Sociobiology
An international journal on social insects

RESEARCH ARTICLE - BEES

Variation in the Morphological Characters of the Hill and Plain Populations of Indian Honey Bee, *Apis cerana indica (*Fab.) in Tamil Nadu, India

J. Lalremliana[1], M.R. Srinivasan[1], V.R. Saminathan[1], N. Chitra[1], S. Mohankumar[2], P. Sabatina[1], Sachin Suresh Suroshe[3], K.M. Kumaranag[3]

1 - Department of Agricultural Entomology, CPPS, TNAU, Coimbatore, India – 641003
2 - Department of Plant Biotechnology, CPBM, TNAU, Coimbatore, Coimbatore, India – 641003
3 - Project Coordinating Unit, ICAR – All India Coordinated Research Project on Honey bees and Pollinators, Indian Agricultural Research Institute, New Delhi, India – 110012

Article History

Edited by
Evandro Nascimento Silva, UEFS, Brazil
Received 03 September 2024
Initial acceptance 03 October 2024
Final acceptance 27 October 2024
Publication date 25 November 2024

Keywords
Morphometric characters, ecotype, hill population, plain population, cubital index, *Apis cerana indica*.

Corresponding author
Dr. M.R. Srinivasan
Department of Agricultural Entomology
Tamil Nadu Agricultural University
Coimbatore - 641 003, Tamil Nadu, India.
E-Mail: mrsrini@tnau.ac.in

Abstract

The present study investigates the morphological differences between the hill and plain populations of the Indian honey bee, *Apis cerana indica* Fabricius, collected from six different locations in Tamil Nadu, India: Coimbatore, Karumandhurai, Coonoor, Madurai, Dindigul, and Chidambaram during 2023-2024. Significant differences were found between the two populations based on a comprehensive morphometric analysis of 29 characters. The hill populations from TNAU Insectary (Marudhamalai hills), Karumandhurai (Kalvarayan hills), and Coonoor (Nilgiri hills), the mean altitude of the locations being 1207 m above MSL exhibited significantly higher values in several morphometric traits than the plain populations from Madurai, Dindigul, and Chidambaram, with a mean altitude of 124 m a.s.l. ($P<0.05$). Component loading analysis highlighted the key morphometric characters contributing to the first and second components of both ecotypes. In the plain population, breadth of the radial cell, breadth of the forewing, and length of the radial cell demonstrated strong positive correlations with the first principal component, explaining 16.4% of the variance. The second principal component, influenced by characters such as the length of the femur and breadth of the metatarsus, showed 12.2% of the variance. In the hill population, the length of the radial cell, length of vein R.L., and length of the hindwing were the most influential traits for the first principal component, explaining 28.0% of the variance. In contrast, the second component, which included the breadth of the forewing and length of vein I.L., explained 12.3% of the variance. Further, the cubital index, a critical morphometric parameter, also showed a statistically significant difference, with the hill population (3.55) showing a higher value than the plain population (3.29). The significant morphometric differences observed between the hill and plain populations of *A. cerana indica* may suggest that they have undergone morphological divergence, likely due to adaptations to their specific environmental conditions.

Introduction

Honey bees, insects taxonomically classified within the order Hymenoptera and family Apidae, are distinguished by unique functional attributes (Bluthgen & Klein, 2011). It is conjectured that bees evolved from predatory wasps of the Sphecidae lineage approximately 130 million years ago during the Cretaceous epoch. Asia, particularly its southern regions, is considered the paleo-biogeographical center of origin and diversification for honey bees (Gupta, 2014).

The genus *Apis* constitutes a compact monophyletic group that is morphologically and behaviourally cohesive (Michener, 2007). Throughout evolutionary history, honey bee populations diverged via allopatric speciation, driven by geographic vicariance and ecological niche adaptations. However, the precise barriers and ecological isolation mechanisms that have constrained gene flow among these populations remain elusive (Zhu et al., 2017). In the Indian subcontinent, the Apini tribe encompasses the giant single comb-building honey bees (subgenus *Megapis*), such as *Apis dorsata* Fabricius and *Apis laboriosa* Smith; the diminutive dwarf honey bees (subgenus *Micrapis*), including *Apis florea* Fabricius and *Apis andreniformis* Smith; and the cavity-nesting honey bees that construct multiple parallel combs (subgenus *Apis*), such as *Apis mellifera* Linnaeus (Shanas et al., 2022), and *Apis cerana indica* Fabricius (Yadav et al., 2017).

The natural range of *Apis cerana indica* spans the Indian subcontinent, serving as the cornerstone of traditional Indian apiculture (Hepburn & Radloff, 2011). Ruttner (1988) categorized *Apis cerana* into several subspecies based on their ecological niches and genetic variability. Within India, *A. cerana indica* and *A. cerana cerana* are the recognized subspecies. Furthermore, *A. cerana indica* is subdivided into two distinct morphotypes: the "hill race" (characterized by its black coloration) and the "plain race" (yellow-colored) (Ramchandra et al., 2012). This differentiation may provide evidence of reproductive isolation between the yellow plain and black hill morphs in southern India, suggesting that the yellow plain honey bees of the region could potentially be classified as a separate species (Shanas et al., 2022). This study aimed to delve deeper into this variation by conducting a comprehensive morphological examination.

Materials and Methods

Sampling

Honey bee samples from India were collected from six geographically distinct locations (Table 1) in Tamil Nadu (Fig 1), encompassing hill and plain regions. Each sample consisted of 20 bees. The hill populations were gathered from Coimbatore (TNAU Insectary, Marudhamalai Hills) with an altitude 1000 m above MSL, Karumandhurai (Kalvarayan Hills) with an altitude of 773 m above MSL, and Coonoor (Nilgiri hills) with an altitude of 1850 m above MSL, while the plain populations were sourced from Madurai, Dindigul, and Chidambaram in Cuddalore districts with altitudes ranging from 3 to 268 m above MSL (bracket may be removed). The collection of honey bee samples was done from managed bee colonies, ensuring standardized and controlled conditions for precise data gathering. In hilly areas such as Karumandurai and Coonoor, where local beekeepers were unavailable, feral worker bees were directly sampled from their natural habitats. The specimens were preserved in 70% ethanol and stored in sterilized Eppendorf tubes, each labeled with the corresponding collection site for accurate identification and analysis.

Comparative morphometric analysis of A. cerana indica in Tamil Nadu

A morphometric analysis of *Apis cerana indica* was performed using ten specimens from six locations. Each bee was carefully dissected and labeled for seamless identification and detailed examination. A Leica M205 A stereo-zoom microscope assessed and measured various morphological traits. In total, 29 morphometric parameters were analyzed, which included tongue length, antenna length,

Table 1. Geographical coordinates of sampling locations.

Species Name	Ecotype (Race)	Sampling Site		Geographical Location		
		Place	State	Longitude	Latitude	Altitude (m above MSL)
A. cerana indica	Hill	TNAU Insectary (Marudhamalai hills)	Tamil Nadu	76° 51' 11.124"E	11° 2' 43.08" N	1000 m*
A. cerana indica	Hill	Karumandurai (Kalvarayan Hills)	Tamil Nadu	78° 37' 38.64" E	11° 49' 4.57"N	773 m
A. cerana indica	Hill	Coonoor (Nilgiri Hills)	Tamil Nadu	76° 49' 12.00" E	11° 20' 60.00" N	1850 m
A. cerana indica	Plain	Madurai	Tamil Nadu	78° 07' 10.63" E	9° 55' 2.46" N	101 m
A. cerana indica	Plain	Dindigul	Tamil Nadu	77° 58' 49.30" E	10° 22' 8.26" N	268 m
A. cerana indica	Plain	Chidambaram	Tamil Nadu	79° 41' 28.07" E	11° 23' 56.65" N	3 m

*These honey bee colonies belonging to the dark coloured hill race were collected from nearby Marudhamalai hills (altitude 1000 m above MSL), which is situated at about 9 kilometers from the TNAU insectary and maintained in TNAU insectary for the past 6 months.

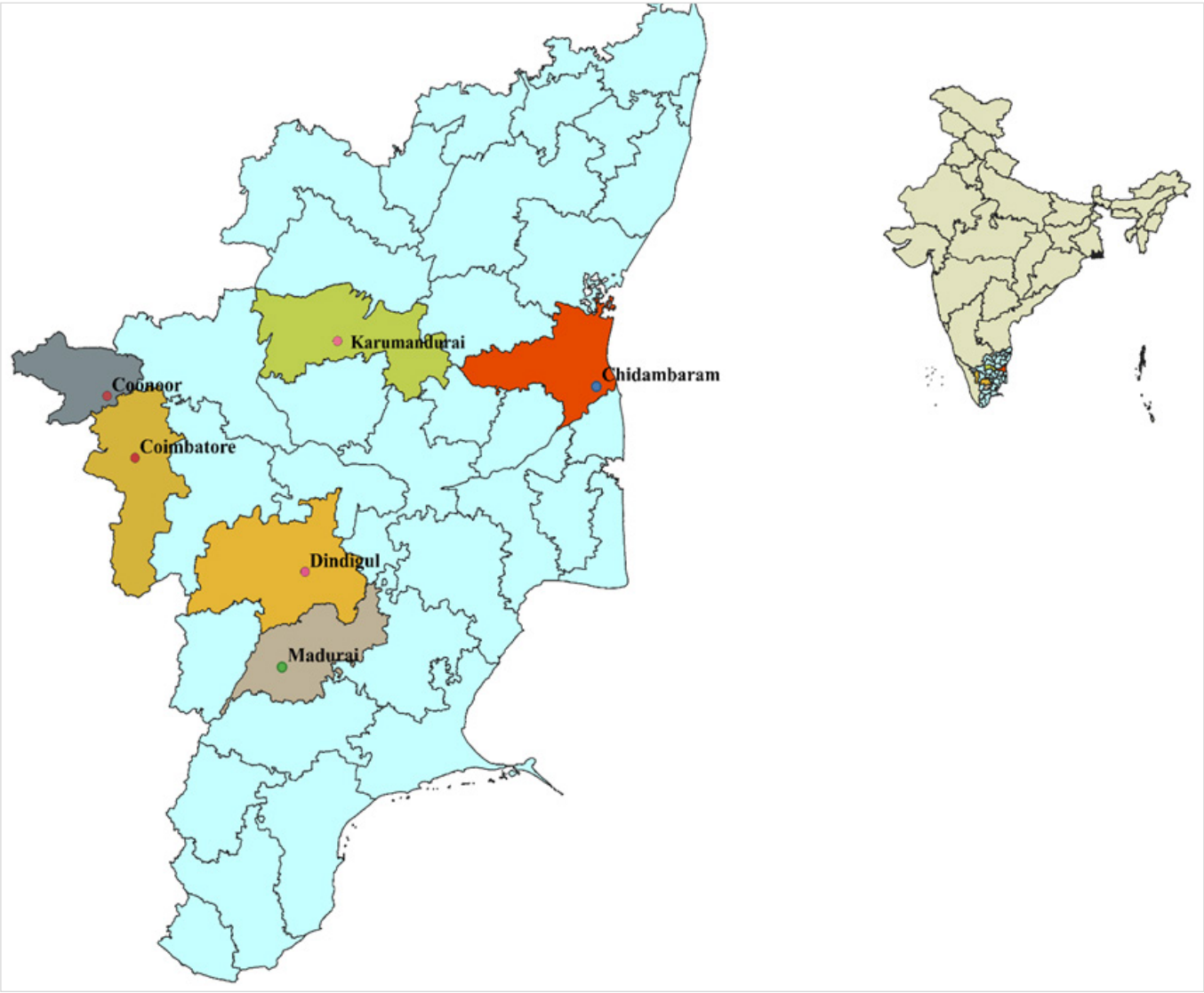

Fig 1. Map showing the location of *A. cerana indica* sampling sites in Tamil Nadu, India.

wing dimensions, leg measurements, and abdominal segment lengths. One critical measurement, the cubital index, was calculated based on wing morphology by determining the lengths of specific veins in the forewing. Specifically, this involved measuring the first abscissa (A) of vein M_3 in the second median cell and the second abscissa (B) of the same vein to derive the cubital index, a crucial factor in wing characterization (Fig 2).

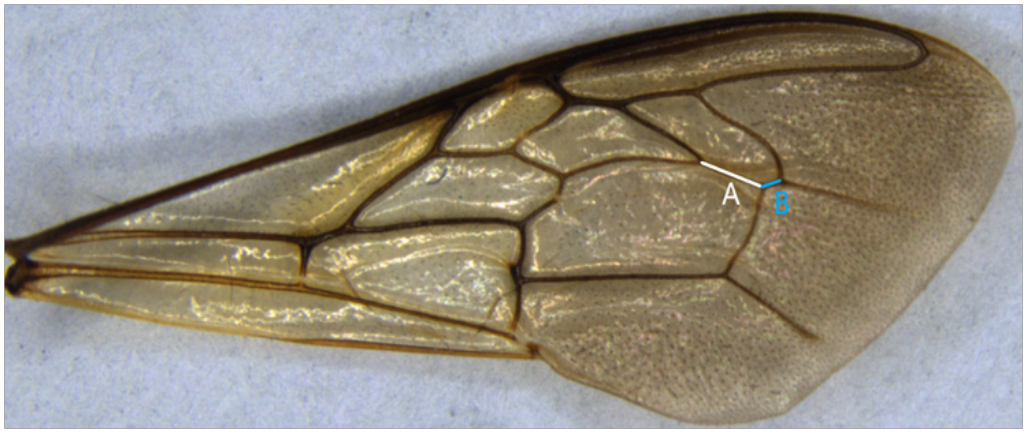

Fig 2. Figure showing 1st abscissa (A) of vein M_3 in the second median cell, and the 2nd abscissa (B) of the same vein of the forewing of *Apis cerana indica*.

The formula for the cubital index is:

$$\text{Cubital index} = \frac{\text{Length of 1st abscissa (A)}}{\text{Length of 2nd abscissa (B)}}$$

Statistical analysis

Several key statistical methods were utilized to analyze the collected data. The colony means, the standard deviation, and the variance for all 29 morphometric traits across the 60 samples were computed using RStudio software. Both one-way Analysis of Variance (ANOVA) and t-tests were performed to assess the significance of the observed variations. Furthermore, Principal Component Analysis (PCA) was applied to simplify the high-dimensional dataset, enabling a clearer identification of the dominant patterns and relationships among the variables. This approach allowed for a more efficient interpretation of the primary factors driving morphological variation.

Results

The morphometric analysis of 29 traits revealed notable variations between the hill and plain races of *A. cerana indica* in Tamil Nadu. A significant overall difference was observed between these ecotypes ($P < 0.05$). The hill races (from TNAU Insectary, Karumandurai, and Coonoor) exhibited significantly larger morphometric characteristics compared to the plain races (from Madurai, Dindigul, and Chidambaram) (Table 2). Component loading analysis indicated that specific morphometric traits contributed substantially to the principal components (Table 3). The Cubital Index (CI) comparison also highlighted a statistically significant difference between hill and plain populations, suggesting distinct morphological adaptations between these ecotypes (Table 3).

Table 2. Comparative morphometric analysis of the hill and plain races of *A. cerana indica*.

S. n^o	Morphometric characters	Plain	Hill	Percentage Difference (%) (P.D)
1.	Total tongue length (mm)	4.25 ± 0.040	5.20 ± 0.043	20.10
2.	Length of Scape (mm)	1.08 ± 0.015	1.18 ± 0.020	8.85
3.	Length of Pedicel (mm)	0.17 ± 0.005	0.20 ± 0.005	16.22
4.	Length of Flagellum (mm)	2.21 ± 0.000	2.67 ± 0.072	18.85
5.	Total length of Antenna (mm)	3.47 ± 0.010	4.08 ± 0.060	16.16
6.	Length of Forewing (mm)	7.69 ± 0.050	8.72 ± 0.011	12.55
7.	Breadth of Forewing (mm)	2.70 ± 0.055	3.09 ± 0.064	13.47
8.	Length of Radial cell (mm)	2.64 ± 0.040	3.18 ± 0.083	22.40
9.	Breadth of Radial cell (mm)	0.34 ± 0.010	0.42 ± 0.020	10.52
10.	Length of 1st abscissa (mm)	0.44 ± 0.020	0.57 ± 0.000	26.00
11.	Length of 2nd abscissa (mm)	0.13 ± 0.010	0.16 ± 0.000	10.34
12.	Length of Hindwing (mm)	5.54 ± 0.015	6.21 ± 0.086	11.41
13.	Breadth of Hindwing (mm)	1.63 ± 0.017	1.74 ± 0.20	3.26
14.	Length of vein R.L. (mm)	1.25 ± 0.011	1.44 ± 0.034	7.06
15.	Length of vein ML (mm)	1.12 ±0.015	1.23 ± 0.020	4.68
16.	Length of vein V.L. (mm)	1.15 ± 0.005	1.29 ± 0.032	5.73
17.	Length of vein I.L. (mm)	0.32 ± 0.30	0.43 ± 0.023	29.3
18.	No. of hooks	18.30 ± 0.100	18.37 ± 0.251	0.31
19.	Extent of Hamuli (mm)	1.10 ± 0.020	1.11 ± 0.005	0.90
20.	Length of Jugal lobe (mm)	1.62 ± 0.036	1.82 ± 0.025	11.62
21.	Length of Venal lobe (mm)	1.22 ± 0.045	1.27 ± 0.026	4.01
22.	Length of Femur (mm)	2.10 ± 0.020	2.55 ± 0.089	19.35
23.	Length of Tibia (mm)	2.57 ± 0.075	3.08 ± 0.005	18.05
24.	Length of Metatarsus (mm)	1.85 ± 0.040	2.09 ± 0.070	12.18
25.	Breadth of Metatarsus (mm)	0.89 ± 0.015	1.10 ± 0.030	21.10
26.	Total length of 3rd Sternite (mm)	1.68 ± 0.011	1.84 ± 0.026	9.09
27.	Total length of 6th Sternite (mm)	1.97 ± 0.005	2.31 ± 0.061	15.88
28.	Total length of 3rd Tergite (mm)	1.91 ± 0.005	2.09 ± 0.011	9.00
29.	Total length of 4th Tergite (mm)	1.95 ± 0.010	2.19 ± 0.069	11.59

Table 3. Principal component analysis on the morphometric characters of the hill and plain race of *A. cerana indica* race.

Hill race				Plain race			
Variable	**PC1**	**Variable**	**PC2**	**Variable**	**PC1**	**Variable**	**PC2**
Length of radial cell	0.855	Length of femur	0.430	Breadth of radial cell	0.892	Length of femur	0.845
Length of vein RL	0.673	Breadth of forewing	0.815	Breadth of forewing	0.810	Breadth of metatarsus	0.762
Length of Hindwing	0.662	Total length of 4th tergite	0.726	Length of radial cell	0.711	Total length of 4th tergite	-0.614
Lenfth of femur	0.564	Length of vein IL	0.725	Length of flagellum	0.613	Length of forewing	-0.598
Breadth of metatarsus	0.486	Breadth of hindwing	0.573	Total length of antenna	0.562	Length of tibia	0.524
Breadth of radial cell	0.467	Length of metatarsus	0.444	Length of pedicel	0.467		
Length of vein VL	0.464						
Length of scape	0.448						
% variance explained	28.0	**% variance explained**	12.3	**% variance explained**	16.4	**% variance explained**	12.2
Cumulative % variance explained	28.0	**Cumulative % variance explained**	12.3	**Cumulative % variance explained**	16.4	**Cumulative % variance explained**	12.2

Among the 29 analyzed traits, certain morphometric characters exhibited substantial variation. The length of vein I.L. showed the highest degree of variation (P.D. = 29.3, $P < 0.05$), followed by the length of the first abscissa (P.D. = 26, $P < 0.05$), and the length of the radial cell (P.D. = 22.40, $P < 0.05$). In contrast, traits such as the number of hooks (P.D. = 0.31, $P < 0.05$), extent of hamuli (P.D. = 0.90, $P < 0.05$), and breadth of the forewing (P.D. = 3.26, $P < 0.05$) displayed the least variation between hill and plain bee populations. Other significant differences were observed in the breadth of the metatarsus (P.D. = 21.10, $P < 0.05$), total tongue length (P.D. = 20.10, $P < 0.05$), and femur length (P.D. = 19.35, $P < 0.05$) (Table 1).

A scree plot determined the number of principal components to retain. The component number on the X-axis corresponds to the principal components in decreasing order of the variance they explain, with the first component accounting for the most variance. The eigenvalue, representing the variance explained by each component, showed a steep decline for the initial components before leveling off, forming an "elbow," indicating the point where additional components contribute minimally to variance (Fig 3, Fig 4).

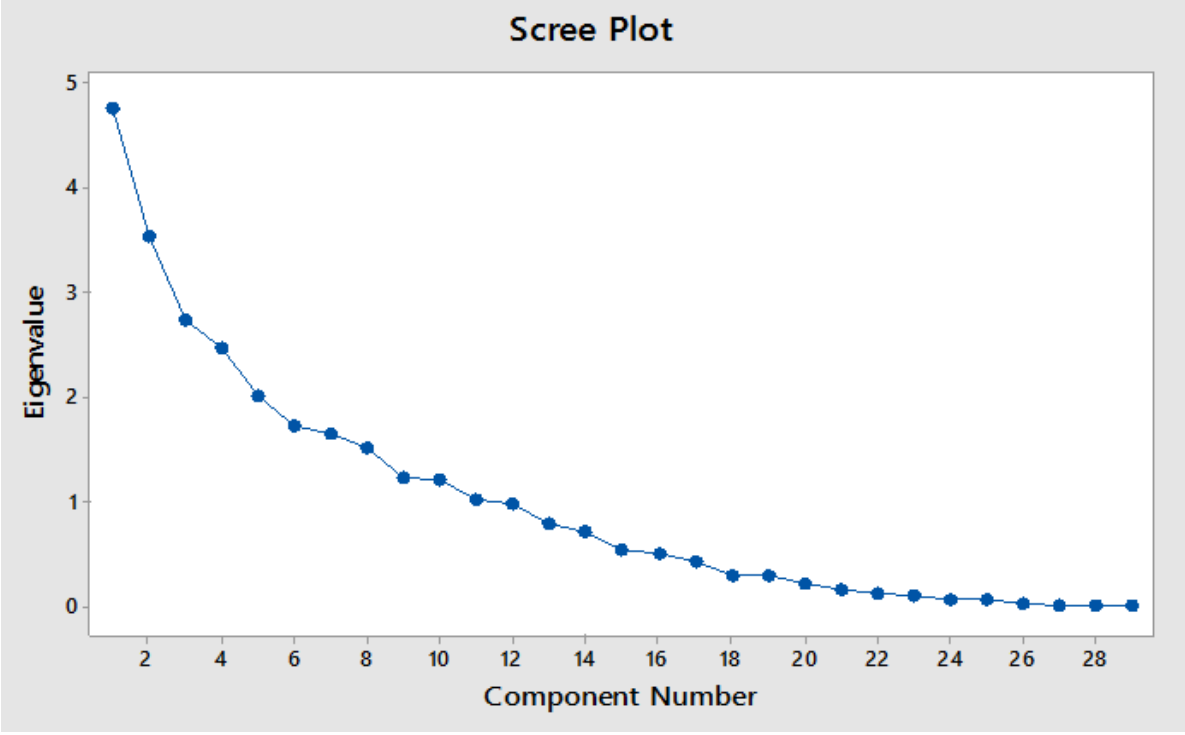

Fig 3. Scree plot for the hill race of *A. cerana indica* showing the relationship between the eigenvalues and each principal component.

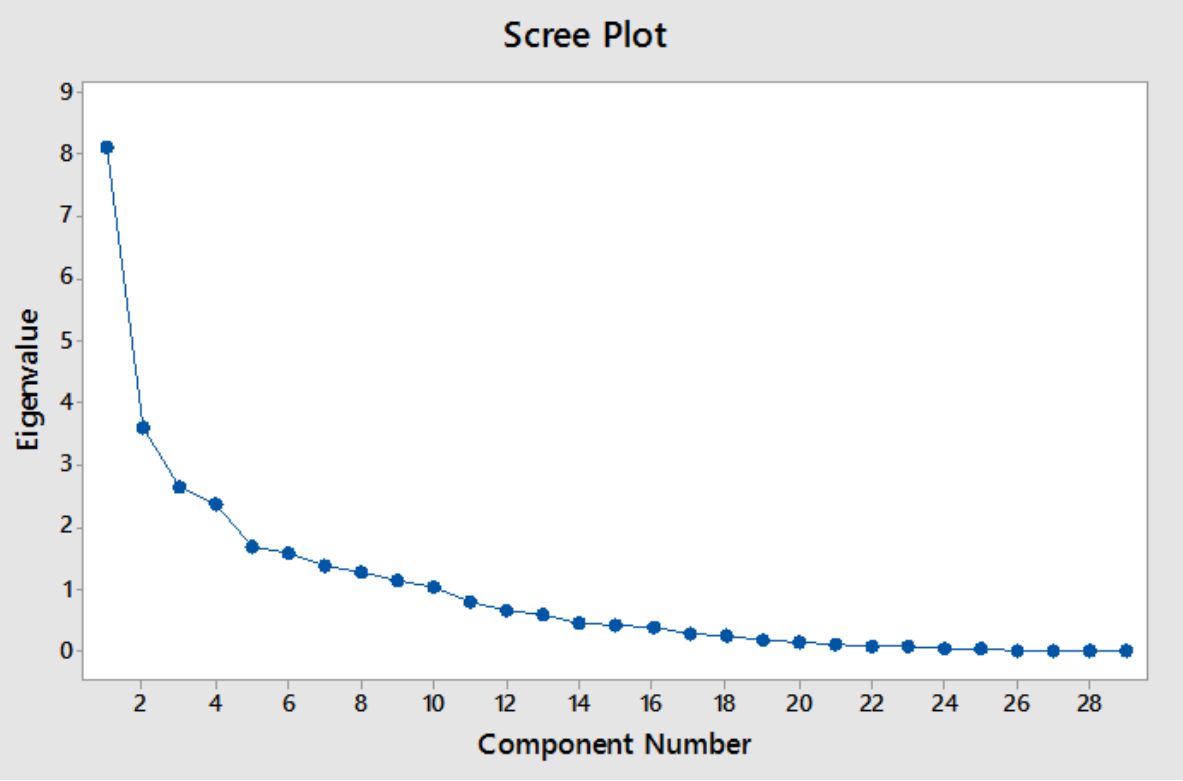

Fig 4. Scree plot for the plain race of *A. cerana indica* showing the relationship between the eigenvalues and each principal component.

Component loading analysis identified key morphometric traits driving, the first and second components in both ecotypes. For the plain ecotype, traits such as radial cell breadth (0.855), forewing breadth (0.810), radial cell length (0.711), flagellum length (0.613), total antenna length (0.562), and pedicel length (0.467) had strong positive correlations with the first principal component. In contrast, femur length (0.845), metatarsus breadth (0.762), and tibia length (0.524) were positively correlated with the second component, while the fourth tergite length (-0.614) and forewing length (-0.598) showed negative correlations. The first principal component explained 16.4% of the variance, and the second component explained 12.2% of the total variance in the plain ecotype (Table 3).

In the hill ecotype, traits like radial cell length (0.855), vein R.L. length (0.673), hindwing length (0.662), femur length (0.564), metatarsus breadth (0.486), radial cell breadth (9.467), vein V.L. length (0.464), and scape length (0.448) strongly correlated with the first principal component. Meanwhile, femur length (0.430), forewing breadth (0.815), fourth tergite length (0.726), vein I.L. length (0.725), hindwing breadth (0.573), and metatarsus length (0.444) had positive correlations with the second component. The first principal component explained 28.0% of the variance, while the second component accounted for 12.3% in the hill ecotype (Table 3).

The cubital index (CI) comparison between the hill and plain populations revealed a significant difference (Fig 5), with the hill populations having a higher mean CI (3.55) than the plain populations (3.29). Although no significant intra-population differences in CI were found within each ecotype, the overall CI variation between hill and plain populations was statistically significant, indicating systematic morphological differences between these groups (Table 4).

Table 4. Comparison of cubital index between hill and plain races of *A. cerana indica*.

Cubital Index ± SD			
Plain race*		**Hill race***	
Madurai	3.27 ± 0.324	TNAU Insectary	3.69 ± 0.444
Dindigul	3.34 ± 0.235	Karumandurai	3.49 ± 0.184
Chidambaram	3.27 ± 0.367	Conoor	3.46 ± 0.341
Average	3.29 ± 0.043	Average	3.55. ± 0.123

*Mean of 10 replications; SD: Standard deviation

Discussion and Conclusion

The Asian hive bee, *Apis cerana*, is part of a clade of cavity-nesting honey bees, along with two closely related species, *A. nigrocincta* (Smith et al., 2000, 2003; Otis & Hadisoesilo, 2001) and *A. nuluensis* (Tingek et al., 1996; Tanaka et al., 2001). The wide morphological diversity across *A. cerana*'s range suggests significant underlying biological variation (Ruttner, 1988; Hepburn et al., 2001a; Radloff et al., 2005). Ruttner (1988) identified distinct morphological differences between the hill and plain races, with hill bees having longer and broader forewings and tongues.

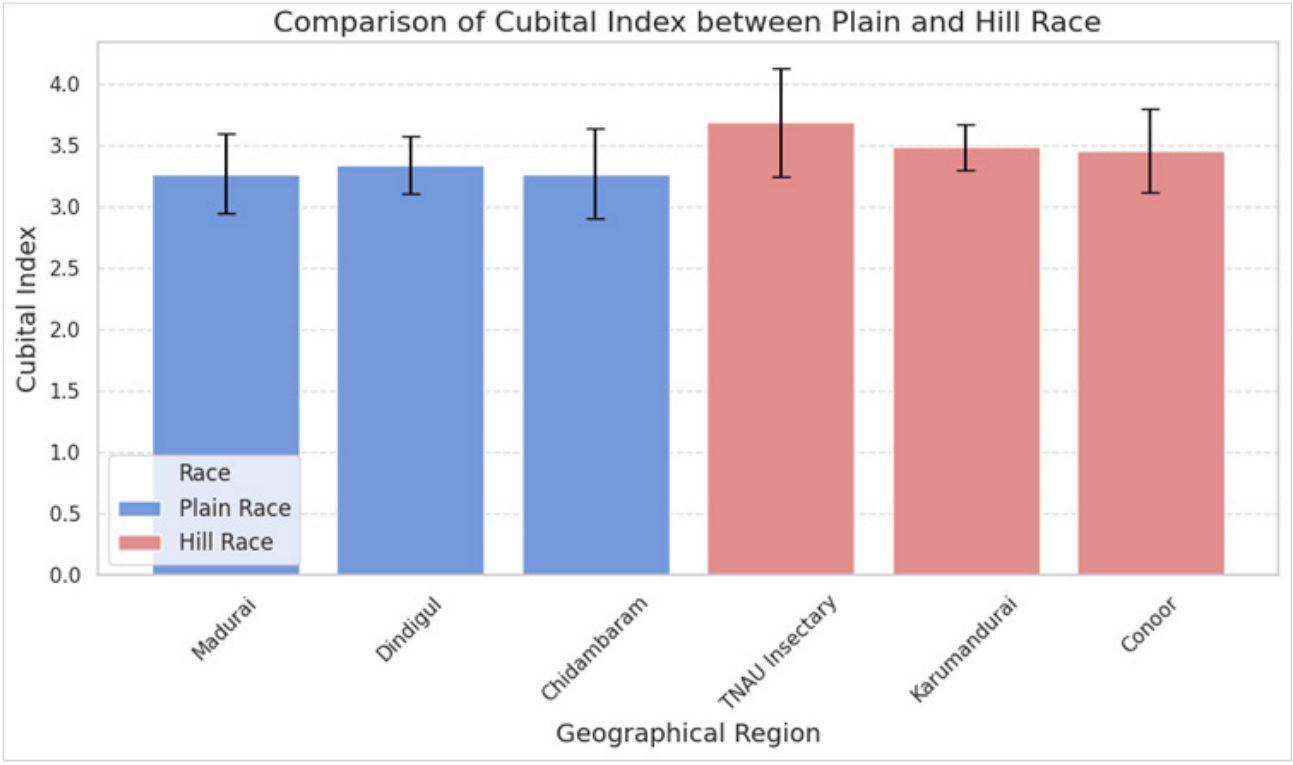

Fig 5. Bar plot shows the variation of cubital index between Plain and Hill race.

Morphometric analysis is critical for distinguishing and classifying honey bee species (Shaibi et al., 2009; Rattanawannee et al., 2013), and variations in these traits are also used to evaluate regional differences within populations (Tilde et al., 2000).

The current study confirmed distinct morphometric differences among the honey bees in Tamil Nadu, reflecting the ecological diversity of their collection sites. Tongue length, a key trait influencing nectar gathering (Morimoto, 1968), was significantly longer in the hill race, aligning with Fernando's (1979) findings. The antenna, essential for detecting pheromones and floral scents and critical for communication, navigation, and foraging, also varied significantly. Specifically, the length of the scape, pedicel, flagellum, and overall antenna length were larger in hill bees, consistent with Kshirsagar's (1976) report that bees at higher altitudes have longer antennae.

Wing morphology significantly impacts flight performance (Jason & Stephen, 2014). The hill bees showed significantly larger values for forewing length and breadth, radial cell dimensions, and the lengths of the first and second abscissas, echoing similar findings from Lindauer (1957) and Hepburn et al. (2001). Hindwing characteristics such as length and breadth and vein lengths R.L., ML, V.L., and I.L. were also notably greater in hill bees, corroborating the work of Kshirsagar (1976), Singh et al. (1990), and Verma et al. (1994). However, the number of hooks and hamuli showed no significant differences, consistent with Kapil (1956) and Fernando (1979) findings. Statistical analysis revealed that the Jugal and vannal lobes were significantly longer in hill bees, aligning with Kshirsagar (1976) and Mattu et al. (1983a) results.

The hindleg size, which influences pollen-carrying capacity, was significantly larger in hill bees, in agreement with Kapil (1956) and Verma et al. (1994). The 3rd and 4th tergites, which indicate abdominal size, were also significantly larger in the hill race, supporting Kshirsagar's (1976) findings. Similarly, the 4th and 6th sternites were larger in hill bees, mirroring the results of Kshirsagar (1976), Verma et al. (1994), and Hepburn et al. (2001).

The significant morphometric differences between hill and plain *A. cerana indica* populations suggest these groups may have undergone morphological divergence (Oldroyd et al., 2006), likely as adaptations to their unique environmental conditions. Traits with the greatest percentage differences, particularly those related to wing and leg morphology, indicate that these bees have evolved to enhance foraging efficiency, flight performance, and overall habitat fitness. These findings support the hypothesis that the hill and plain ecotypes of *A. cerana indica* represent distinct evolutionary lineages, adapted to their environments, and potentially on divergent evolutionary trajectories, possibly leading to speciation. This morphological divergence has essential implications for conserving and managing these bee populations, particularly in the face of environmental changes and habitat fragmentation. Further genetic research is needed to understand the extent of divergence fully and whether these populations could be classified as separate species.

Authors' Contribution

J.L., M.R.S.: Conceptualization, methodology, and writing original draft.
J.L., V.R.S.: Supervision, review and editing, and data curation.
N.C., S.M.: Validation, review and editing, and supervision.
P.S., S.S.S., K.K.M.: Formal analysis and supervision.
All authors have gone through and approved the manuscript.

References

Bluthgen, N. & Klein, A.M. (2011). Functional complementarity and specialization: the role of biodiversity in plant-pollinator interactions. Basic Journal of Applied Ecology, 12: 282-291. https://doi.org/10.1016/j.baae.2010.11.001

Bornus, L. (1960). Investigations on the size of honeybee body and some of its parts. Pszczelnicze Zeszyty Naukowe, 4: 175- 182.

Fernando, E.F.W. (1979, 2001). Some biometrical features of *Apis cerana* F. from Sri Lanka. Indian Bee Journal, 41: 5-8.

Gupta, R.K. (2014). Taxonomy and distribution of different honey bee species (Eds). Beekeeping for Poverty Alleviation and Livelihood Security, pp 63-101. https://doi.org/10.1007/978-94-017-9199-1_2

Hepburn, H.R., Radloff, S.E., Verma, S., & Verma, L.R. (2001a). Morphometric analysis of *Apis cerana* populations in the southern Himalayan region. Apidologie, 32: 435-447. https://doi.org/10.1051/apido:2001142

Hepburn, H.R., Radloff, S.E., Verma, S. & Verma, L.R. (2001). Analysis of *Apis cerana* populations in the southern Himalayan region. Apidologie, 32: 435-447. https://doi.org/10.1051/apido:2001142

Hepburn, H.R. & Radloff, S.E. (2011). Honeybees of Asia. Springer. https://doi.org/10.1007/978-3-642-16422-4

Jason, T.V. & Stephen, P.R. (2014). The effects of artificial wing wear on the flight capacity o f t he h oney b ee *Apis mellifera*. Journal of Insect Physiology, 65: 27-36. https://doi.org/10.1016/j.jinsphys.2014.04.003

Kapil, R.P. (1956). Variation in biometrical characters of the Indian honeybee (*Apis indica* F.). Indian Journal of Entomology, 18: 440-457.

Kshirsagar, K.K. (1976). Studies on Indian Apidae with special reference to Indian hive bee, *Apis cerana indica* F. Ph.D. thesis in Zoology University of Poona, Pune.

Lindauer, M. (1957). Communication among the honeybees and stingless bees of India. Bee World, 38: 521. https://doi.org/10.1080/0005772X.1957.11094964

Mattu, V.K. & Verma, L.R. (1983a). Comparative morphometric studies on introduced European bee *Apis mellifera* L. and Indian honeybee *Apis cerana indica* F. in Himachal Pradesh, Proc. 2nd Int. Conf. Apic. Trop. Clim., New Delhi, 262-277.

Michener, C.D. (2007). The bees of the world [2nd ed.]. Johns Hopkins University Press, Baltimore. xvi + [i] + 953pp., +20 pls.

Morimoto, H. (1968). The use of the labial palpus as a measure of proboscis length in worker honeybees, *Apis mellifera ligustica* and *Apis cerana cerana*. Journal of Apiculture Research, 7: 147-150. https://doi.org/10.1080/00218839.1968.11100205

Oldroyd, P.B., Reddy, M.S.R., Chapman, N.C., Thompson, G.J. & Beekman, M. (2006). Evidence for reproductive isolation between two colour morphs of cavity nesting honey bees (*Apis*) in south India. Insectes Sociaux, 53: 428-434. https://doi.org/10.1007/s00040-005-0889-2

Otis, G.W. & Hadisoesilo, S. (2001). Apis nigrocincta, a previously unrecognised honey bee species from Indonesia: lessons in speciation. In: 3rd Asian Apic. Assoc. Conf. Bee Research and Beekeeping Development In: Matsuka M., TamD.Q., Enomoto H., Dap N.T., Trung L.Q., Dau T.T., NiemN.V., Hang N.T. & Chinh P.H., (Eds). Bee Research and Development Centre, Ministry of Agriculture of Vietnam, Hanoi, Vietnam, pp 2 - 6.

Radloff, S.E., Hepburn, H.R., Hepburn, C., Fuchs, S., Otis, G.W., Sein, M.M., Aung, H.L., Pham, H.T., Tam, D.Q., Nuru, A.M. & Ken T. (2005). Multivariate morphometric analysis of *Apis cerana* of southern mainland Asia. Apidologie, 36: 127-139. https://doi.org/10.1051/apido:2004077

Ramchandra, T.V., Subashchandran, M.D., Joshi, N.V., & Balachandran, C. (2012). ENVIS technical. report: 49, Centre for ecological sciences. Indian Institute of Science, Bangalore, 65.

Rattanawannee, A., Chanchao, C. & Wongsiri, S. (2010). Gender and species identification of four native honey bees (Apidae: *Apis*) in Thailand based on wing morphometic analysis. Annals of the Entomological Society of America, 103: 965-970. https://doi.org/10.1603/AN10070

Ruttner, F. (1988). Biogeography and Taxonomy of Honeybees. Springer-Verlag. https://doi.org/10.1007/978-3-642-72649-1

Ruttner F. (1988). Biogeography and Taxonomy of Honeybees. Springer-Verlag Berlin. 284 pp. https://doi.org/10.1007/978-3-642-72649-1

Shanas, S., Anju, K.G. & Mashhoor, K. (2022). Identity of cavity nesting honey bees of the Indian subcontinent with description of a new species (Hymenoptera: Apidae: Apinae: Apini: *Apis*). Entomon, 47: 197-220. https://doi.org/10.33307/entomon.v47i3.755

Shaibi, T., Fuchs, S. & Moritz, R. F. (2009). Morphological study of Honeybees (*Apis mellifera*) from Libya. Apidologie, 40: 97-105. https://doi.org/10.1051/apido/2008068

Smith, D.R., Villafuerte, L., Otis, G. & Palmer, M.R. (2000). Biogeography of *Apis cerana* F. and *A. nigrocincta* Smith: insights from mtDNA studies. Apidologie, 31: 265-279. https://doi.org/10.1051/apido:2000121

Smith, D.R., Palmer, M.R., Otis G.W. & Damus M. (2003). Mitochondrial DNA and AFLP markers support species status of *Apis nigrocincta*. Insectes Sociaux, 50: 185-190. https://doi.org/10.1007/s00040-003-0645-9

Singh, M.P., Verma, L.R. & Daly, H.V. (1990). Morphometric analysis of the Indian honeybee in the northeast Himalayan region. Journal Apiculture Research, 29: 3-14. https://doi.org/10.1080/00218839.1990.11101191

Tilde, A. C., Fuchs, S., Koeniger, N. & Cervancia, C. R. (2000). Morphometric diversity of *Apis cerana* Fabr. within the Philippines. Apidologie, 31: 249-263. https://doi.org/10.1051/apido:2000120

Tanaka, H., Roubik, D.W., Kato, M., Liew, F. & Gunsalam, G. (2001). Phylogenetic position of Apis nuluensis of northern Borneo and phylogeography of *A. cerana* as inferred from mitochondrial DNA sequences. Insectes Sociaux, 48: 44-51 https://doi.org/10.1007/PL00001744

Tingek, S., Koeniger, G. & Koeniger, N. (1996). Description of a new cavity nesting species of *Apis* (*Apis nuluensis* n. sp.) from Sabah, Borneo, with notes on its occurrence and reproductive biology. Senckenbergiana Biologica, 76: 115-119.

Verma, L.R., Mattu, V.K. & Daly, H.V. (1994). Multivariate morphometrics of the Indian honeybee in the northwest Himalayan region. Apidologie, 25: 203-223. https://doi.org/10.1051/apido:19940208

Yadav, S., Kumar, Y. & Jat, B.L. (2017). Honey bee: Diversity, Castes and Life Cycle. In Industrial Entomology. Springer, Singapore (pp. 5-34). https://doi.org/10.1007/978-981-10-3304-9_2

Zhu, X., Zhou, S., Xu, X., Wang, J., Yu, Y., Yang, K.C., Luo, Q., Xu, Y., Wang, S. & Zhou, B. (2017). Morphological differentiation in Asian honey bee (*Apis cerana*) populations in the basin and highlands of southwestern China. Journal of Apicultural Research, 56: 1-7. https://doi.org/10.1080/00218839.2017.1306374