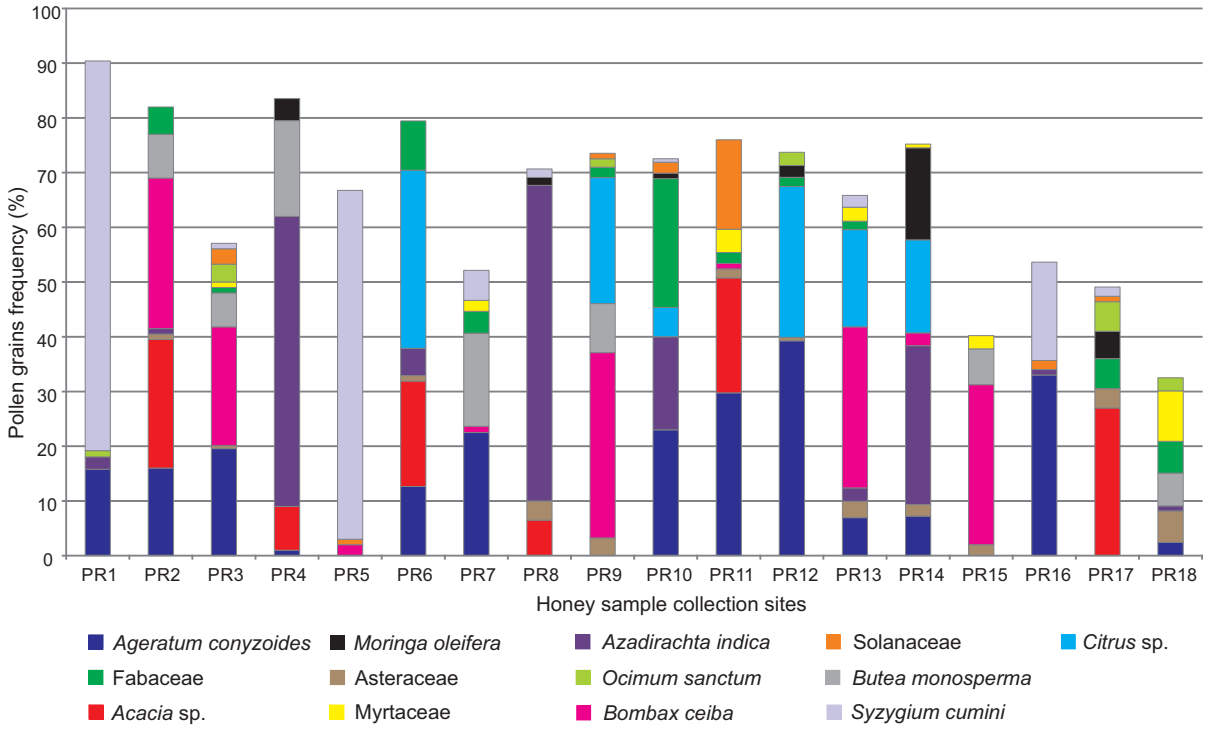

Fig. 3. Nectariferous/polleniferous plant taxa and plant families found in >25% of samples of summer honey collected from Prayagraj District, Uttar Pradesh

(n = 4) of the samples belong to Group II (in samples PR1, PR5, PR12, PR16), 38.89% (n = 7) to group III (PR4, PR6, PR9, PR13, PR15, PR18), 22.22% (n = 4) to group IV (PR2, PR7, PR8, PR17) and 16.67% (n = 3) to group V (found in PR3, PR10, PR14) (Fig. 5).

DISCUSSION

Our study yielded the first new insights into the pollen composition of summer honey produced by *Apis dorsata* in Prayagraj District of Uttar Pradesh. A total of 43 plant taxa belonging to 26 plant families comprising shrubs, trees, weeds and grasses were identified as bee forage sources. The most visited plants were in the family Asteraceae, followed by Fabaceae. Our results are similar to those reported from the Indo-Gangetic plains (Chauhan and Singh, 2010; Chauhan and Trivedi, 2011; Chauhan et al., 2015; Sahney et al., 2018; Shukla and Kumar, 2020).

Among the predominant pollen types, *Syzygium cumini* was high in frequency of occurrence and also relative frequency. *Syzygium cumini* was the predominant pollen type in two samples, a secondary pollen type in one sample, an important pollen type in one sample and a minor pollen type in five samples, indicating that *Syzygium cumini* is a major nectar and pollen source for *Apis dorsata* during the summer season when *Syzygium cumini* attains peak flowering. In a study from Lucknow District, Uttar Pradesh, Chauhan et al. (2015) found that *Syzygium cumini* was the main bee forage plant during the summer season. *Syzygium cumini* is a widely cultivated tree conserved for apiculture, as the flowers have abundant nectar and the honey produced is of very good quality. Due to its pan-Indian distribution, *Syzygium cumini* has also been recorded as a predominant pollen type in honey from Karnataka (Singh and Suryanarayana, 1997) and Andhra Pradesh (Lakshmi and Suryanarayana, 2004).

Azadirachta indica, another plant with a pan-Indian distribution, showed high frequency of occurrence and relative frequency. It was the predominant pollen type in two samples, a secondary pollen type in two samples, an important pollen type in one sample and a minor pollen type in four samples. It is considered to be a chief nectar and pollen source in the study area during the summer season. *Azadirachta indica* can be the predominant pollen type of unifloral honey in homogeneous vegetation with low plant diversity or when intensive bursts of flowering temporarily dominate the floral resources in the summer. Honeybees eagerly forage on *Azadirachta indica*.

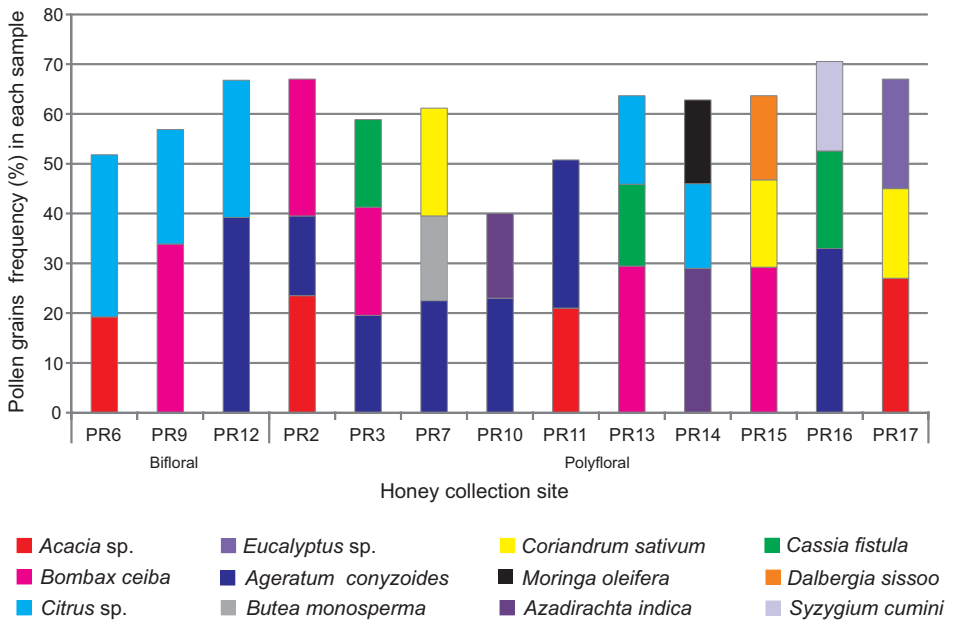

Fig. 4. Frequency of secondary pollen types found in both bifloral and polyfloral summer honey collected from Prayagraj District, Uttar Pradesh

Azadirachta indica has also been documented as the predominant pollen type in honey from Hyderabad (Kalpana et al., 1990), Nagpur (Cherian et al., 2011) and Bhandara District, Maharashtra (Ghugal et al., 2015). *Azadirachta indica* produces very low nectar. Nectar and pollen grains of *Azadirachta indica* are considered to be slightly toxic to honeybees (De Mesquita et al., 2010).

Coriandrum sativum, a cultivated plant, was the predominant pollen type in one honey sample we collected. It has also been documented as an important honeybee forage plant in Murshidabad District (Jana et al., 2002), West Bengal (Chakraborti and Bhattacharya, 2011) and Western Ghats (Bhargav et al., 2009).

Acacia sp. was recorded as a secondary pollen type in both bifloral and polyfloral honey. In their study from the slopes of Kotagiri, Nilgiris (Tamil Nadu, India), Rehel and Padwamathi (2014) found that *Acacia* sp. provided forage for honeybees. *Ageratum conyzoides* was found in our study as a secondary pollen type in both bifloral and polyfloral honey. It was also recorded as an important minor and minor pollen type. *Ageratum conyzoides* is an invasive weed. It showed high frequency of occurrence in the summer honey. *Ageratum conyzoides* was found to be the exclusive source of nectar and pollen in honey studies from Andhra Pradesh (Ramakrishna and Swati, 2013), Uttarakhand (Dixit et al., 2013) and Uttar Pradesh (Chauhan and Trivedi, 2011; Chauhan et al., 2017; Sahney et al., 2018; Shukla and Kumar, 2020). In our study, *Bombax ceiba* was a secondary pollen type in five samples and a minor pollen type in four samples, and showed high frequency of occurrence. Similar observations were reported in other studies (Siavaram, 2012; Chauhan et al., 2015, 2017). *Cassia fistula* was recorded from six honey samples. In three of them it was a secondary pollen type and in the others it was an important minor type. It was of frequent occurrence. *Cassia fistula* is a polleniferous/nectarless tree species. Pollen grains of *Cassia fistula* have been reported in honey from various parts of India (Tiwari et al., 2010; Harugade et al., 2016; Tripathi et al., 2017). *Citrus* was identified as a secondary pollen type in the present study. *Citrus* species are an important horticultural crop and are recognized as a major pollen source for apiculture in India (Pal and Karmarkar, 2013; Sahney et al., 2018). Pollen grains of *Eucalyptus* sp. and *Moringa oleifera* were also represented as secondary pollen types in our honey samples. Both *Eucalyptus* sp. and *Moringa oleifera* are important bee forage plants having a wide distribution (Noor et al., 2016). *Parthenium hysterophorus* is an exotic weed plant with a widely expanding distribution in India. Though it flowers profusely, we found that it was of minor importance for foraging by bees. Chauhan et al. (2015) also found *Parthenium hysterophorus* to be a minor forage plant for bees in Uttar Pradesh. Suryanarayana et al. (1992) reported *Parthenium hysterophorus* as

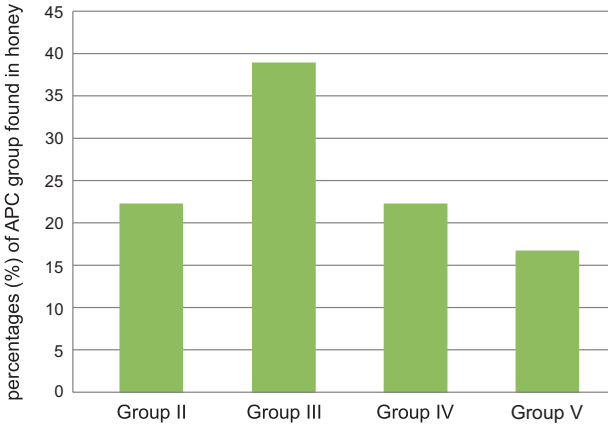

Fig. 5. Absolute pollen counts (pollen grains per 10 g honey) of summer honey, by APC group (Louveaux et al., 1978): Group II found in 4 samples (22.22%), Group III found in 7 samples (38.89%), Group IV found in 4 samples (22.22%) and Group V found in 3 samples (16.67%)

a major forage plant in their study in Muzaffarpur (Bihar). *Prosopis juliflora* was documented as an important minor pollen type and minor pollen type in the present study. *Prosopis juliflora* is an invasive woody species that blooms from March to May around the study sites. This species has been registered as a significant forage plant for bees in agricultural tracts of Ranga Reddy and Guntur districts of Andhra Pradesh during the summer (Kalpana and Ramanujam, 1990; Ramanujam and Khatija, 1992). We found that *Tamarindus indica* was a minor source for *Apis dorsata*. Seethalakshmi (1983) recognized *Tamarindus indica* as a chief source of both nectar and pollen for *Apis cerana* during the summer. Ramanujam and Kalpana (1992) reported *Tamarindus indica* as a predominant pollen type in their study of honey from *Apis flora* honeybees in Ranga Reddy District, Andhra Pradesh. The low pollen counts we obtained for *Madhuca longifolia*, *Mangifera indica* and *Phyllanthus emblica* indicate that they were only occasionally visited by the honeybees or that these plants were not common in the vicinity of the study area. Similar observations were made by Chauhan and Trivedi (2011).

Pollen grains from many species of Asteraceae were recorded as of very frequent occurrence, followed by members of Fabaceae, Myrtaceae, Solanaceae, Cyperaceae and Poaceae. Various authors have documented these families as forage plants for bees (Bhusari et al., 2005; Shubharani et al., 2012; Layek et al., 2016). Some families (Cyperaceae, Poaceae, Solanaceae, Myrtaceae) were documented as nectarless/polleniferous plant taxa in our present study. The presence of pollen from nectarless plants in squeezed honey has been reported from Orissa (Upadhyay et al., 2014) and West Bengal (Layek et al., 2015, 2016, 2020).Von Der Ohe et al. (2004) reported nectarless pollen grains under quaternary enrichment.

In terms of absolute pollen counts, 14 honey samples were registered as rich (group III) to

Table 3. Frequency of occurrence (FC) and relative frequency (RF) of plant species recorded in pollen analyses of summer honey collected from Prayagraj District, Uttar Pradesh

Plant species	FC	RF
Acacia sp.	33.33	2.21
Ageratum conyzoides	72.22	4.80
Amaranthus sp.	22.22	1.48
Argemone mexicana	22.22	1.48
Asteraceae	72.22	4.80
Azadirachta indica	55.56	3.69
Bauhinia variegata	16.67	1.11
Bombax ceiba	50.00	3.32
Butea monosperma	33.33	2.21
Cassia fistula	33.33	2.21
Catharanthus sp.	16.67	1.11
Chrysanthemum sp.	22.22	1.48
Citrus sp.	22.22	1.48
Combretum indicum	16.67	1.11
Coriandrum sativum	22.22	1.48
Cucurbita maxima	22.22	1.48
Cyperaceae	27.78	1.85
Dalbergia sissoo	27.78	1.85
Delonix regia	11.11	0.74
Dianthus sp.	16.67	1.11
Eucalyptus sp.	27.78	1.85
Fabaceae	61.11	4.06
Helianthus annuus	27.78	1.85
Justicia adhatoda	22.22	1.48
Lycopersicon esculentum	27.78	1.85
Madhuca longifolia	22.22	1.48
Mangifera indica	27.78	1.85
Mimosa pudica	27.78	1.85
Moringa oleifera	33.33	2.21
Morus alba	22.22	1.48
Myrtaceae	38.89	2.58
Ocimum sanctum	33.33	2.21
Parthenium hysterophorus	33.33	2.21
Phaseolus sp.	22.22	1.48
Phyllanthus sp.	16.67	1.11
Prosopis juliflora	27.78	1.85
Poaceae	44.44	2.95
Sesamum indicum	16.67	1.11
Spilanthus sp.	16.67	1.11
Solanaceae	38.89	2.85
Sonchus arvensis	22.22	1.48
Stellaria sp.	22.22	1.48
Syzygium cumini	50.00	3.32
Tagetes erecta	27.78	1.85
Tamarindus indica	22.22	1.48
Tecoma stans	22.22	1.48
Terminalia sp	27.78	1.85
Vernonia sp.	27.78	1.85
Type A	16.67	1.11
Type B	27.78	1.85
Type C	27.78	1.85
Type D	27.78	1.85

extremely rich (V), indicating high availability of the various forage taxa we recorded in the study area. Nectarless plants (*Amaranthus* sp., *Cassia fistula*, Cyperaceae and Poaceae) had low absolute pollen counts. The highest number of pollen morphotypes belonged to entomophilous taxa, followed by amphiphilous and anemophilous taxa. Similar observations were made by Chanda and Ganguly (1981) in their study of honey samples from Andhra Pradesh, Karnataka, Kerala, Orissa and West Bengal. The scanty record of pollen from anemophilous plant taxa such as *Amaranthus* sp. and Poaceae indicated that it was trapped in the hives incidentally by wind or was inadvertently transported by worker honeybees.

The study area's climate is mainly humid subtropical. Blooming of trees, shrubs and herbs peaks during the summer. These plants are abundant among agricultural fields. Our pollen analysis showed that the main forage flora for bees of Prayagraj District comprises *Ageratum conyzoides*, *Azadirachta indica*, *Bombax ceiba*, *Butea monosperma*, *Citrus* sp., *Coriandrum sativum*, *Eucalyptus* sp. and *Syzygium cumini*. The pollen grains found in the honey samples belong to the locally dominant flowering plants, both wild and cultivated.

CONCLUSION

This study is the first pollen analysis of summer honey samples collected from Prayagraj District, Uttar Pradesh. The obtained data reflect the abundance of nectar and pollen sources in the vicinity of the bee hive sites during honey production, and frequent visiting of those sources by the area's honeybees. With respect to the bee's preferences, the majority of the foraged plants are trees, followed by shrubs and herbs. *Ageratum conyzoides*, *Azadirachta indica*, *Bombax ceiba*, *Butea monosperma*, *Citrus* sp., *Coriandrum sativum*, *Eucalyptus* sp. and *Syzygium cumini* are the main summer-blooming plants preferred. The high frequency of their pollen in the samples means that they should be considered important and reliable sources of nectar and pollen for honey production. The study shows that Prayagraj District has a rich flora conducive to production of good-quality honey of high potential for commercialization of regional honey.

ACKNOWLEDGEMENTS

Vibhasa Shukla gratefully acknowledges financial support from the University Grant Commission, New Delhi, India, under the Postdoctoral Fellowship scheme for women, and thanks Prof. S.B. Babbar, Head of the Botany Department, University of Delhi, for providing the necessary facilities for this work.

REFERENCES

Attri, P.K., 2010. Melissopalynological studies of *Apis cerena* summer honey from Chamba district of the Himachal Pradesh. Asian Journal of Experimental Biological Sciences 1(4), 930–939.

Barth, O.M., 2004. Melissopalynology in Brazil: a review of pollen analysis of honeys, propolis and pollen loads of bees. Scientia Agricola 69, 342–350. https://doi.org/10.1590/s0103-90162004000300018

Bera, S., Mukhopadhyay, S.K., Dhar, J., Das, A.P., De, S., 1997. A melittopalynological investigation of *Apis cerana indica* Fabr. summer honey from Sikkim and Sub-Himalayan West Bengal, India. Palynology 33, 209–128.

Bera, S., Dixit, S., Basumatary, S., Sharma, G.C., 2007. Pollen analysis of honey from Kamrup Reserve forests, Assam. Journal of Palynology 43, 57–65.

Bhargava, H.R., Jyothi, J.V.A., Bhushanam, M., Surendra, N.S., 2009. Pollen analysis of *Apis* honey Karnataka, India. Apiacta 44, 14–19.

Bhusari, N.V., Mate, D.M., Makde, K.H., 2005. Pollen of *Apis* honey from Maharashtra. Grana 44, 216–224. https://doi.org/10.1080/00173130510010585

Chakraborti, T., Bhattacharya, K., 2011. Vegetational impact over bee forage in relation to seasonal variation: An observation in some honey samples of West Bengal and Orissa. Journal of Palynology 47, 69–76.

Chanda, S., Ganguly, P., 1981. Comparative analysis of pollen content of Indian honeys with reference to entomophily and anemophily. IV International Palynology Conference, Lucknow. 3, 485–490.

Chauhan, M.S., Murthy, S., 2010. Melittopalynological investigation of honeys from Chamarajanagar district, Southern Karnataka, India. Geophytology 39(1–2), 41–47.

Chauhan, M.S., Quamar, M.F., 2010. Melissopalynological investigation of honeys from Harda district, Madhya Pradesh. Phytomorphology 60(3–4), 122–127.

Chauhan, M.S., Singh, S.K., 2010. Melittopalynological investigation of honey from Unnao district, Uttar Pradesh. Journal of Applied Bioscience 36(2), 133–136.

Chauhan, M.S., Trivedi, A., 2011. Pollen analysis of honey from Lucknow district Uttar Pradesh. Journal of Applied Biosciences 37(1), 48–51.

Chauhan, M.S., Farooqui, A., Trivedi, A., 2015. Impact of urbanization, deforestation and foraging pattern of honey bees. Indian Journal of Applied Research 5(4), 44–47.

Chauhan, M.S., Farooqui, A., Trivedi, A., 2017. Plant foraged by bees for honey production in northern India: The diverse flora of India and its implications for apiculture. Acta Palaeobotanica 57(1), 119–132. https://doi.org/10.1515/acpa-2017-0003

Cherian, K.J., Bhowal, M., Godghate, S.D., 2011. Pollen and physicochemical analysis of honey produced by *Apis cerana indica* of Nagpur, Maharashtra (India). Journal of Environmental Research and Development 5(3), 542–550.

De Mesquita, L.X., Maracajá, P.B., Sakamoto, S.M., Soto-Blanco, B., 2010. Toxic evaluation in honey bees (*Apis mellifera*) of pollen from selected plants from the semi-arid region of Brazil. Journal of Apicultural Research 49(3), 265–269. https://doi.org/10.3896/ibra.1.49.3.06

Dixit, S., Basumatary, S.K., Bera, S.K., Rahman, A., Rabha, D., Thomas, S., 2012. Melissopalynological investigation from Goalpara district of Assam, northeast India. Journal of Palynology 47, 77–87.

Dixit, S., Basumatary, S.K., Singh, H., Bera, S.K., 2013. Melissopalynological studies of western part of Almora district, Uttarakhand. The Palaeobotanist 62, 39–46.

CENSUS OF INDIA. 2011. District Census Handbook Allahabad, Series-10 Part Xii-A, Directorate of Census Operations Uttar Pradesh India.

Erdtman, G., 1960. The Acetolysis method: A revised description. Svensk Botanisk Tidskrift 54, 561–564.

Feller-Demalsy, J., Parent, J., Strachan, A.A., 1987. Microscopic analysis of honeys from Alberta, Canada. Journal of Apicultural Research 27(2), 123–132. https://doi.org/10.1080/00218839.1987.11100748

Ghugal, S.I., Rahile, B.S., Bramhankar, K.B., 2015. Pollen analysis of honey samples from different geographic area of Bhandara district of Maharashtra. International Journal for Researches in Biosciences, Agriculture & Technology 35(1), 183–187.

Harugade, S., Gawate, A.B., Shinde, B., 2016. Bee flora diversity of medicinal plants in Vidya Pratishtan campus, Baramati, Pune, District (M.S.) India. International Journal of Current Microbiology and Applied Sciences 5, 425–431. https://doi.org/10.20546/ijcmas.2016.511.049

Jana, D., Bera, S., 2004. *Sonneratia apetala* Buch-ham as major nectar sources for honey bees during midsummer days in Sundarbans, West Bengal, India. Phytomorphology 54(1–2), 51–57.

Jana, D., Bandyopadhyay, A., Bera, S., 2002. Pollen analysis of winter honey samples from Murshidabad district, West Bengal. Geophytology 30, 91–97.

Jhansi, P., Kalpana, T.P., Ramanujam, C.G.K., 1991. Pollen analysis of rock bee summer honeys from the Prakasam district of the Andhra Pradesh, India. Journal of Apicultural Research 30, 33–40. https://doi.org/10.1080/00218839.1991.11101232

Jose, M., Demalsy, F., Parent, J., Alexander, A.S., 1989. Microscopic analysis of honey from Manitoba, Canada. Journal of Apicultural Research 28, 41–49. https://doi.org/10.1080/00218839.1989.11100819

Kalpana, T.P., Ramanujam, C.G.K., 1990. Melittopalynology of *Prosopis juliflora* honeys from Ranga Reddy district (Andhra Pradesh) and its significance. Indian Bee Journal 52(1–4), 44–46.

Kalpana T.P., Fatima, K., Ramanujam, C.G.K., 1990. Pollen analysis of *Apis cerana* and *Apis florae* honeys from Adikmet area, Hyderabad. Proceedings of the Indian Academy of Sciences (Plant Sci.) 100(3), 183–193.

Laxmikant, B., Mate, D., 2014. Summer pollen source to *Apis dorsata* honey bees from Bramhapuri forest area of Chandrapur district Maharashtra state (India). International Journal of Life Sciences 2(2), 160–164.

Laxmikant, B., Mate, D., 2016. Melittopalynological study of squeezed summer honey collected from forest area of Sindewahi tahasil of Chandrapur district (Maharashtra state). International Journal of Science and Research 5(6), 2053–2060. https://doi.org/10.21275/v5i6.nov164804

Lakshmi, K., Suryanarayana, M.C., 2004. Melittopalynological investigation of *Apis dorsata* honeys from forest area of Cuddaph district, Andhra Pradesh. Journal of Palynology 40, 189–198.

Layek, U., Bhakat, R.K., Karmakar, P., 2015. Foraging behavior of *Apis florae* Fabricius during winter and spring-summer in Bankura and Paschim Medinipur districts, West Bengal. Global Journal of Bio-Science and Biotechnology 4(3), 255–263.

Layek, U., Nandi, T., Karmakar, P., 2016. Pollen forage and storage pattern of *Apis dorsata* Fabri. in Bankura and Paschim Medinipur district, West Bengal. International Journal of Pure & Applied Bioscience 4(5), 59–71. https://doi.org/10.18782/2320-7051.2384

Layek, U., Mondal, R., Karmakar, P., 2020. Honey sample collection methods influence pollen composition in determining true-nectar foraging bee plants. Acta Botanica Brasilica 34(3), 478–486. https://doi.org/10.1590/0102-33062020abb0086

Louveaux, J., Maurizio, A.,Vorwohl, G., 1978. Methods of melissopalynology. Bee World 59, 139–157. https://doi.org/10.1080/0005772x.1978.11097714

Mate, D.M., 2015. Melittopalynological studies on *Apis dorsata* honey samples collected during the summer season in Bhiwapur tahsil of Nagpur District, Maharashtra state. Journal of Innovation in Sciences II(2), 69–72.

Mishra, B.K., Verma, B.K., 1992. Flora of Allahabad district U.P., India. Bishan Singh, Mahendra Pal Singh, Dehradun. pp. 283.

Noor, M.J., Ahmad, M., Ashraf, M.A., Zafar, M., Sultana, S., 2016. A review of pollen analysis of South Asian honey to identify the bee floras of the region. Palynology 40, 54–65. https://doi.org/10.1080/01916122.2014.988383

Pal, P.K., Karmarkar, P., 2013. Pollen analysis in understanding the foraging behavior of *Apis mellifera* in Gangetic West Bengal. Geophytology 42, 93–114.

Ponnuchamy, R., Bonhomme, V., Prasad, S., 2014. Honey pollen: using melissopalynology to understand foraging preferences of bees in tropical South India. PLoS ONE 9, 1016–1018. https://doi.org/10.1371/journal.pone.0101618

Ramakrishna, H., Swati, S., 2013. Pollen diversity in some *Apis florae* honeys from Adilabad district, Andhra Pradesh, India. Geophytology 42, 11–20.

Ramanujam, C.G.K., 1994. Forage resources for rock bees during May to July in deciduous forests of Ranga reddy district, Andhra Pradesh. Geophytology 24, 119–122.

Ramanujam, C.G.K., Khatija, F., 1992. Summer pollen sources of *Apis dorsata* honeybees in deciduous forest of Mahboobnagar District, Andhra Pradesh. Geophytology 21, 155–161.

Ramanujam, C.G.K., Kalpana, T.P., 1992. *Tamarindus indica* L.: An important forage plant for *Apis florae* F in south central India. Apidologie 23, 403–413. https://doi.org/10.1051/apido:19920503

Ramirez-Arriaga, E., Navarro-Calvo, L.A., Diaz-Carbajal, E., 2011. Botanical characterisation of Mexican honeys from a subtropical region (Oaxaca) based on pollen analysis. Grana 50, 40–54. https://doi.org/10.1080/00173134.2010.537767

Rehel, S.M., Padmavathi, S., 2014. Melittopalynological analysis of *Apis dorsata* honey of Kotagiri slopes, Nilgiris, Tamil Nadu. International Journal of Innovative Research and Development 3, 391–394.

Sahney, M., Rahi, S., Kumar, A., Jaiswal, R., 2018. Melissopalynological studies on winter honeys from Allahabad, Uttar Pradesh. Palynology 42(4), 540–552. https://doi.org/10.1080/01916122.2017.1418445

Seethalakshmi, T.S., 1983. Melittopalynological investigations on some Indian honeys. In: Proc 2nd Int. Conf. Apic. Trop. Climates (1980), Indian Agricultural Research Institute New Delhi. pp. 609–622.

Shubharani, R., Sivaram, V., Roopa, P., 2012. Assessment of honey plants resources through pollen analysis in Coorg honeys of Karnataka state. International Journal of Plant Reproductive Biology 4, 31–39.

Shukla, V., Kumar, A., 2020. Melissopalynological and physicochemical analysis of honey samples from Prayagraj district, Uttar Pradesh. Acta Palaeobotanica 60(1), 123–133. https://doi.org/10.35535/acpa-2020-0004

Singh, T.S., Suryanarayana, M.C., 1997. Melittopalynological investigation on honey of Karnataka. Indian Bee Journal 59(2), 79–83.

Sivaram, V., Roopa, P., Shubharani, R., Suwannapong, G., 2012. Pollen analysis in honeys collected from Karnataka region of Nilgiri Biosphere, South India. Journal of Apiculture 27(3), 223–231.

Suryanarayana, M.C., Seethalakshmi, T.S., Phadke R.P., 1981. Pollen analysis of Indian honeys 1. Honeys from Litchi (*Nephelium litchi*) and Jamun (*Syzygium cumini*). Proc. IV International Palynology Conference, Lucknow 3, 491–498.

Suryanarayana, M.C., Rao, G.M., Singh, T.S.M.S., 1992. Studies on pollen sources for *Apis cerana* Fabr. and *Apis mellifera* L. bees at Muzaffarpur, Bihar, India. Apidologie 23, 33–48. https://doi.org/10.1051/apido:19920104

Tiwari, P., Tiwari, J.K., Ballabha, R., 2010. Studies on sources of bee-forage for rock bee (*Apis dorsata* F.) from Garhwal Himalaya, India: A melissopalynological approach. Nature and Science 8(6), 5–15.

Tripathi, S., Basumatary, S.K., Bera, S.K., Brahma, M., Sharma, G.C., 2017. A palynological study of natural honeys from the Bongaigaon district of Assam, northeast India. Palynology 41(3), 389–400. https://doi.org/10.1080/01916122.2016.1217950

Upadhyay, D., Bhattacharya, S., Ferguson, D.K., Bera, S., 2014. Prospects of apicultural entrepreneurship in coastal district of eastern India: A melissopalynological evaluation. PLoS ONE 9(4), e94572.https://doi.org/10.1371/journal.pone.0094572

Von Der Ohe, W., Persano, O.L., Piana, L., Morlot, M., Martin, P., 2004. Harmonized methods of melissopalynology. Apidologie 35, 18–25. https://doi.org/10.1051/apido:2004050

Wodehouse, R.P., 1935. Pollen Grains, their Structure, Identification and Significance in Science and Medicine. New York and London: Mc. Graw Hill. Book Company, Inc.