Observation of bee pollinators (Apoidea) on a medicinal plant, *Lippia alba* (Mill.) (Verbenaceae)

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***Lippia alba*, an introduced species of *Lippia* has widely been used in traditional and folk medicine. Being incompatible with self-pollination, these plants rely on pollinators, particularly bees, for reproduction. In this study, floral association of the bee pollinators/visitors belonging to four families of Apoidea with *L. alba* has been examined.**

Keywords: Bees, floral association, *Lippia alba*, pollinators, traditional medicine.

LIPPIA ALBA (Mill.), also known as bushy lippia, is a widely studied species within the genus *Lippia* from a pharmacological aspect. This species belongs to the family Verbenaceae, which comprises 34 genera and 1200 species mainly distributed in the Neotropics, with few species groups reported from Europe, Asia, Africa and Madagascar[1]. Although several other species within the genus *Lippia* are native to the Indian subcontinent, *L. alba* is native to the Neotropical region and exotic to India.

Lippia alba is a bushy shrub reaching up to 2 m height with few branches and a minty aroma[2]. Leaves are broadly elliptic-oblong and opposite, and flowers are pinkish-white. The flowers are bisexual, with functional male and female reproductive organs pollinated predominantly by insects. The plants have axillary inflorescence with spicate, cylindrical heads and sessile flowers, which produce nectar and pollen, thus attracting pollinators[3].

Corolla has four lobes, stamens four, didynamous; ovary biloculed with one ovule in each locule, style regressed within the floral tube, stigma oblique. Fruits are drupaceous with two seeds[4]. Naturally occurring *L. alba* flowers are self-incompatible and allogamous, thus relying solely on external agents for pollination. Therefore, natural propagation in the wild is through seeds[5]. *L. alba* leaves are widely used in Indian folk medicine for their antidepressant, somatic and analgesic properties. Leaf paste is used to treat ear pain and giddiness caused by heatwaves by the Savara people[4]. In addition, the plant is used as louse repellent in poultry by the upper Godavari tribals. Several studies have identified chemical compounds, viz. citral, linalool, b-caryophyllene, tagetenone, limonene, carvone, monoterpenic ketones, iridoids, geniposides and bioflavonoids[6], which are responsible for the antimicrobial, sedative, anti-ulcerogenic, anti-hypertensive and anti-inflammatory properties in the *Lippia* species[7]. Indian studies on the efficiency of the chemical constituents of *L. alba* have shown that the leaf volatile oil vapours possess strong antifungal activity against sugarcane pathogens[8]. Essential oils extracted from *L. alba* have been proven to be effective preservatives against fungal infections and mycotoxins of food legumes[9], and toxic fumigants for management of *Callosobruchus chinensis* Linnaeus, the beetle pest of stored pulses[10]. CIMAP, Lucknow, has developed a new chemotype of *L. alba* named 'Bhurakshak' to make a genotype with a novel aroma suitable for the cosmetic and soap industry[11]. A study conducted in Juiz de Fora, Minas Gerais, Brazil, revealed that the hymenopterans are significant flower visitors. Bees, especially the European honey bee, *Apis mellifera*, are the most dominant pollinators of *L. alba* along with several other bee visitors like *Megachile* (*Austromegachile*) *susurrans* Haliday, *Exomalopsis* (*Exomalopsis*) *fernandoi* Moure, *Melipona quadrifasciata* Lepeletier and several unidentified species under different genera within the bee families Megachilidae, Apidae, Halictidae and Andrenidae[5].

Despite such medicinal importance of this species, there is no record of any extensive study on its pollinators from India, given the extensive distribution of this plant and its ability to thrive in almost any sort of plain land conditions, from roadsides and wasteland to river banks. Considering the medicinal and anti-microbial properties of *L. alba* in the context of the Indian subcontinent, the plant may be commercially cultivated as in Latin American countries and for this commercialization, knowledge of its propagation and thus its pollinators is essential. It is also noteworthy that due to the consideration of *L. alba* as weeds, these plants are cleared-off from areas surrounding agricultural fields, which negatively affects the pollinator diversity supported by them. As shown in Table 1, the pollinators associated with *L. alba* are also important pollinators of several other food crops. Therefore, for implementing conservation strategies for both the plant and its pollinators, knowledge of the importance of *L. alba* and the diversity of pollinators sustained by it is essential. Therefore, the present study examines the bee pollinators and floral visitors of *L. alba* in India.

The study was conducted on flowering patches of *L. alba* plants along the western bank of River Karo in Uliburu, Odisha (22.1252297°N, 85.356002°E) during monsoon (July 2021). A population with ~90 individuals of *L. alba* in an open rocky area formed in the reduced water flow of the river was observed (Figure 1 *a*). The temperature ranged between 31°C during the morning to 28°C in the evening, and the average humidity was 69.5%, with bright sunny mornings and cloudy post afternoons. Observations were made between 9:00 am and 5:00 pm and representatives were collected using an insect net for identification. Field photographs of *L. alba* were obtained using a Nikon D7000 digital camera. The collected specimens were preserved in

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Table 1. Floral associations between bee pollinators/visitors and *Lippia alba*

Family	Species	Material examined	Known floral associations
Apidae	*Amegilla zonata* (Linnaeus, 1758)	01 ♀	*Ocimum kilimandscharicum* (Lamiaceae)[19], *Solanum lycopersicum* (Solanaceae)[20], *Lippia alba* (Verbenaceae)*
	Ceratina binghami Cockerell, 1908	01 ♂	*Anacardium occidentale* (Anacardiaceae)[21], *Psophocarpus tetragonolobus*, *Cajanus cajan*, *Crotalaria juncea* (Fabaceae), *S. lycopersicum* (Solanaceae), *Zea mays* (Poaceae)[22], *Cucumis sativus* (Cucurbitaceae), *Medicago sativa* (Fabaceae), *Solanum melongena* (Solanaceae)[23], *L. alba* (Verbenaceae)*
	Ceratina lieftincki van der Vecht, 1952	02 ♀	*Cleome rutidosperma* (Cleomaceae), *Eugenia* sp. (Myrtaceae)[24], *C. cajan*, (Fabaceae), *C. sativus* (Cucurbitaceae), *Gizotia abyssinica* (Asteraceae)[23], *L. alba* (Verbenaceae)*
	Ceratina simillima Smith, 1854	01 ♀	*Convolvulus arvensis* (Convolvulaceae), *Luffa echinata* (Cucurbitaceae), *Solanum nigrum* (Solanaceae)[25], *C. cajan* (Fabaceae), *C. sativus* (Cucurbitaceae), *G. abyssinica* (Asteraceae)[23], *L. alba* (Verbenaceae)*
	Ceratina smaragdula (Fabricius, 1787)	01 ♀	*A. occidentale* (Anacardiaceae)[21], *Abelmoschus esculentus* (Malvaceae), *Cucurbita* sp., *L. echinata* (Cucurbitaceae)[26], *C. cajan* (Fabaceae), *C. sativus* (Cucurbitaceae), *G. abyssinica* (Asteraceae)[23], *L. alba* (Verbenaceae)*
	Thyreus takaonis (Cockerell, 1911)	01 ♂	*L. alba* (Verbenaceae)*
Colletidae	*Hylaeus* sp.	01 ♀	*L. alba* (Verbenaceae)*
Halictidae	*Austronomia* sp.	01 ♂	*L. alba* (Verbenaceae)*
	Hoplonomia elliotii (Smith, 1875)	01 ♂	*Ipomoea* sp. (Convolvulaceae), *S. melongena* (Solanaceae), *C. cajan* (Fabaceae)[23], *L. alba* (Verbenaceae)*
	Hoplonomia westwoodi (Gribodo, 1894)	01 ♂	*S. lycopersicum*, *S. melongena* (Solanaceae)[27], *L. alba* (Verbenaceae)*
	Lasioglossum sp.	01 ♀	*L. alba* (Verbenaceae)*
	Nomia curvipes (Fabricius, 1793)	01 ♂	*Carthamus tinctorius* (Asteraceae), *Arachis hypogaea*, *Phaseolus vulgaris* (Fabaceae)[28], *L. alba* (Verbenaceae)*
	Coelioxys (*Allocoelioxys*) *angulatus* Smith, 1870	01 ♂	*Vitex negundo* (Lamiaceae)[29], *L. alba* (Verbenaceae)*
	Megachile (*Aethomegachile*) *conjuncta* Smith, 1853	01 ♂	*C. cajan*, *C. juncea* (Fabaceae), *V. negundo* (Lamiaceae), *Derris pinnata* (Fabaceae), *Justicea* sp. (Acanthaceae), *Tecoma stans*, *Jacaranda mimosifolia* (Bignoniaceae), *Duranta* sp. (Verbenaceae)[29], *L. alba* (Verbenaceae)*
Megachilidae	*Megachile* (*Aethomegachile*) *laticeps* Smith, 1853	01 ♂	*C. cajan*, *Crotalaria pallida*, *C. juncea*, *Dendrolobium umbellatum*, *Lablab purpureus*, *Peltophorum pterocarpum* (Fabaceae), *Memecylon caeruleum* (Melastomataceae), *Ocimum basilicum*, *Vitex trifolia* (Lamiaceae)[30], *L. alba* (Verbenaceae)*
	Megachile (*Amegachile*) *bicolor* (Fabricius, 1781)	02 ♂	*Acacia* sp., *C. juncea*, *C. cajan*, *Bauhinia latifolia*, *D. pinnata*, *Parkinsonia* sp., *P. pterocarpum*, *Vigna mungo*, *Tephrosia hamiltonii* (Fabaceae), *Lagerstroemia indica* (Lythraceae), *Campsis radicans*, *J. mimosifolia* (Bignoniaceae), *Murraya peniculata* (Rutaceae), *Helianthus* sp., *Tagetes* sp., *Verbesina encelioides*, *Gaillardia* sp. (Asteraceae), *V. negundo* (Lamiaceae), *Nerium* sp., *T. stans* (Bignoniaceae), *Justicea thyrsiflora*, *Adhatoda vasica* (Acanthaceae), *Ipomoea* sp. (Convolvulaceae), *Callistemon lanceolatus* (Myrtaceae), *Grewia asiatica* (Malvaceae), *Tridax procumbens* (Asteraceae)[29], *Lippia alba* (Verbenaceae)*
	Megachile (*Creightonella*) *fraterna* Smith, 1853	01 ♂	*C. juncea* (Fabaceae)[30], *L. alba* (Verbenaceae)*
	Megachile (*Eutricharaea*) sp.	01 ♂	*L. alba* (Verbenaceae)*

*New floral associations reported in the present study.

70% ethanol and returned to the laboratory. The samples were pinned or dry-mounted and identified to family, genus, subgenus and species level with the help of appropriate identification keys and the literature[12–18]. Specimens were studied and photographed using a Nikon SMZ25 stereo-zoom microscope attached with a Nikon DS-Ri2 camera and processed employing NIS-Elements BR Analysis, version 5.20.00. Voucher specimens have been deposited in

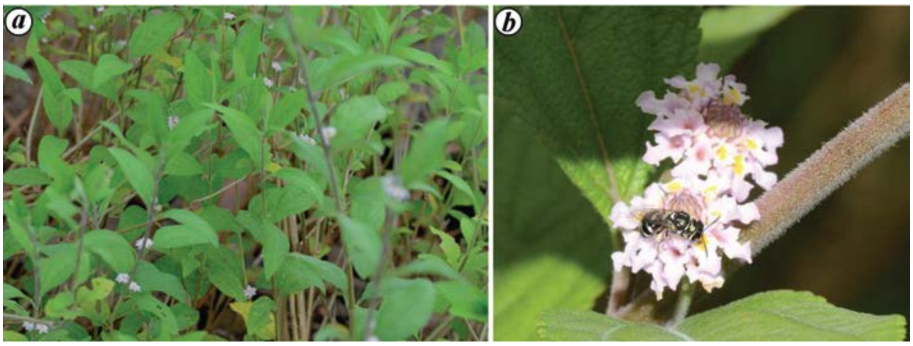

Figure 1. ***a***, Observed populations of *Lippia alba*. ***b***, *Ceratina simillima* visiting flowers of *Lippia alba*.

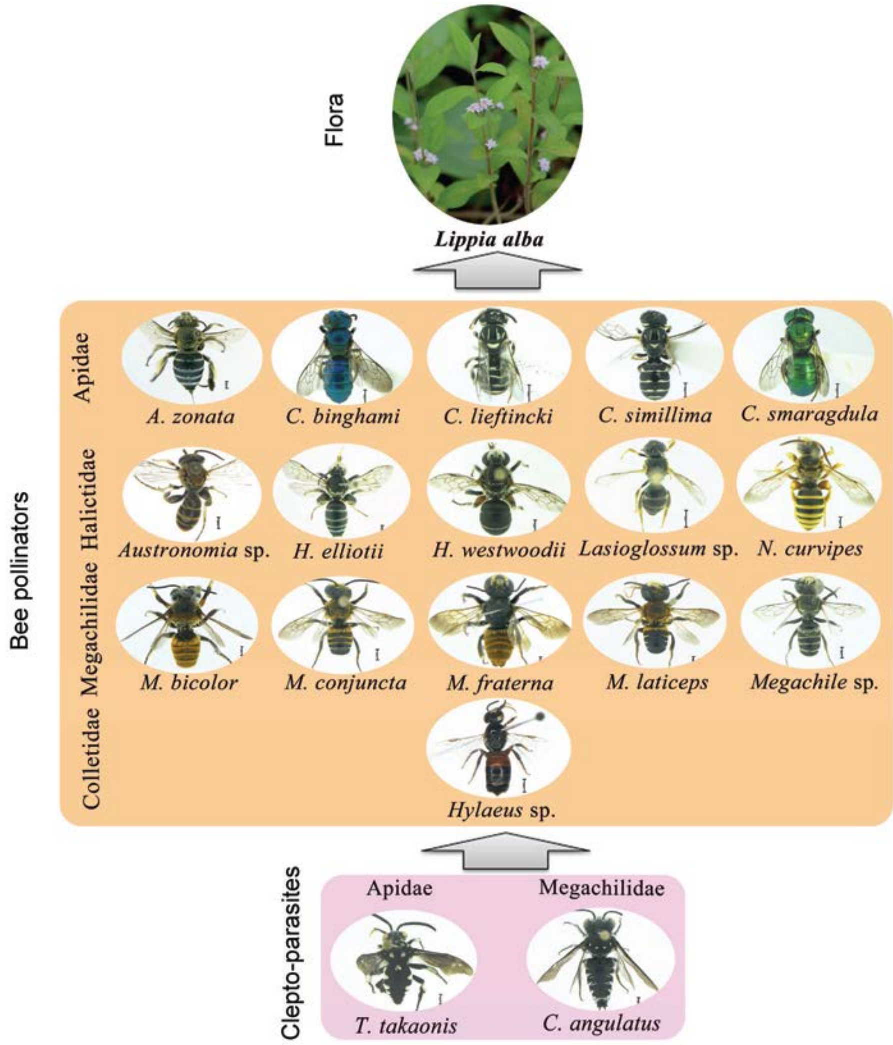

Figure 2. Flow chart showing the bee pollinators and cleptoparasitic associations of *L. alba*.

the National Zoological Collection (NZC), Zoological Survey of India, Kolkata.

The present study reveals the variety of bees with the potential to pollinate *L. alba*. Bees belonging to four families (out of seven extant bee families) were observed in the flowers of *L. alba*[16]. A total of 20 bees belonging to four families were observed and collected during the study period. Among them, 35% each belonged to Apidae and Megachilidae, followed by Halictidae (25%) and Colletidae (5%) (Table 1; refs 19–30 and Figure 2). Constant bee visitation to the flowers indicates that *Lippia* flowers might be a continuous food source to the foraging bees. However,

Table 2. Comparative analysis of morphology of *Ceratina simillima* and females (of the male megachilids observed) from vouchered specimens of the National Zoological Collection, Zoological Survey of India

Bee species	Body length (mm)	Head length (mm)	Head width (mm)	Mesosoma length (mm)	Mesosoma width (mm)	Metasoma length (mm)	Metasoma width (mm)
C. simillima	6.98	1.90	2.03	2.30	1.76	3.08	2.39
M. bicolor	16.11	3.49	5.07	5.28	4.64	7.99	5.41
M. conjuncta	12.91	2.88	4.24	3.47	3.69	6.30	3.97
M. fraterna	17.68	4.56	5.33	5.37	5.12	8.25	5.51
M. laticeps	14.74	3.22	4.48	4.26	4.26	4.32	4.32

during the study it was observed that only male megachilids visited the flowers. The visit of male megachilids could be because of insufficient space for the females, which are almost twice the size both in length and breadth compared to the *Ceratina simillima* (Table 2) photographed while visiting the flower (Figure 1 *b*) to collect pollen by rubbing its sternal scopa on the anthers inside the flower. Hence, it is not much rewarding for them, resulting in only males visiting the *Lippia* flowers for nectar. Further observations revealed that bee activity was highest during the sunny daytime between 10:30 am and 2:30 pm, after which the sky became overcast, and bee activity reduced.

On the other hand, apid and halictid bees, which collect pollen on the scopa on their hind legs, probably have sufficient space inside the floral tube to collect pollen. The male megachilids cannot be ruled out as pollinators and considered floral visitors as they transferred pollen via body hairs. Among all the bees observed to be foraging on the flowers, two, viz. *Coelioxys* (*Allocoelioxys*) *angulatus* Smith and *Thyreus takaonis* (Cockerell), are cleptoparasites of other bees. *Coelioxys* sp. has been reported as a cleptoparasite of apid[31] and megachilid bees[32]. *Thyreus* sp. is a well-known cleptoparasite of blue-banded bees within the genus *Amegilla*.

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Is crop diversification vulnerable to climate, agricultural and socio-economic factors in Himachal Pradesh, India?

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Crop diversification is essential for long-term farm income, rural livelihood and agricultural development in Himachal Pradesh (HP), India. The present study aims to examine the effect of climate, agricultural and socio-economic factors on crop diversification. Sirmaur district was found to be diverse, Kangra and Mandi districts were highly diversified, but Solan district was highly specialized in agriculture in HP. The fixed effects were found to be significant, indicating the role of farm-level changes in agronomic and cropping practices as a result of climate change. Crop diversification was led by population density, percentage of marginal and small farmers, cropping intensity, cultivators, marginal workers and total main workers. The important climate parameters like rainfall and minimum temperature, as well as other factors such as irrigation intensity and food crop productivity, had a negative impact on crop diversification, implying crop specialization.

Keywords: Agricultural development, climate change, crop diversification, panel regression, socio-economic factors.

CLIMATE change has become a major threat to the long-term development of agriculture and rural livelihood around the world. The regular occurrence of extreme events has a negative impact on agricultural production and food supply. It also causes losses to productive assets, exacerbates rural poverty, forces out-migration, reduces demand for industrial products and services and causes overexploitation of natural resources such as water, land and forests. In India, extreme drought reduces household income by 25–60% and increases poverty by 12–33% (ref. 1). Despite using multiple risk-coping strategies, farm households are unable to recover their loss of assets just after an extreme event[2]. Farmers take various adaptation steps to address development risks depending on their risk aversion, access to weather information and the availability of resources for adoption. Indian agriculture is highly vulnerable to climatic shocks due to its reliance on rainfall. Rainfed agriculture accounts for roughly 45% of the total cropped area in the country, and evidence suggests that rainfed production

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