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Research Article

Morphometric Profiling of Hymenopteran Pollinators from Cherry Orchards in the Kashmir Valley, India

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ABSTRACT

Hymenoptera, a diverse and ecologically important insect order, plays a vital role in enhancing fruit crop productivity through pollination. Despite their significance, morphometric data on pollinators from the temperate cherry orchards of the Kashmir Valley are limited. The present study, therefore, assessed interspecific and intraspecific morphological variation among 10 hymenopteran species belonging to four families: Apidae (*Apis mellifera*, *A. cerana*, *Bombus albopleuralis*), Halictidae (*Lasioglossum rugifrons*, *L. matianense*, *L. marginatum*), Andrenidae (*Andrena fucata*, *A. pilipes*, *A. agilissima*), and Vespidae (*Vespula vulgaris*). A total of 38 morphometric traits were recorded from the head, thorax, abdomen, and wings. Multivariate analysis, including Principal Component Analysis and Hierarchical Cluster Analysis using Python, revealed clear patterns of morphometric divergence and genus-level clustering. Closely related species such as *A. mellifera* and *A. cerana*, and the *Lasioglossum* group, formed tight clusters. In contrast, distinct species like *B. albopleuralis* and *V. vulgaris* were separated due to larger body sizes and unique structural adaptations. Morphological diversity among species has ecological relevance, influencing pollination efficiency, foraging behavior, and floral specialization. Robust bees like *B. albopleuralis*, with strong tibiae and long wings, are suited for long-distance foraging and pollinating deep flowers. In contrast, *L. matianense* is adapted to localized foraging and shallow blooms. These functional differences highlight the complementary roles of diverse pollinators in supporting stable and efficient pollination services. The integration of morphometric and ecological analyses emphasizes the value of both *Apis* and non-*Apis* bees in cherry orchard ecosystems.

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Introduction

The order *Hymenoptera* is one of the largest and most diverse insect groups. Members typically possess two pairs of membranous wings (with smaller hindwings), well-developed compound eyes, and chewing or chewing-lapping mouthparts adapted to varied feeding behaviors (Papa et al., 2022). A distinctive trait in many species, especially bees, ants, and wasps, is the narrow

petiole separating the thorax and abdomen. Advanced social behavior is observed in families such as Apidae (honey bees, bumblebees) and Formicidae (ants), characterized by complex colony structures and division of labor (Yokoi et al., 2025). Bees (superfamily *Apoidea*) are key pollinators of wild and cultivated plants, supporting both biodiversity and food production. Many hymenopterans are also parasitoids that regulate pest populations, making them vital to biological control. Their ecological adaptability and intricate interspecies interactions position Hymenoptera as central to studies on biodiversity, pollination, and ecosystem functioning (Techer et al., 2025).

Insect pollinators exhibit remarkable morphological diversity, which can be effectively analyzed through morphometric approaches. Morphometric analysis provides critical insights into species identification, interspecific variation, and the functional morphology of pollinators, thereby enhancing our understanding of their biology and ecological adaptations (Xue et al., 2025). Among Hymenoptera, bees are particularly valuable for detailed morphological characterization due to their specialized structural adaptations for pollen and nectar collection.

The application of morphometric tools enables the precise quantification of traits such as body size, head dimensions, thoracic structures, antennal segments, and wing morphology. These traits are essential for distinguishing closely related species and understanding patterns of interspecific variation. Although Hymenoptera is one of the most species-rich insect orders, with over 153,000 described extant species and more than 2,000 known from the fossil record, it remains relatively understudied. Estimates, particularly considering the vast diversity of parasitic wasps, suggest that the total number of surviving species could range from one million to as many as 2.5 million (Grissell, 1999).

The superfamily Apoidea (bees) includes species that are morphologically adapted for efficient pollen collection and floral interaction. This morphological diversity, especially among native and wild bees, is reflected in traits that influence foraging behavior, flight performance, and floral compatibility. Consequently, morphometric analysis has become a vital tool for taxonomic identification, particularly in complex ecosystems such as orchards, where multiple bee species may coexist and exhibit overlapping phenotypic traits (Klein et al., 2006).

In regions like the Kashmir Valley, where cherry orchards are a significant component of temperate horticulture, systematic morphometric studies of pollinators remain scarce. Although ecological surveys have documented the presence of key pollinators such as *Apis mellifera*, *A. cerana*, and various solitary bees, few studies have conducted rigorous morphometric characterizations to differentiate these taxa (Michener, 2007). The absence of standardized morphometric data hampers accurate species identification and may result in under- or overestimation of pollinator diversity and their ecological roles.

A comprehensive morphometric framework is therefore essential to address these gaps. By recording measurements of key morphological traits, such as body length, head width, thorax size, inter-ocellar distance, wing dimensions, and hind leg segment lengths, researchers can develop reliable datasets for species discrimination and phenotypic comparisons. These data not only enhance taxonomic resolution but also provide a foundation for studying developmental biology, sexual dimorphism, and adaptation to local environmental conditions (Doğan et al., 2024).

In the present study, we conducted a detailed morphometric investigation of hymenopteran pollinators collected from cherry orchards in the Kashmir Valley. The resulting dataset serves as a reference for future taxonomic, ecological, and genetic studies, thereby contributing to a more comprehensive understanding of pollinator biology in temperate fruit production systems. Understanding the ecological significance of morphometric variation is crucial for optimizing crop pollination, as traits such as body size, wing span, and tibia length are closely linked to foraging range, pollen-carrying capacity, and pollination efficiency (Dar et al., 2025).

Consequently, this study aims to investigate morphometric variation among hymenopteran pollinators in the cherry orchards of the Kashmir Valley using both traditional morphometric techniques and multivariate statistical analyses. By characterizing key pollinator taxa, the study contributes to a deeper understanding of pollinator functionality within temperate fruit agroecosystems.

Materials and Methods

Survey and collection of insect pollinators

The study was conducted from 2022 to 2024 in the Kashmir Valley, India, to assess the morphometric characteristics of hymenopteran pollinators associated with cherry orchards. The two-year duration was intentionally selected to capture inter-annual variability

in pollinator populations and environmental conditions, thereby enhancing the robustness and reliability of the data. Sampling was carried out during the peak cherry blooming period (March-May), which coincides with the highest pollinator activity.

An extensive field survey was undertaken across four districts of the Kashmir Valley, Srinagar, Shopian, Baramulla, and Ganderbal (Figure 1). Within each district, two representative locations were selected based on their prominence in cherry cultivation and ecological relevance: Shalimar and Dhara in Srinagar; Kullar and Aerhal in Shopian; Tangmarg and Sopore in Baramulla; and Lar and Baba-Wayil in Ganderbal.

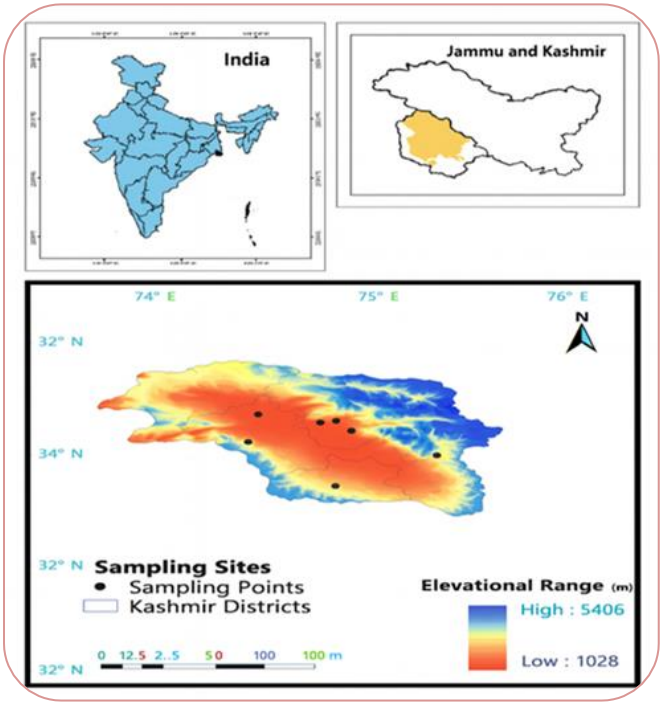


Figure 1. Map of study area showing the geographical layout of the Kashmir Valley, highlighting four key districts involved in cherry cultivation.

Pollinator collection was conducted during daylight hours to coincide with the peak activity period of the insects, ensuring optimal sampling efficiency. The survey was synchronized with the peak flowering season of cherry orchards at each site. Two primary collection methods were employed: sweep nets/aerial nets for active sampling and fluorescent pan traps for passive collection.

Captured specimens were euthanized in air-tight glass killing bottles containing 95% ethyl acetate to preserve their morphological integrity for subsequent morphometric analysis (Nuttman et al., 2011). This methodological framework aimed to provide a robust reference for understanding the relationship between morphological diversity and the pollination services provided by various hymenopteran species within cherry agroecosystems.

Identification of Hymenopteran pollinators

Different species of hymenopteran pollinators were identified using the taxonomic keys (Dichotomous Key) provided below.

Dichotomous key for *Apis* species (Michener, 2007; Kitnya et al., 2024)

1. Body size larger (12-14 mm); abdomen with distinct yellow or orange bands; commonly domesticated species……*Apis mellifera* (Western Honeybee)

1. Body size smaller (less than 12 mm); abdomen with or without distinct bands……2

2. Abdomen with distinct yellow bands; smaller in size (7-10 mm); less aggressive behavior……*Apis cerana* (Asian Honeybee)

Dichotomous key for Andrena species (Michener, 2007; Wood et al., 2020)

1. Hind tibia with long, dense, black hairs (scopa) ……2

1. Hind tibia with shorter, less dense, pale hairs (scopa)……..3

2. Body size larger (13-15 mm); scutum and scutellum distinctly punctate; facial foveae broad and distinct…… …..*Andrena agilissima*

2. Body size smaller (8-11 mm); scutum and scutellum with fine punctation; facial foveae narrow…… ……*Andrena pilipes*

3. Facial foveae narrow; abdomen with distinct, broad, pale bands on the terga…… .*Andrena fucata*

3. Facial foveae broad; abdomen without distinct bands……..…*Andrena agilissima*

Dichotomous key for *Lasioglossum* species (Gibbs, 2009**)**

1. Face and front of the head with distinct rugose (wrinkled) texture - *Lasioglossum rugifrons*

1. Face and front of the head not distinctly rugose……2

2. Body with broad, shiny metallic green or blue sheen …… *Lasioglossum marginatum*

2. Body with less pronounced metallic sheen, generally duller ……..*Lassioglossum matianense*

Dichotomous key for wasp and non-*Apis* bee species (Devi et al., 2024)

1. Body covered in fuzzy hairs and generally robust, with a more rounded appearance……2

1. Body smooth, not fuzzy, and with a more wasp-like appearance……..4
2. Body large and robust, with a very fuzzy appearance, and usually black with yellow or orange bands……..*Bombus albopleuralis*
3. Body with relatively smaller yellow or orange patches and shorter legs……..4
4. Body with a smooth, shiny appearance and a distinctive yellow and black striped pattern……*Vespula vulgaris*
4. Body with a more uniform colour and less distinct striping or banding……5

Morphological studies of insect pollinators

Specimen selection and preparation

Morphometric analysis was conducted to accurately characterize the diversity of insect pollinators in cherry orchards using standardized and precise measurement protocols. A total of six adult specimens per species were dissected and analyzed to ensure adequate representation and allow for statistical validation.

The dissection process began with the careful removal of the head capsule and mouthparts under a stereo zoom microscope (OLYMPUS SZX16) equipped with a high-resolution image acquisition system. Heads were delicately detached using fine-tipped forceps under a dissecting microscope to avoid structural damage.

Tissue clearing and mounting

To enhance the visibility of sclerotized morphological structures, the dissected parts were treated overnight in 10% potassium hydroxide (KOH), following the clearing protocol described by Barbosa and Kary (2014). After digestion, specimens were thoroughly rinsed with distilled water to remove residual KOH and then preserved in 70% ethanol. Temporary mounts were prepared in glycerine to facilitate clear, distortion-free visualization of morphological features (Marquina et al., 2021).

Morphometric imaging and measurement

High-resolution images were captured, and morphometric measurements were performed using Magvision v3.0 software, allowing precise digital analysis of fine structures. A total of 38 morphometric traits were recorded for each specimen, with measurements taken in millimetres to assess interspecific variability among *Apis* and non-*Apis* taxa.

Measurement of traits

The morphometric traits measured included the following:

General body dimensions

These consisted of body length, head length, and head width.

Thoracic features

These included thorax length and thorax width.

Facial metrics

These comprised clypeus length and width; inter-orbital distances (upper, lower, and across the antennal sockets); clypeo-antennal distance; and compound eye length and width.

Antennal features

These included scape length, pedicel length, third flagellomere diameter, total flagellum length, and the number of flagellomeres.

Ocellar region

Measurements included inter-ocellar distance, ocellocular and antennocellar distances, median ocellus diameter, and clypeocular distance.

Mouthparts

Traits included labrum length and width, as well as the maximum diameter of the antennal socket.

Wing dimensions

These comprised forewing and hindwing length and width, the Jugovanmal index, and the number of hamuli.

Leg parameters

These included hind tibia length, basitarsus length, and basitarsus width.

Statistical analysis

To evaluate interspecific morphological variation, statistical analyses were conducted. One-way Analysis of Variance (ANOVA) was performed using Microsoft Excel (Office 2021), while Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) were conducted using the Python programming environment (version 3.11).

Results

Abundance and diversity of hymenopteran pollinators in cherry orchards of the Kashmir valley

A total of 10 insect pollinator species belonging to the order *Hymenoptera* were identified from cherry orchards in the Kashmir Valley (Table 1). These species were distributed across four families: *Apidae* (3 species), *Halictidae* (3 species), *Andrenidae* (3 species), and *Vespidae* (1 species). The most frequently observed pollinators included *Apis mellifera* (Western honey bee), *A. cerana* (Asiatic honey bee), and *Bombus albopleuralis* (White-banded bumble bee), representing managed and wild bee populations. The remaining species comprised various solitary bees and a wasp, indicating a diverse array of pollinators in the region.

A total of 1,220 individual insect pollinators representing 10 species were collected from cherry orchards across eight sites within four districts of the Kashmir Valley (Table 2). *A. cerana* (197 individuals) and *A. mellifera* (196) were the most abundant species, reflecting their dominance and widespread distribution. Among solitary bees, *Lasioglossum matianense* (133) was the most prevalent, followed by *L. marginatum* (118), *Andrena fucata* (113), *A. agilissima* (110), and *L. rugifrons* (107). The least abundant species was *Vespula vulgaris* (67), followed by *Bombus albopleuralis* (81). On the whole, Apidae and Halictidae were the dominant pollinator families across the surveyed districts.

Table 1. Identified insect pollinators collected from cherry orchards in the Kashmir valley.

Order	Family	Scientific Name	Common Name
Hymenoptera	Apidae	*Apis mellifera*	Western honey bee
		Apis cerana	Asiatic honey bee
		Bombus albopleuralis	White-banded bumble bee
	Halictidae	*Lasioglossum rugifrons*	Sweat bee (Rugose-fronted)
		Lasioglossum matianense	Sweat bee (*Matianense*)
		Lasioglossum marginatum	Margined sweat bee
	Andrenidae	*Andrena fucata*	Toothed mining bee
		Andrena pilipes	Hairy-legged mining bee
		Andrena agilissima	Agile mining bee
	Vespidae	*Vespula vulgaris*	Common wasp

Table 2. Total number of insect pollinator individuals collected across different districts of the Kashmir valley.

Species	Srinagar		Ganderbal		Baramulla		Shopian		Total
	Shalima	Dhara	Lar	Baba	Tangma	Sopore	Kullar	Aerhal	
A. mellifera	29	24	21	29	22	24	21	26	196
A. cerana	30	21	20	31	22	21	30	22	197
L. rugifrons	10	9	18	20	10	12	17	11	107
L. marginatum	13	15	12	20	13	14	18	13	118
L. matianense	12	19	15	17	19	18	13	20	133
A. agilissima	15	12	11	16	14	12	13	17	110
A. pilipes	14	18	13	11	11	12	10	9	98
A. fucata	15	13	12	14	18	13	17	11	113
B. albopleuralis	12	11	9	10	6	8	13	12	81
V. vulgaris	9	12	7	10	8	6	8	7	67
Total species									1220

Morphometric measurements

The analyses revealed statistically significant differences ($p < 0.05$) in several morphometric traits among species, thereby validating their effectiveness in species-level identification and differentiation within hymenopteran pollinator communities.

Apis cerana

Distribution

The species is native to South and Southeast Asia, including India, China, and Japan.

Diagnostic characters

This species closely resembled *A. mellifera* but was smaller, with workers typically measuring 10-13 mm in length. It had a more slender body, darker coloration, and more pronounced black bands on the abdomen. The thorax was covered with shorter, finer hairs compared to *A. mellifera* (Figure 2). The wings were more translucent and slightly shorter. A key distinguishing feature was the narrower and more pointed abdomen. The hind legs also possessed corbiculae, although smaller than those of *A. mellifera*. Queens were larger with a more elongated body, while drones exhibited larger eyes for locating queens during mating flights.



Figure 2. Morphological measurements of *A. cerana* specimens: (a) Full body, (b) Abdomen, (c) Foreleg, (d) Midleg, (e) Hindleg, (f) Thorax, (g) Hindwing, (h) Forewing, (i) Antenna, and (j) Head.

Measurements

A. cerana exhibited a body length of 11.15 ± 0.05 mm, a head length of 2.67 ± 0.03 mm, and a head width of 3.31 ± 0.01 mm. The thorax length and width were 3.35 ± 0.02 mm and 2.92 ± 0.03 mm, respectively. The clypeus length measured 0.88 ± 0.01 mm, while the clypeus width was 1.03 ± 0.03 mm. The lower and upper inter-orbital distances were 1.83 ± 0.03 mm and 1.46 ± 0.03 mm, respectively. The inter-orbital distance across the antennal sockets was 2.01 ± 0.03 mm, and the clypeo-antennal distance was 0.03 ± 0.01 mm. The compound eye length measured 2.04 ± 0.03 mm.

The scape, pedicel, and flagellum lengths were 1.05 ± 0.02 mm, 0.21 ± 0.01 mm, and 2.66 ± 0.08 mm, respectively. The diameter of the third flagellomere was 0.18 ± 0.01 mm. The distance between the antennal sockets was 0.22 ± 0.02 mm, while the inter-ocellar distance measured 0.31 ± 0.02 mm. The ocellocular distance and antennocellar distance were 0.31 ± 0.20 mm and 1.79 ± 0.25 mm, respectively. The clypeocular distance was 0.27 ± 0.25 mm.

The median ocellus diameter was 0.20 ± 0.30 mm. The labrum length and width were 0.19 ± 0.30 mm and 0.84 ± 0.30 mm, respectively. The maximum diameter of the antennal socket was 0.25 ± 0.05 mm, and the compound eye width was 0.49 ± 0.07 mm. The forewing length and width were 7.92 ± 0.40 mm and 2.64 ± 0.15 mm, respectively. The Jugovanmal index was recorded as 59.38 ± 1.80 mm, and the species possessed 17.9 ± 1.30 hamuli. The hindwing measured 5.50 ± 0.40 mm in length and 3.31 ± 0.15 mm in width. The hind basitarsus length and width were 1.76 ± 0.10 mm and 0.89 ± 0.10 mm, respectively. The species had 10 flagellomeres, with an abdomen length of 5.25 ± 0.30 mm, an abdomen width of 3.64 ± 0.02 mm, and a hind tibia length of 2.84 ± 0.01 mm (Table 3-9).

Table 3. Morphometric measurements (mean ± SE in mm) of body length, head length and width, thorax width, and clypeus length in *Apis* and non-*Apis* bee species collected from cherry orchards in the Kashmir Valley.

Species	Body length	Head length	Head width	Thorax	Thorax width	Clypeus length
A. fucata	12.59± 0.08	2.47± 0.03	3.35± 0.02	3.41± 0.02	2.58± 0.03	1.21± 0.02
A. pilipes	9.73± 0.05	2.68± 0.02	3.20± 0.03	3.46± 0.02	3.23± 0.03	1.13± 0.03
A. agilissima	13.29± 0.06	2.95± 0.02	3.21± 0.03	3.53± 0.03	3.29± 0.02	1.38± 0.02
L. rugifrons	10.23± 0.03	2.75± 0.04	2.43± 0.02	3.61± 0.02	2.34± 0.02	1.14± 0.02
L. matianense	9.08± 0.03	2.55± 0.02	2.35± 0.03	3.32± 0.02	2.14± 0.03	1.18± 0.02
L. marginatum	9.36± 0.04	2.63± 0.03	2.40± 0.03	3.40± 0.02	2.23± 0.03	1.15± 0.02
V. vulgaris	16.02± 0.05	3.09± 0.03	3.46± 0.03	4.43± 0.03	3.46± 0.03	1.45± 0.03
B. albopleuralis	24.41± 0.08	4.12± 0.03	6.21± 0.02	7.32± 0.03	8.12± 0.03	1.43± 0.02
A. mellifera	11.61± 0.04	2.92± 0.03	3.72± 0.03	4.55± 0.02	3.18± 0.02	1.09± 0.02
A. cerana	11.15± 0.05	2.67± 0.03	3.31± 0.01	3.35± 0.02	2.92± 0.03	0.88± 0.01
C.D(p≤0.05)	0.256	0.096	0.064	0.064	0.096	0.064

Table 4. Morphometric measurements (mean ± SE in mm) of clypeus width; lower and upper inter-orbital distances; inter-orbital distance through antennal sockets; clypeo-antennal distance; and compound eye length in *Apis* and non-*Apis* bee species collected from cherry orchards in the Kashmir Valley.

Species	Clypeus width	Lower inter-orbital distance	Upper inter-orbital distance	Inter-orbital distance through antennal sockets	Clypeo-antennal distance	Compound eye length
A. fucata	2.20± 0.04	2.40± 0.04	2.13± 0.04	2.34± 0.04	0.06± 0.01	2.41± 0.04
A. pilipes	1.80± 0.03	1.82± 0.03	2.06± 0.03	0.41± 0.03	0.02± 0.01	1.64± 0.03
A. agilissima	2.37± 0.05	2.62± 0.05	2.72± 0.05	2.86± 0.05	0.05± 0.01	2.32± 0.05
L. rugifrons	1.65± 0.03	1.70± 0.03	1.62± 0.03	0.31± 0.03	0.06± 0.01	1.44± 0.03
L. matianense	1.32± 0.02	1.48± 0.02	1.78± 0.02	0.34± 0.02	0.08± 0.01	1.67± 0.02
L. marginatum	1.46± 0.03	1.54± 0.03	1.81± 0.03	0.33± 0.03	0.01± 0.01	1.55± 0.03
V.vulgaris	2.21± 0.05	2.34± 0.05	2.46± 0.05	2.45± 0.05	0.55± 0.02	4.18± 0.05
B. albopleuralis	2.22± 0.05	2.45± 0.05	2.34± 0.05	2.47± 0.05	0.54± 0.02	4.20± 0.05
A. mellifera	1.34± 0.03	2.18± 0.03	1.95± 0.03	2.44± 0.03	0.03± 0.01	2.34± 0.03
A. cerana	1.03± 0.03	1.83± 0.03	1.46± 0.03	2.01± 0.03	0.03± 0.01	2.04± 0.03
C.D(p≤0.05)	0.043	0.027	0.042	0.032	0.040	0.036

Table 5. Morphometric measurements (mean ± SE in mm) of scape length, pedicel length, flagellum length, third flagellomere diameter, distance between antennal sockets, and inter-ocellar distance in *Apis* and non-*Apis* bee species collected from cherry orchards in the Kashmir Valley.

Species	Scape length	Pedicel length	Flagellum length	3rd Flagellomere diameter	Distance between antennal sockets	Inter-ocellar distance
A. fucata	1.05± 0.02	0.20± 0.01	3.74± 0.10	0.24± 0.01	0.51± 0.03	0.40± 0.02
A. pilipes	1.02± 0.03	0.12± 0.01	2.12± 0.08	0.16± 0.01	0.20± 0.02	0.21± 0.01
A. agilissima	1.06± 0.02	0.19± 0.01	3.73± 0.09	0.22± 0.01	0.49± 0.03	0.38± 0.02
L. rugifrons	1.04± 0.02	0.13± 0.01	2.10± 0.08	0.14± 0.01	0.19± 0.02	0.20± 0.01
L. matianense	1.03± 0.02	0.14± 0.01	2.36± 0.10	0.12± 0.01	0.13± 0.01	0.24± 0.02
L. marginatum	1.04± 0.02	0.11± 0.01	2.46± 0.09	0.15± 0.01	0.20± 0.02	0.19± 0.01
V.vulgaris	1.05± 0.02	0.19± 0.01	4.12± 0.10	0.25± 0.01	0.56± 0.03	0.52± 0.02
B. albopleuralis	2.10± 0.04	0.18± 0.01	4.78± 0.12	0.34± 0.02	0.65± 0.04	0.68± 0.03
A. mellifera	1.26± 0.03	0.24± 0.01	2.70± 0.08	0.20± 0.01	0.24± 0.02	0.40± 0.02
A. cerana	1.05± 0.02	0.21± 0.01	2.66± 0.08	0.18± 0.01	0.22± 0.02	0.31± 0.02
C.D(p≤0.05)	0.064	0.032	0.320	0.032	0.096	0.064

Table 6. Morphometric measurements (mean ± SE in mm) of ocellocular distance, antennocellar distance, clypeocular distance, median ocellus diameter, labrum length, and labrum width in *Apis* and non-*Apis* bee species collected from cherry orchards in the Kashmir Valley.

Species	Ocellocular distance	Antennocellar distance	Clypeocular distance	Median ocellus diameter	Labrum length	Labrum width
A. fucata	0.89± 0.15	0.79± 0.15	0.15± 0.15	0.27± 0.15	0.16± 0.15	0.34± 0.15
A. pilipes	0.41± 0.22	0.67± 0.22	0.10± 0.20	0.19± 0.30	0.12± 0.30	0.20± 0.30
A. agilissima	0.87± 0.28	0.77± 0.32	0.12± 0.30	0.25± 0.30	0.14± 0.30	0.30± 0.30
L. rugifrons	0.31± 0.15	0.47± 0.12	0.19± 0.18	0.13± 0.12	0.10± 0.20	0.21± 0.25
L. matianense	0.47± 0.14	0.58± 0.15	0.14± 0.20	0.18± 0.20	0.16± 0.20	0.19± 0.22
L. marginatum	0.37± 0.20	0.53± 0.16	0.12± 0.20	0.15± 0.20	0.13± 0.20	0.17± 0.20
V.vulgaris	0.23± 0.10	0.32± 0.10	0.13± 0.20	0.43± 0.30	0.30± 0.30	1.45± 0.30
B. albopleuralis	0.30± 0.20	0.47± 0.20	0.12± 0.20	0.45± 0.25	0.31± 0.30	1.56± 0.30
A. mellifera	0.47± 0.25	1.58± 0.25	0.23± 0.30	0.25± 0.30	0.24± 0.30	0.93± 0.30
A. cerana	0.31± 0.20	1.79± 0.25	0.27± 0.25	0.20± 0.30	0.19± 0.30	0.84± 0.30
C.D(p≤0.05)	0.48	0.48	0.64	0.80	0.96	0.96

Table 7. Morphometric measurements (mean ± SE in mm) of antennal socket maximum diameter, compound eye width, forewing length and width, Jugovanmal index, and number of hamuli in Apis and non-Apis bee species collected from cherry orchards in the Kashmir Valley.

Species	Antennal socket max. diameter	Compound eye width	Fore wing length	Fore wing width	Jugovanmal index	Hemuli number
A. fucata	0.37± 0.05	0.80± 0.08	12.85± 0.75	3.83± 0.30	78.64± 2.00	17.00± 1.50
A. pilipes	0.20± 0.04	0.50± 0.07	11.32± 0.60	2.79± 0.25	83.77± 0.50	13.00± 1.00
A. agilissima	0.36± 0.06	0.75± 0.09	12.74± 0.70	3.72± 0.28	65.60± 2.10	17.00± 1.50
L. rugifrons	0.23± 0.05	0.56± 0.08	11.21± 0.65	2.65± 0.22	78.20± 1.80	16.00± 1.20
L. matianense	0.22± 0.04	0.65± 0.09	10.89± 0.60	2.50± 0.20	65.66± 2.00	16.00± 1.20
L. marginatum	0.19± 0.03	0.40± 0.06	11.54± 0.55	2.90± 0.25	75.37± 1.90	16.00± 1.00
V.vulgaris	0.34± 0.06	1.20± 0.15	14.23± 0.80	3.64± 0.35	79.33± 2.20	19.00± 1.80
B. albopleuralis	0.38± 0.08	1.96± 0.25	20.21± 1.00	6.34± 0.50	82.52± 3.00	35.5± 2.50
A. mellifera	0.10± 0.02	0.78± 0.10	8.91± 0.45	3.08± 0.20	62.04± 1.50	20.20± 1.50
A. cerana	0.25± 0.05	0.49± 0.07	7.92± 0.40	2.64± 0.15	59.38± 1.80	17.9± 1.30
C.D(p≤0.05)	0.16	0.32	2.39	0.96	6.39	4.79

Table 8. Morphometric measurements (mean ± SE in mm) of hindwing length and width, hind basitarsus length and width, number of flagellomeres, and abdomen length in *Apis* and non-*Apis* bee species collected from cherry orchards in the Kashmir Valley.

Species	Hindwing length	Hind wing width	Hind basitarsus length	Hind basitarsus width	Number of flagellomeres	Abdomen length
A. fucata	9.43 ± 0.50	2.89 ± 0.10	2.30 ± 0.15	0.40 ± 0.05	10 ± 0	6.71 ± 0.30
A. pilipes	7.56 ± 0.60	2.57 ± 0.15	1.78 ± 0.10	0.28 ± 0.05	10 ± 0	3.59 ± 0.25
A. agilissima	9.36 ± 0.55	2.70 ± 0.12	2.26 ± 0.15	0.38 ± 0.05	10 ± 0	6.81 ± 0.30
L. rugifrons	7.45 ± 0.50	2.45 ± 0.10	1.77 ± 0.12	0.23 ± 0.05	10 ± 0	3.87 ± 0.20
L. matianense	7.68 ± 0.55	2.33 ± 0.12	1.66 ± 0.15	0.34 ± 0.05	10 ± 0	3.21 ± 0.20
L. marginatum	7.58 ± 0.50	2.23 ± 0.10	1.59 ± 0.20	0.67 ± 0.10	10 ± 0	3.33 ± 0.25
V. vulgaris	6.56 ± 0.50	1.23 ± 0.10	2.67 ± 0.15	0.39 ± 0.05	10 ± 0	8.94 ± 0.30
B. albopleuralis	11.34 ± 0.70	4.23 ± 0.20	4.56 ± 0.12	0.76 ± 0.10	10 ± 0	12.97 ± 0.50
A. mellifera	6.44 ± 0.40	1.64 ± 0.10	2.06 ± 0.10	0.10 ± 0.05	10 ± 0	5.56 ± 0.30
A. cerana	5.50± 0.40	3.31 ± 0.15	1.76 ± 0.10	0.89 ± 0.10	10 ± 0	5.25 ± 0.30
C.D(p≤0.05)	0.90	0.22	0.23	0.11	0.00	0.51

Table 9. Morphometric measurements (mean ± SE in mm) of abdomen width and hind tibia length in *Apis* and non-*Apis* bee species collected from cherry orchards in the Kashmir Valley.

Species	Abdomen width	Hind tibia length
A. fucata	3.30 ± 0.03	2.63 ± 0.02
A. pilipes	2.81 ± 0.02	1.21 ± 0.01
A. agilissima	4.29 ± 0.03	3.72 ± 0.02
L. rugifrons	2.64 ± 0.01	1.23 ± 0.01
L. matianense	2.53 ± 0.01	1.20 ± 0.01
L. marginatum	2.32 ± 0.01	1.26 ± 0.01
V.vulgaris	5.59 ± 0.02	3.23 ± 0.02
B. albopleuralis	9.23 ± 0.02	4.52 ± 0.03
A. mellifera	4.26 ± 0.02	3.15 ± 0.01
A. cerana	3.64 ± 0.02	2.84 ± 0.01
C.D (p≤0.05)	0.082	0.056

A. mellifera

Distribution

A. mellifera is native to Europe, Africa, and the Middle East, and had been introduced worldwide.

Diagnostic characters

A. mellifera was a medium-sized honey bee, measuring approximately 12-15 mm in length. It possessed a golden-brown body with alternating dark and light brown bands on the abdomen. The thorax was densely covered with short, golden hairs (Figure 3). The wings were translucent with well-defined venation and exhibited a slight brownish tint. The head was relatively small, bearing large compound eyes and short, curved antennae. The hind legs featured well-developed corbiculae for pollen collection. A distinctive characteristic was the presence of a hairy depression (pollen press) on the hind tibia. Queens were larger and had a more elongated abdomen compared to workers and drones.



Figure 3. Morphological measurements of *A. mellifera*: (a) Full body, (b) Abdomen, (c) Forewing, (d) Midleg, (e) Hindwing, (f) Hindleg, (g) Thorax, (h) Head, (i) Antenna, and (j) Foreleg.

Measurements

A. mellifera exhibited a body length of 11.61 ± 0.04 mm, a head length of 2.92 ± 0.03 mm, and a head width of 3.72 ± 0.03 mm. The thorax measured 4.55 ± 0.02 mm in length and 3.18 ± 0.02 mm in width. The clypeus length and width were 1.09 ± 0.02 mm and 1.34 ± 0.03 mm, respectively. The lower and upper inter-orbital distances were 2.18 ± 0.03 mm and 1.95 ± 0.03 mm, respectively. The inter-orbital distance across the antennal sockets was 2.44 ± 0.03 mm, while the clypeo-antennal distance was 0.03 ± 0.01 mm. The compound eye length measured 2.34 ± 0.03 mm.

The scape, pedicel, and flagellum lengths were 1.26 ± 0.03 mm, 0.24 ± 0.01 mm, and 2.70 ± 0.08 mm, respectively. The third flagellomere diameter was 0.20 ± 0.01 mm. The distance between the antennal sockets was 0.24 ± 0.02 mm, while the inter-ocellar distance was 0.40 ± 0.02 mm. The ocellocular distance and antennocellar distance were 0.47 ± 0.25 mm and 1.58 ± 0.25 mm, respectively. The clypeocular distance measured 0.23 ± 0.30 mm.

The median ocellus diameter was 0.25 ± 0.30 mm. The labrum length and width were 0.24 ± 0.30 mm and 0.93 ± 0.30 mm, respectively. The maximum diameter of the antennal socket was 0.10 ± 0.02 mm, and the compound eye width was 0.78 ± 0.10 mm. The forewing measured 8.91 ± 0.45 mm in length and 3.08 ± 0.20 mm in width. The Jugovanmal index was 62.04 ± 1.50 mm, and the species possessed 20.20 ± 1.50 hamuli. The hindwing length and width were 6.44 ± 0.40 mm and 1.64 ± 0.10 mm, respectively.

The hind basitarsus measured 2.06 ± 0.10 mm in length and 0.10 ± 0.05 mm in width. This species had 10 flagellomeres. The abdomen length and width were 5.56 ± 0.30 mm and 4.26 ± 0.02 mm, respectively, while the hind tibia length was 3.15 ± 0.01 mm (Table 3-9).

Andrena agilissima

Distribution

This species is native to Southern and Central Europe, extending into the Middle East.

Diagnostic characters

This species was relatively large, with females reaching approximately 12-15 mm in body length. The thorax was covered with dense, shiny black hairs, while the abdomen exhibited a striking metallic blue or bluish-green sheen, which distinguished it from other *Andrena* species (Figure 4). The legs were predominantly black with dark brown hairs. The face was broad, featuring a strongly developed clypeus that was slightly punctured. The wings appeared slightly smoky, with well-defined venation. The propodeum displayed a rough, sculptured surface. Males possessed a slender body, with a less pronounced metallic sheen and longer antennae.



Figure 4. Measurements of various morphological characters of *A. agilissima*: (a) Full body, (b) Abdomen, (c) Midleg, (d) Antenna, (e) Foreleg, (f) Hindleg, (g) Hindwing, (h) Forewing, (i) Head, and (j) Thorax.

Measurements

A. agilissima exhibited a body length of 13.29 ± 0.06 mm, with a head length of 2.95 ± 0.02 mm and a head width of 3.21 ± 0.03 mm. The thorax length was 3.53 ± 0.03 mm, and the thorax width was 3.29 ± 0.02 mm. The clypeus length measured 1.38 ± 0.02 mm, while the clypeus width was 2.37 ± 0.05 mm. The lower inter-orbital distance was 2.62 ± 0.05 mm, and the upper inter-orbital distance was 2.72 ± 0.05 mm. The inter-orbital distance through the antennal sockets measured 2.86 ± 0.05 mm, and the clypeo-antennal distance was 0.05 ± 0.01 mm. The compound eye length was 2.32 ± 0.05 mm. The scape length measured 1.06 ± 0.02 mm, the pedicel length was 0.19 ± 0.01 mm, and the flagellum length was 3.73 ± 0.09 mm. The diameter of the 3rd flagellomere was 0.22 ± 0.01 mm, the distance between the antennal sockets was 0.49 ± 0.03 mm, and the inter-ocellar distance was 0.38 ± 0.02 mm. The ocellocular distance measured 0.87 ± 0.28 mm, the antennocellar distance was 0.77 ± 0.32 mm, and the clypeocular distance was 0.12 ± 0.30 mm. The median ocellus diameter was 0.25 ± 0.30 mm. The labrum length and width were 0.14 ± 0.30 mm and 0.30 ± 0.30 mm, respectively. The maximum diameter of the antennal socket was 0.36 ± 0.06 mm, and the compound eye width was 0.75 ± 0.09 mm. The forewing length was 12.74 ± 0.70 mm, and the forewing width was 3.72 ± 0.28 mm. The Jugovanmal index was recorded at 65.60 ± 2.10 mm, and the species possessed 17.00 ± 1.50 Hemuli. The hindwing length was 9.36 ± 0.55 mm, and the hindwing width was 2.70 ± 0.12 mm. The hind basitarsus length was 2.26 ± 0.15 mm, and its width was 0.38 ± 0.05 mm. This species possessed 10 flagellomeres, an abdomen length of 6.81 ± 0.30 mm, an abdomen width of 4.29 ± 0.03 mm, and a hind tibia length of 3.72 ± 0.02 mm (Table 3-9).

A. fucata

Distribution

A. fucata is found in Europe and parts of Asia, including temperate regions.

Diagnostic characters

A. fucata was a medium-sized mining bee belonging to the family Andrenidae. It exhibited sexual dimorphism, with females typically larger than males. The body length ranged from 10-13 mm (Figure 5). It had a predominantly black thorax and abdomen covered with fine, short hairs. A key distinguishing feature was the reddish-brown coloration of the hind tibiae and tarsi in females. The face showed dense yellowish-white pubescence, particularly around the clypeus. The wings were translucent with a slightly smoky tint and well-defined venation. The scopa (pollen-collecting hairs) on the hind legs was well-developed and yellowish. Males were more slender and had longer antennae compared to females.



Figure 5. Measurement of various morphological characters of *A. fucata*: (a) Full body, (b) Abdomen, (c) Foreleg, (d) Midleg, (e) Hindleg, (f) Head, (g) Forewing, (h) Hindwing, (i) Thorax, (j) Antenna.

Measurements

A. fucata had a body length of 12.59 ± 0.08 mm, a head length of 2.47 ± 0.03 mm, and a head width of 3.35 ± 0.02 mm. The thorax length measured 3.41 ± 0.02 mm, while the thorax width was 2.58 ± 0.03 mm. The clypeus length was 1.21 ± 0.02 mm, the clypeus width was 2.20 ± 0.04 mm, the lower inter-orbital distance was 2.40 ± 0.04 mm, and the upper inter-orbital distance was 2.13 ± 0.04 mm. The inter-orbital distance through the antennal sockets measured 2.34 ± 0.04 mm, while the clypeo-antennal distance was 0.06 ± 0.01 mm. The compound eye length was 2.41 ± 0.04 mm. The scape length measured 1.05 ± 0.02 mm, the pedicel length was 0.20 ± 0.01 mm, and the flagellum length was 3.74 ± 0.10 mm. The 3rd flagellomere diameter was 0.24 ± 0.01 mm, the distance between antennal sockets was 0.51 ± 0.03 mm, and the inter-ocellar distance was 0.40 ± 0.02 mm. The ocellocular distance measured 0.89 ± 0.15 mm, the antennocellar distance was 0.79 ± 0.15 mm, and the clypeocular distance was 0.15 ± 0.15 mm. The median ocellus diameter was 0.27 ± 0.15 mm. The labrum length and width were 0.16 ± 0.15 mm and 0.34 ± 0.15 mm, respectively. The maximum diameter of the antennal socket was 0.37 ± 0.05 mm, and the compound eye width was 0.80 ± 0.08 mm. The forewing length measured 12.85 ± 0.75 mm, while the forewing width was 3.83 ± 0.30 mm. The Jugovanmal index for this species was recorded as 78.64 ± 2.00 mm, and it possessed 17.00 ± 1.50 Hemuli. The hindwing length and width were 9.43 ± 0.50 mm and 2.89 ± 0.10 mm, respectively. The hind basitarsus measured 2.30 ± 0.15 mm in length and 0.40 ± 0.05 mm in width. This species possessed 10 flagellomeres, with an abdomen length of 6.71 ± 0.30 mm, an abdomen width of 3.30 ± 0.03 mm, and a hind tibia length of 2.63 ± 0.02 mm (Table 3-9).

A. pilipes

Distribution

This species is mostly found in Europe, North Africa, and parts of Asia.

Diagnostic characters

This species was one of the larger *Andrena* bees, with females reaching up to 16 mm in length. It was characterized by a robust black body covered with dense, dark brown or black hairs on the thorax and abdomen. The hind tibiae and tarsi were entirely black, in contrast to the reddish coloration observed in *A. fucata*. The face bore short, dense hairs, and the clypeus was slightly more prominent (Figure 6). The wings appeared clear with a brownish tinge, and the veins were distinct. A key diagnostic feature was the presence of strong ridges on the propodeum. Males were smaller, with longer, thinner antennae and a more slender body structure.

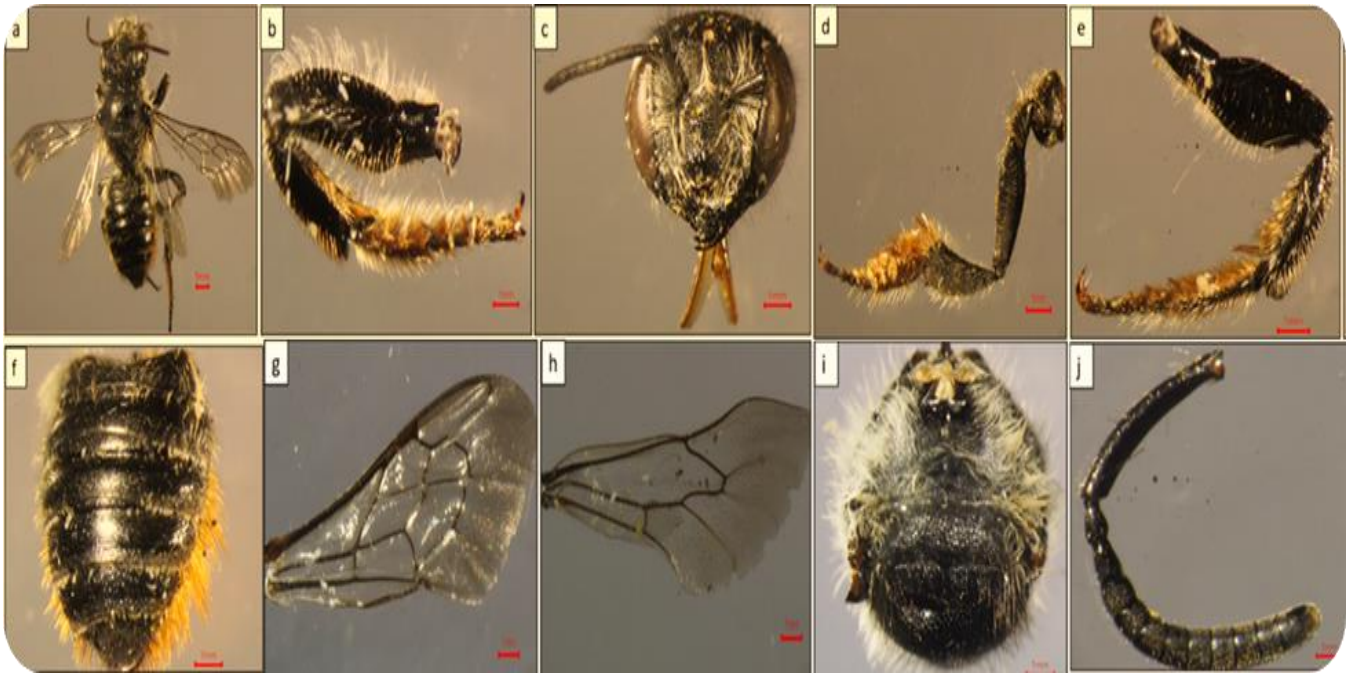


Figure 6. Measurements of different morphological characters of *A. pilipes*: (a) Full body, (b) Foreleg, (c) Head, (d) Midleg, (e) Hindleg, (f) Abdomen, (g) Forewing, (h) Hindwing, (i) Thorax, (j) Antenna.

Measurements

A. pilipes had a body length of 9.73 ± 0.05 mm, a head length of 2.68 ± 0.02 mm, and a head width of 3.20 ± 0.03 mm. The thorax length measured 3.46 ± 0.02 mm, while the thorax width was 3.23 ± 0.03 mm. The clypeus length was 1.13 ± 0.03 mm, and the clypeus width was 1.80 ± 0.03 mm. The lower inter-orbital distance measured 1.82 ± 0.03 mm, and the upper inter-orbital distance was 2.06 ± 0.03 mm. The inter-orbital distance through the antennal sockets was 0.41 ± 0.03 mm, and the clypeo-antennal distance was 0.02 ± 0.01 mm. The compound eye length was 1.64 ± 0.03 mm. The scape length measured 1.02 ± 0.03 mm, the pedicel length was 0.12 ± 0.01 mm, and the flagellum length was 2.12 ± 0.08 mm. The diameter of the third flagellomere was 0.16 ± 0.01 mm, and the distance between the antennal sockets was 0.20 ± 0.02 mm. The inter-ocellar distance measured 0.21 ± 0.01 mm, the ocellocular distance was 0.41 ± 0.22 mm, the antennocellar distance was 0.67 ± 0.22 mm, and the clypeocular distance was 0.10 ± 0.20 mm. The median ocellus diameter measured 0.19 ± 0.30 mm, while the labrum length and width were 0.12 ± 0.30 mm and 0.20 ± 0.30 mm, respectively. The maximum diameter of the antennal socket was 0.20 ± 0.04 mm, and the compound eye width was 0.50 ± 0.07 mm. The forewing length was 11.32 ± 0.60 mm, with a forewing width of 2.79 ± 0.25 mm. The Jugovanmal index measured 83.77 ± 0.50 mm, and the species had 13.00 ± 1.00 hemuli. The hindwing length was 7.56 ± 0.60 mm, and the hindwing width was 2.57 ± 0.15 mm. The hind basitarsus length measured 1.78 ± 0.10 mm, with a width of 0.28 ± 0.05 mm. This species possessed 10 flagellomeres, and the abdomen length and width were 3.59 ± 0.25 mm and 2.81 ± 0.02 mm, respectively. The hind tibia length measured 1.21 ± 0.01 mm (Table 3-9).

Lassioglossum marginatum

Distribution

L. marginatum is primarily distributed in South and Southeast Asia.

Diagnostic characters

This species was a small sweat bee, generally measuring between 5-7 mm in length. It possessed a predominantly dark brown to black body with a subtle metallic sheen on the thorax. The head was slightly broader than in *L. rugifrons*, with fine punctures on the clypeus and frons. The wings were transparent with light brown venation (Figure 7). The propodeum exhibited fine striations but lacked the strongly rugose sculpturing observed in *L. rugifrons*. The abdomen appeared smooth, with faint transverse bands of hair. The legs were dark and bore short scopal hairs on the hind tibiae. Males were more slender, with longer antennae and reduced pubescence.



Figure 7. Measurement of various morphological characteristics of *L. marginatum*: (a) Full body, (b) Abdomen, (c) Hindwing, (d) Forewing, (e) Midleg, (f) Foreleg, (g) Head, (h) Thorax, (i) Hindleg, and (j) Antenna.

Measurements

L. marginatum had a body length of 9.36 ± 0.04 mm, a head length of 2.63 ± 0.03 mm, and a head width of 2.40 ± 0.03 mm. The thorax length measured 3.40 ± 0.02 mm, and the thorax width was 2.23 ± 0.03 mm. The clypeus length was 1.15 ± 0.02 mm, and the clypeus width was 1.46 ± 0.03 mm. The lower inter-orbital distance measured 1.54 ± 0.03 mm, while the upper inter-orbital distance was 1.81 ± 0.03 mm. The inter-orbital distance through the antennal sockets measured 0.33 ± 0.03 mm, and the clypeo-antennal distance was 0.01 ± 0.01 mm. The compound eye length was 1.55 ± 0.03 mm. The scape length measured 1.04 ± 0.02 mm, the pedicel length was 0.11 ± 0.01 mm, and the flagellum length was 2.46 ± 0.09 mm. The 3rd flagellomere diameter was 0.15 ± 0.01 mm, the distance between antennal sockets was 0.20 ± 0.02 mm, and the inter-ocellar distance was 0.19 ± 0.01 mm. The ocellocular distance was 0.37 ± 0.20 mm, the antennocellar distance was 0.53 ± 0.16 mm, and the clypeocular distance was 0.12 ± 0.20 mm. The median ocellus diameter measured 0.15 ± 0.20 mm. The labrum length and width were 0.13 ± 0.20 mm and 0.17 ± 0.20 mm, respectively. The maximum diameter of the antennal socket was 0.19 ± 0.03 mm, and the compound eye width was 0.40 ± 0.06 mm. The forewing length was 11.54 ± 0.55 mm, and the forewing width was 2.90 ± 0.25 mm. The Jugovanmal index measured 75.37 ± 1.90 mm, and the species possessed 16.00 ± 1.00 hemuli. The hindwing length was 7.58 ± 0.50 mm, with a hindwing width of 2.23 ± 0.10 mm. The hind basitarsus length was 1.59 ± 0.20 mm, and its width was 0.67 ± 0.10 mm. The species had 10 flagellomeres. The abdomen length measured 3.33 ± 0.25 mm, with an abdomen width of 2.32 ± 0.01 mm. The hind tibia length was 1.26 ± 0.01 mm (Table 3-9).

L. matianense

Distribution

This species is widely distributed across Eurasia, including Europe and parts of Asia.

Diagnostic characters

This species was slightly larger than *L. matianense*, with a body length ranging from approximately 7-9 mm. The thorax exhibited a dull metallic green to bluish-green reflection, while the abdomen was primarily black with a faint metallic sheen (Figure 8). The face was relatively broad with a well-defined clypeus. The wings were translucent with brownish veins, and the hind legs bore well-developed scopal hairs adapted for pollen collection. A key distinguishing feature was the well-defined, slightly raised margin along the sides of the propodeum. Males were smaller, possessing longer antennae and a less metallic appearance.



Figure 8: Measurement of various morphological characteristics of *L. matianense*: (a) Full body, (b) Forewing, (c) Hindwing, (d) Abdomen, (e) Foreleg, (f) Head, (g) Thorax, (h) Midleg, (i) Antenna, (j) Hindleg.

Measurements

L. matianense exhibited a mean body length of 9.08 ± 0.03 mm, a head length of 2.55 ± 0.02 mm, and a head width of 2.35 ± 0.03 mm. The thorax length and width measured 3.32 ± 0.02 mm and 2.14 ± 0.03 mm, respectively. The clypeus length was 1.18 ± 0.02 mm, and the clypeus width was 1.32 ± 0.02 mm. The lower inter-orbital distance was 1.48 ± 0.02 mm, while the upper inter-orbital distance was 1.78 ± 0.02 mm. The inter-orbital distance through the antennal sockets was 0.34 ± 0.02 mm, and the clypeo-antennal distance was 0.08 ± 0.01 mm. The compound eye length measured 1.67 ± 0.02 mm. The scape length was 1.03 ± 0.02 mm, pedicel length was 0.14 ± 0.01 mm, and flagellum length was 2.36 ± 0.10 mm. The 3rd flagellomere diameter was 0.12 ± 0.01 mm, the distance between antennal sockets was 0.13 ± 0.01 mm, and the inter-ocellar distance was 0.24 ± 0.02 mm. The ocellocular distance measured 0.47 ± 0.14 mm, the antennocellar distance 0.58 ± 0.15 mm, and the clypeocular distance 0.14 ± 0.20 mm. The median ocellus diameter was 0.18 ± 0.20 mm. The labrum length and width were 0.16 ± 0.20 mm and 0.19 ± 0.22 mm, respectively. The maximum diameter of the antennal socket was 0.22 ± 0.04 mm, while the compound eye width was 0.65 ± 0.09 mm. The forewing length was 10.89 ± 0.60 mm and its width was 2.50 ± 0.20 mm. The Jugovanmal index was 65.66 ± 2.00 mm, and the species had 16.00 ± 1.20 Hemuli. The hindwing length was 7.68 ± 0.55 mm and its width was 2.33 ± 0.12 mm. The hind basitarsus measured 1.66 ± 0.15 mm in length and 0.34 ± 0.05 mm in width. This species possessed 10 flagellomeres and an abdomen length of 3.21 ± 0.20 mm. The abdomen width was 2.53 ± 0.01 mm, and the hind tibia length measured 1.20 ± 0.01 mm (Table 3-9).

L. rugifrons

Distribution

L. rugifrons is distributed in the temperate regions of Europe and parts of North America.

Diagnostic characters

This species was a small to medium-sized sweat bee, generally measuring around 6-8 mm in length. It exhibited a metallic greenish-bronze coloration on the thorax and head, while the abdomen was typically dark brown to black with faint metallic reflections. The face appeared relatively narrow, with a slightly elongated clypeus (Figure 9). A distinguishing characteristic was the rugose (wrinkled) texture of the frons, which gave the species its name. The wings were translucent with light brown veins. The legs were dark brown, with the hind tibiae bearing sparse scopal hairs for pollen collection. Males were more slender, exhibiting a reduced metallic sheen and longer antennae compared to females.



Figure 9. Measurements of various morphological characteristics of *L. rugifrons*: (a) Full body, (b) Abdomen, (c) Forewing, (d) Hindwing, (e) Foreleg, (f) Midleg, (g) Hindleg, (h) Head, (i) Antenna, (j) Thorax.

Measurements

L. rugifrons had a body length of 10.23 ± 0.03 mm, with a head length of 2.75 ± 0.04 mm and a head width of 2.43 ± 0.02 mm. The thorax length was 3.61 ± 0.02 mm, and the thorax width was 2.34 ± 0.02 mm. The clypeus length measured 1.14 ± 0.02 mm, and the clypeus width was 1.65 ± 0.03 mm. The lower inter-orbital distance was 1.70 ± 0.03 mm, and the upper inter-orbital distance was 1.62 ± 0.03 mm. The inter-orbital distance through the antennal sockets measured 0.31 ± 0.03 mm, while the clypeo-antennal distance was 0.06 ± 0.01 mm. The compound eye length was 1.44 ± 0.03 mm. The scape length was 1.04 ± 0.02 mm, pedicel length 0.13 ± 0.01 mm, and flagellum length 2.10 ± 0.08 mm. The diameter of the third flagellomere was 0.14 ± 0.01 mm, the distance between antennal sockets was 0.19 ± 0.02 mm, and the inter-ocellar distance was 0.20 ± 0.01 mm. The ocellocular distance was 0.31 ± 0.15 mm, the antennocellar distance 0.47 ± 0.12 mm, and the clypeocular distance 0.19 ± 0.18 mm. The median ocellus diameter measured 0.13 ± 0.12 mm. The labrum length and width were 0.10 ± 0.20 mm and 0.21 ± 0.25 mm, respectively. The maximum diameter of the antennal socket was 0.23 ± 0.05 mm, and the compound eye width was 0.56 ± 0.08 mm.

The forewing length measured 11.21 ± 0.65 mm, and the forewing width was 2.65 ± 0.22 mm. The Jugovanmal index was recorded as 78.20 ± 1.80 mm, and this species possessed 16.00 ± 1.20 hemuli. The hindwing length was 7.45 ± 0.50 mm, and the hindwing width measured 2.45 ± 0.10 mm. The hind basitarsus had a length of 1.77 ± 0.12 mm and a width of 0.23 ± 0.05 mm. This species possessed 10 flagellomeres. The abdomen length was 3.87 ± 0.20 mm, the abdomen width 2.64 ± 0.01 mm, and the hind tibia length was 1.23 ± 0.01 mm (Table 3-9).

Vespula vulgaris

Distribution

V. vulgaris is native to Europe but has also been introduced in North America, Australia, and New Zealand.

Diagnostic characters

This species was a medium to large social wasp, measuring 12-17 mm in length. It exhibited a characteristic black and yellow banded body, with bright yellow markings on the face (Figure 10). The thorax was predominantly black with yellow lateral markings. The wings were slightly smoky and folded longitudinally when at rest. A key distinguishing feature was the anchor-shaped black mark on the clypeus. The legs were yellow with black femora. The abdomen displayed well-defined black bands, each tergite bearing a distinctive black arrowhead marking. The antennae were black, slightly curved, and shorter in females, while males possessed longer, more curved antennae.



Figure 10. Measurement of different morphological characteristics of *V. vulgaris*: (a) Full body, (b) Abdomen, (c) Forewing, (d) Hind leg, (e) Hind wing, (f) Mid leg, (g) Antenna, (h) Head, (i) Thorax, (j) Foreleg.

Measurements

V. vulgaris had a body length of 16.02 ± 0.05 mm, a head length of 3.09 ± 0.03 mm, and a head width of 3.46 ± 0.03 mm. The thorax length was 4.43 ± 0.03 mm, and the thorax width was 3.46 ± 0.03 mm. The clypeus length measured 1.45 ± 0.03 mm, with a clypeus width of 2.21 ± 0.05 mm. The lower inter-orbital distance was 2.34 ± 0.05 mm, while the upper inter-orbital distance was 2.46 ± 0.05 mm. The inter-orbital distance through the antennal sockets was 2.45 ± 0.05 mm, and the clypeo-antennal distance was 0.55 ± 0.02 mm. The compound eye length measured 4.18 ± 0.05 mm. The scape length was 1.05 ± 0.02 mm, pedicel length 0.19 ± 0.01 mm, and flagellum length 4.12 ± 0.10 mm. The 3rd flagellomere diameter was 0.25 ± 0.01 mm, and the distance between antennal sockets was 0.56 ± 0.03 mm. The inter-ocellar distance was 0.52 ± 0.02 mm, the ocellocular distance was 0.23 ± 0.10 mm, the antennocellar distance was 0.32 ± 0.10 mm, and the clypeocular distance was 0.13 ± 0.20 mm. The median ocellus diameter was 0.43 ± 0.30 mm, labrum length was 0.30 ± 0.30 mm, and labrum width was 1.45 ± 0.30 mm. The maximum diameter of the antennal socket was 0.34 ± 0.06 mm, and the compound eye width was 1.20 ± 0.15 mm. The forewing length measured 14.23 ± 0.80 mm, with a forewing width of 3.64 ± 0.35 mm. The Jugovanmal index was recorded as 79.33 ± 2.20 mm, and the species possessed 19.00 ± 1.80 hemuli. The hindwing length was 6.56 ± 0.50 mm and the hindwing width was 1.23 ± 0.10 mm. The hind basitarsus length was recorded at 2.67 ± 0.15 mm, with a hind basitarsus width of 0.39 ± 0.05 mm. This species possessed 10 flagellomeres, an abdomen length of 8.94 ± 0.30 mm, an abdomen width of 5.59 ± 0.02 mm, and a hind tibia length of 3.23 ± 0.02 mm (Table 3-9).

Bombus albopleuralis

Distribution

B. albopleuralis is found in the Himalayas, including regions of India, Nepal, China, and Bhutan.

Diagnostic characters

This species was identified as a relatively large bumblebee, with workers measuring 12-16 mm in length and queens reaching up to 20 mm. It possessed a distinctive white or pale yellow thorax that contrasted with its black abdomen (Figure 11). The head was large, featuring a short and broad clypeus. The wings were semi-transparent with brownish venation. The hind legs were adapted for pollen collection, characterized by a well-developed corbicula (pollen basket) on the hind tibiae. Males exhibited longer antennae and a more slender body compared to females. The dense hair covering the body was a key feature that distinguished it from other bumblebee species.



Figure 11. Measurement of various morphological characteristics of *B. albopleuralis*: (a) Full body, (b) Abdomen, (c) Head, (d) Midleg, (e) Foreleg, (f) Hindleg, (g) Antenna, (h) Ossicles, (i) Thorax, (j) Hindwing, (k) Forewing.

Measurements

B. albopleuralis was the largest species in the dataset, with a body length of 24.41 ± 0.08 mm, head length of 4.12 ± 0.03 mm, and head width of 6.21 ± 0.02 mm. The thorax length was 7.32 ± 0.03 mm, and the thorax width was 8.12 ± 0.03 mm. The clypeus length measured 1.43 ± 0.02 mm, while the clypeus width was 2.22 ± 0.05 mm. The lower inter-orbital distance was 2.45 ± 0.05 mm, and the upper inter-orbital distance was 2.34 ± 0.05 mm. The inter-orbital distance through the antennal sockets was 2.47 ± 0.05 mm, while the clypeo-antennal distance was 0.54 ± 0.02 mm. The compound eye length was 4.20 ± 0.05 mm. The scape length measured 2.10 ± 0.04 mm, pedicel length was 0.18 ± 0.01 mm, and flagellum length was 4.78 ± 0.12 mm. The diameter of the 3rd flagellomere was 0.34 ± 0.02 mm, the distance between antennal sockets was 0.65 ± 0.04 mm, and the inter-ocellar distance was 0.68 ± 0.03 mm. The ocellocular distance measured 0.30 ± 0.20 mm, antennocellar distance was 0.47 ± 0.20 mm, and clypeocular distance was 0.12 ± 0.20 mm. The diameter of the median ocellus was 0.45 ± 0.25 mm. The labrum length measured 0.31 ± 0.30 mm, and labrum width was 1.56 ± 0.30 mm. The maximum diameter of the antennal socket was 0.38 ± 0.08 mm, and the compound eye width was 1.96 ± 0.25 mm. The forewing length was 20.21 ± 1.00 mm, with a forewing width of 6.34 ± 0.50 mm. The Jugovanmal index was 82.52 ± 3.00 mm, and it possessed 35.5 ± 2.50 Hemuli. The hindwing length measured 11.34 ± 0.70 mm, with a hindwing width of 4.23 ± 0.20 mm. The hind basitarsus length was 4.56 ± 0.12 mm, and the width was 0.76 ± 0.10 mm. This species possessed 10 flagellomeres and an abdomen length of 12.97 ± 0.50 mm, with an abdomen width of 9.23 ± 0.02 mm. The hind tibia length was recorded as 4.52 ± 0.03 mm (Table 3-9).

Hierarchical cluster analysis (HCA)

HCA of hymenopteran pollinators based on standardized morphometric traits revealed distinct patterns of morphological similarity and divergence among species. *A. mellifera* and *A. cerana* clustered closely together, indicating a high degree of morphological resemblance, likely due to their shared taxonomic lineage and ecological roles. Similarly, *Lasioglossum* species, including *L. rugifrons*, *L. marginatum*, and *L. matianense*, formed a tight group, reflecting intra-genus consistency in body structure. In contrast, species such as *B. albopleuralis* and *V. vulgaris* were positioned on separate branches, signifying substantial differences in body size and morphology (Figure 12). *Andrena* species such as *A. agilissima* and *A. fucata* also formed a distinct cluster, suggesting moderate similarity within the genus. These grouping patterns emphasized the morphometric diversity among *Apis* and non-*Apis* pollinators and provided insights into their potential specialization and ecological differentiation in pollination dynamics.

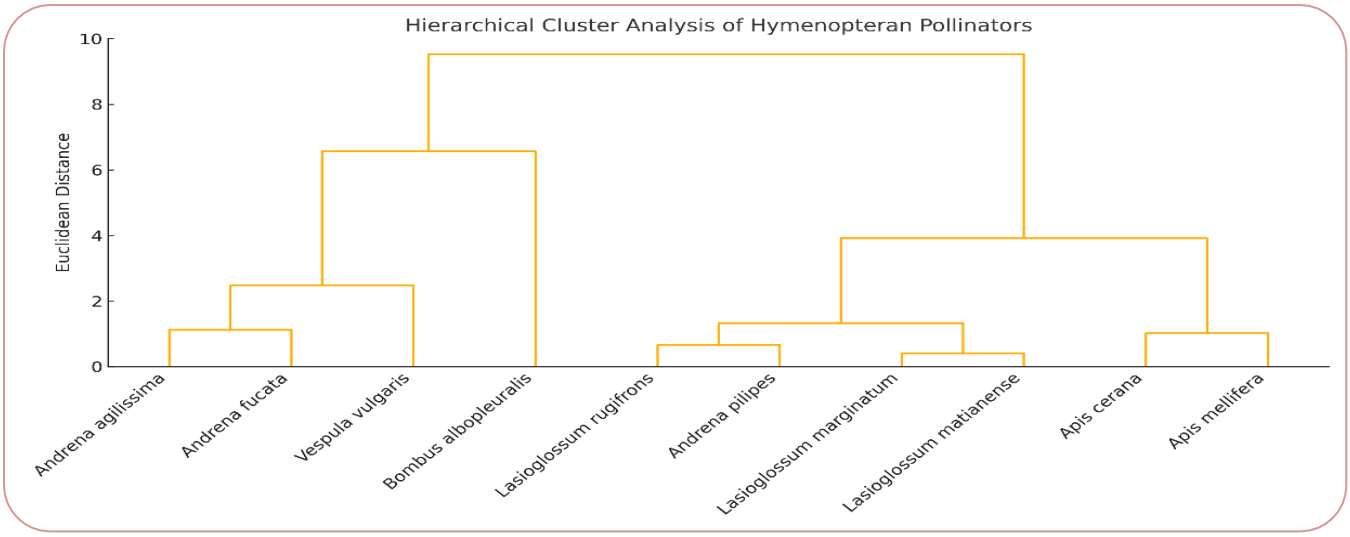


Figure 12. Dendrogram showing the hierarchical clustering of hymenopteran pollinators based on standardized morphometric traits. Species with similar body structures, such as *A. mellifera* and *A. cerana*, cluster closely, indicating morphological similarity. In contrast, *B. albopleuralis* and *V. vulgaris* appear on distinct branches due to their divergent morphologies. The clustering reflects both taxonomic relationships and potential functional roles in pollination.

Principal Component Analysis (PCA)

PCA based on standardized morphometric characters of hymenopteran pollinators revealed clear patterns of species separation along the first two principal components. Species such as *A. mellifera* and *A. cerana* were positioned closely together in the lower left quadrant, indicating strong morphological similarity. *Lasioglossum* species, particularly *L. rugifrons*, *L. matianense*, and *L. marginatum*, clustered in the upper region, reflecting consistent traits within the genus (Figure 13). In contrast, *B. albopleuralis* and *V. vulgaris* were separated from other taxa along the principal axes, suggesting substantial divergence in body size and structure. The *Andrena* species were moderately spread across the central and right-hand regions, signifying intra-genus variation. The spatial distribution of species in the PCA plot highlighted morphometric differentiation that supported their taxonomic classification and potential ecological roles in pollination.

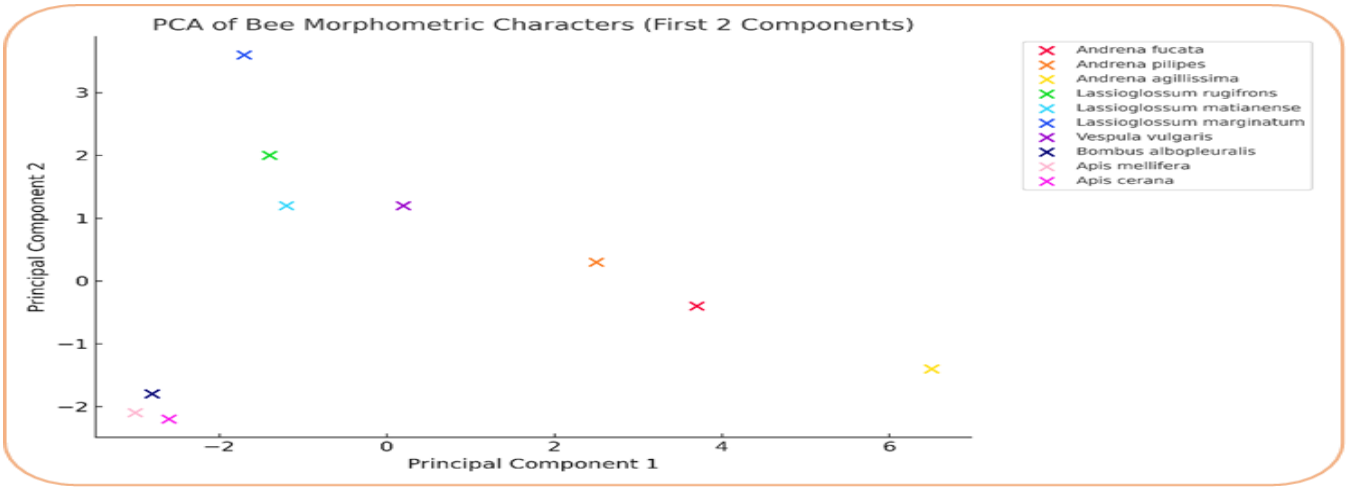


Figure 13. PCA plot showing the distribution of 10 hymenopteran species based on 38 morphometric traits from the head, thorax, abdomen, and wings. PC1 and PC2 capture the major variations in body size and shape. *B. albopleuralis* and *V. vulgaris* are distinctly separated, reflecting their larger morphologies, while *A. mellifera* and *A. cerana* cluster closely, indicating high similarity. *Andrena* and *Lasioglossum* species form separate intra-genus clusters, supporting their taxonomic and ecological differentiation.

Discussion

This study documented 10 hymenopteran pollinator species across cherry orchards in the Kashmir Valley, representing four major families. This observed diversity highlights the ecological heterogeneity and pollinator richness characteristic of temperate orchard systems, patterns consistent with those reported in other temperate agroecosystems (Paray et al., 2014). The dominance of species from the families Apidae, Halictidae, Andrenidae, and Vespidae reflects the adaptive radiation of hymenopteran pollinators under region-specific climatic and floral conditions.

Within the Apidae, *A. mellifera*, *A. cerana*, and *B. albopleuralis* exhibited marked morphological variability. Notably, *B. albopleuralis* demonstrated the greatest hind tibia length and wingspan, traits associated with extended foraging ranges and enhanced flight capabilities (Mir et al., 2021). Similar findings by Pull et al. (2022) suggest that larger body size in bumble bees correlates positively with landscape-level foraging efficiency. Such morphological advantages likely enable *Bombus* species to exploit floral resources across fragmented orchard landscapes (Walther-Hellwig and Frankl, 2003).

In contrast, members of Halictidae, including *L. rugifrons*, *L. matianense*, and *L. marginatum*, displayed more compact body morphologies. Their smaller body size and narrower thoraxes likely confer advantages when foraging on tightly clustered cherry blossoms, highlighting the functional importance of small-bodied bees in crops with dense floral arrangements (Gibbs, 2009).

Andrenidae species, particularly *A. fucata*, *A. pilipes*, and *A. agilissima*, were characterized by enlarged thoraxes and relatively long antennae, features associated with early-spring foraging and thermoregulation. These morphological traits support activity during cooler temperatures, coinciding with cherry bloom periods. Similar adaptations in early-season solitary bees have been reported in relation to fluctuating spring temperatures (Polidori et al., 2020).

The only representative of Vespidae, *V. vulgaris*, exhibited prominent head and mandible structures. Although not a specialized pollinator, its occasional floral visits for nectar or prey may provide incidental pollination services. This observation aligns with Borchardt et al. (2024), who identified vespids as generalist visitors playing dual roles in agroecosystems.

In terms of abundance, *A. cerana* (197 individuals) and *A. mellifera* (196) were the most frequently recorded species, consistent with their managed status and established colonies in orchard environments. These findings reaffirm the observations by Abrol (2011), who documented the predominance of managed honey bees in Himalayan fruit production systems. However, the substantial presence of solitary species such as *L. matianense* (133), *L. marginatum* (118), and *A. fucata* (113) emphasizes the complementary ecological role of wild pollinators. These species contribute significantly to pollen deposition and floral constancy, particularly under conditions of reduced honey bee activity (Cortés-Gómez et al., 2023).

Less abundant taxa like *B. albopleuralis* (81) and *V. vulgaris* (67) may reflect habitat specificity, limited nesting resources, or seasonal fluctuations, findings consistent with the landscape and temporal influences on wild pollinator populations reported by von Königslöw et al. (2022).

Morphometric data (Tables 3-9) revealed that non-*Apis* species, particularly *B. albopleuralis*, generally exhibited larger structural dimensions than smaller taxa such as *L. matianense* and *A. pilipes*. The substantial body length of *B. albopleuralis* (24.41 mm) compared to *L. matianense* (9.08 mm) suggests enhanced long-distance foraging potential and more efficient pollination performance. Variations in head dimensions, including length and width, reflect adaptations for pollen collection and nectar extraction, with larger-headed species such as *B. albopleuralis* likely possessing stronger mandibular musculature (Parrey et al., 2021).

Antenna lengths were generally greater in non-*Apis* species, a trait associated with enhanced olfactory sensitivity and navigation efficiency (Moreno et al., 2022). Similarly, compound eye length was significantly larger in larger-bodied bees, suggesting superior floral detection abilities (Araújo et al., 2019). Wing measurements, specifically forewing and hindwing lengths, were also greater in non-*Apis* taxa, implying superior flight endurance and broader foraging ranges (Parrey et al., 2021). These traits are advantageous in landscapes with widely dispersed floral resources.

Furthermore, structural head metrics such as ocellocular and antennocellar distances varied among species, likely contributing to differences in flight stabilization and sensory processing (Moreno et al., 2022). Leg structures also showed significant variation, with *B. albopleuralis* exhibiting a hind basitarsus length of 4.56 mm and hind

tibia length of 4.52 mm. These robust segments provide greater surface area for pollen collection, enhancing pollination efficiency, especially in crops requiring substantial pollen transfer (Parrey et al., 2021). In contrast, narrower basitarsi in species like *A. mellifera* and *L. rugifrons* may reflect specialization for more delicate floral architectures.

According to Bie et al. (2025), *B. albopleuralis* is considered a highly effective pollinator in high-altitude and colder environments, such as the Himalayas. Its dense, hairy body enhances pollen adhesion, while its capacity for buzz pollination enables effective pollen extraction from flowers inaccessible to many other bees.

The HCA delineated groups based on morphometric similarity (Figure 12). *A. mellifera* and *A. cerana* formed a close cluster, indicating strong intra-genus similarity, while *L. rugifrons*, *L. matianense*, and *L. marginatum* formed another, reflecting intra-generic uniformity. In contrast, *B. albopleuralis* and *V. vulgaris* appeared morphometrically distinct, forming separate clusters due to their large body sizes and divergent morphological traits. These patterns are consistent with previous clustering studies, where body traits successfully delineated honey bee populations by regional or genetic differences (Zhang et al., 2025).

PCA (Figure 12) further supported these findings, with PC1 and PC2 capturing major variation in body size and shape. Larger-bodied species such as *B. albopleuralis* and *V. vulgaris* were separated from smaller species. Tight clustering of *A. mellifera* and *A. cerana* reaffirmed their morphometric similarity, while *Andrena* and *Lasioglossum* species formed genus-level clusters. Prior studies on *A. cerana* have shown that PC1 typically reflects body size, while PC2 often corresponds to wing venation and structural variation (Nannan et al., 2022). These results are in line with our findings and confirm that PCA is a robust tool for visualizing morphometric divergence related to ecological and taxonomic boundaries. Collectively, the morphometric and multivariate analyses highlight the value of detailed trait-based assessments in pollinator taxonomy, functional ecology, and conservation planning.

Conclusion

This study provides a comprehensive morphometric dataset of hymenopteran pollinators inhabiting cherry orchards in the Kashmir Valley, offering critical insights into species-level distinctions necessary for accurate identification and ecological interpretation. Through quantitative assessment of 38 morphological traits across ten species from four major families, the research enhances our understanding of structural diversity among both *Apis* and non-*Apis* taxa.

Multivariate analyses, particularly PCA and HCA, revealed clear patterns of morphometric clustering. *A. mellifera* and *A. cerana* showed tight grouping, reflecting intra-genus similarity, while *Lasioglossum* species exhibited comparable genus-level clustering. In contrast, *B. albopleuralis* and *V. vulgaris* were distinctly separated, highlighting their larger body sizes and unique structural features. The separation along principal components effectively illustrated variation in body size, wing dimensions, and sensory appendages, reinforcing the utility of PCA for visualizing morphological divergence.

These findings validate the effectiveness of standardized morphometric measurements in species delimitation, trait-based ecological assessment, and pollinator monitoring. The trait-based approach not only supports the refinement of regional identification keys but also informs broader conservation strategies in temperate orchard systems. As pollination services are increasingly threatened by climate variability, habitat fragmentation, and pesticide exposure, such detailed morphometric analyses provide a foundation for species-specific, ecologically informed conservation planning.

Ultimately, this research emphasizes the enduring relevance of morphometrics in pollinator biology, bridging taxonomy, ecology, and conservation to support sustainable agroecosystem management.

Authors' Contributions

AKR, SAG and AJ conceptualized the study; SAG and AJ developed the methodology; SAG, AJ and AKR performed the identification of the specimens; AJ and KAB handled software-related tasks; AJ conducted the formal analysis; AJ, SAG and AKR undertook the investigations; SAG provided the resources; KAB and AJ managed data; AJ, KAB and AKR prepared the original draft of the manuscript; KAB and AJ reviewed and edited the manuscript; AKR and SAG supervised the studies; AJ, SAG, and AKR administered the project.

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Conflict of Interest

The authors declare no conflict of interest.

Sustainable Development Goals Targeted

SDG 2: Zero Hunger
SDG 12: Responsible Consumption and Production
SDG 15: Life on Land

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