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MORPHOMETRY OF FEMALE AND ASSOCIATED MALE STINGLESS BEES OF THE GENUS *TETRAGONULA* (HYMENOPTERA: APIDAE: MELIPONINI) FROM INDIA

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ABSTRACT
As a first step to understand the extent of diversity of Indian stingless bees of the genus *Tetragonula*, morphometry of 346 female and 222 associated male stingless bees from 17 states and Andaman Islands was studied for the first time in India by selecting 36 morphological parameters for female and 30 for male bees. Female and male bees from Meghalaya were the biggest measuring 4.86 and 5.20 mm in length, respectively while female bees from Andhra Pradesh and male bees from Kerala were the smallest with body length of 3.39 and 3.43 mm, respectively. Female bees from Andaman Islands had the widest head measuring 1.88 mm while in males widest head was observed in the bees from Meghalaya. In both female and male bees longest forewings (4.74 and 4.70 mm, respectively) and hind basitarsus (0.74 and 0.63 mm, respectively) was recorded in the bees from Meghalaya. Results of Principal Component analysis resulted in 6 clusters while 8 clusters were formed in Canonical Discriminant analysis of female bees. However, male bees did not form any distinct cluster in Principal Component analysis but in Canonical Discriminant analysis 9 clusters were formed. Both males and female bees from Andaman Islands, Assam, Manipur, Meghalaya, Nagaland and Tripura formed separate individual clusters. Clustering pattern of bees from other states varied. We conclude that Indian fauna of stingless bees belonging to the genus *Tetragonula* is rich with many unknown species. Further critical studies are needed to identify the species based on male genitalial structures and DNA sequences.

INTRODUCTION

Stingless bees (Hymenoptera: Apidae: Meliponini) are receiving greater attention by the bee scientists throughout the world as they are one of the economically important as well as biologically intriguing groups of insects. They yield honey which is considered as having high medicinal value than the honey from *Apis* bees (Cortopassi-Laurino *et al*., 2006) and costs rupees 1000 per liter (Kumar *et al*., 2012). Recent survey in India by the first author (SV) revealed the price of honey ranging from rupees 1000 to 2000 in Karnataka, Kerala, Tamil Nadu and north-eastern region of India while in Gujarat a premium price of rupees 5000 to 10000 a liter. Stingless bees also play an important role in pollinating several species of plants including cultivated crops (Heard, 1999).

About 600 species belonging to 60 genera are described worldwide (Michener, 2000; Rasmussen and Cameron, 2010; Rasmussen *et al*.,2017) but many more species are yet to be discovered. They are distributed in tropical and subtropical regions of the world (Michener, 2000; Rasmussen, 2013). In India, though stingless bees are widely distributed, only 14 species are known so far that belong to three genera *viz*. *Tetragonula, Lepidotrigona* and *Lisotrigona* (Viraktamath and Shishira, 2020). The genus *Tetragonula* is the most common and widely distributed in India. Rasmussen (2013) predicts several species in India which need to be discovered by making intensive collections and careful studies of both male and female bees.

Morphometry is one of the important tools to identify and delineate species in Meliponini which includes several cryptic and complex species (Moure, 1961; Sakagami, 1978; Francoy *et al*., 2015; Halcroft *et al*., 2015). Studies on morphometry of Indian stingless bees are largely made with reference to female (worker) bees and mainly on state basis like Karnataka (Gajanan *et al*., 2005; Kuberappa et al, 2005; Danaraddi and Viraktamath, 2009; Ramya, 2014), Kerala (Devanesan *et al*., 2003 Sajan Jose, 2015; Divya, 2016), Tamil Nadu (Kishan Tej *et al*., 2017), Gujarat (Pallavi, 2011; Patel and Pastagia, 2016); north-east India (Akum *et al*., 2012; Rathor *et al*., 2013). Odisha (Patnaik and Prasad, 2007) and Punjab (Makkar *et al*., 2018). The first wing geometric morphometry studies in a larger scale involving female stingless bees from 150 locations of seven states of India was made by Francoy *et al*. (2015).

Rasmussen (2013) while summarizing information on the diversity of Indian stingless bees stressed that both female and male bees need to be collected and studied to understand the full diversity of Indian stingless bees. Since males are extremely important as they have more diagnostic characters than female bees (Sakagami, 1978; Rasmussen, 2013; Attasopa *et al*., 2018) and no systematic efforts have been made to study both female and male bees in India, we made intensive collections of female bees with associated males of all the three genera occurring in India (*Tetragonula, Lepidotrigona* and *Lisotrigona*) in 17 states and Andaman Islands of India. As a first step to understand the extent of diversity of stingless bees, we made a comprehensive study on morphometry of 346 female with associated 222 male bees of the genus

Tetragonula for the first time in India and the results of these studies are presented in this paper.

MATERIALS AND METHODS

We collected females and associated male bees in 39 places that belonged to 17 states and Andaman Islands (hence forth referred as 18 states) of India from 2017 to 2019 (Fig.1). In each state, 10 to 20 stingless bee colonies were examined which were either wild colonies or kept by the beekeepers in random places. From each colony 20 to 100 outgoing bees were collected in a specimen tube containing a cotton swab having a few drops of ethyl acetate. Bees were also collected by installing a water trap from a few colonies (2 to 5 colonies/ place) in these places (Viraktamath et al, 2020). Sample from each colony was transferred to a vial containing 95% ethyl alcohol and labeled indicating the place and date of collection. Each sample was later examined in the Systematic laboratory at the Department of Entomology, University of Agricultural Sciences, Bengaluru, under a stereoscopic binocular microscope. Bees of the genus *Tetragonula* were first sorted by using key characters enumerated by Rasmussen (2013). Males were identified based on the presence of genitalia, counted and recorded along with the females. Though we collected large samples of bees from different places we selected the samples having both male and female bees from the same colony for the morphometry studies. We used up to 10 female bees and 2 to 10 male bees from the same colony for our studies. Thus, there were 346 female and 222 male bees in our study.

Thirty-six morphological parameters for females and 30 for males (modified from Sakagami,1978 and Rasmussen, 2013) were selected for morphometry studies (Table 1). These parameters that included various body parts of head, thorax and abdomen were measured under a stereoscopic binocular microscope fitted with ocular micrometer. The number of hamuli on the right wing were counted. All the measurements were expressed in millimeter.

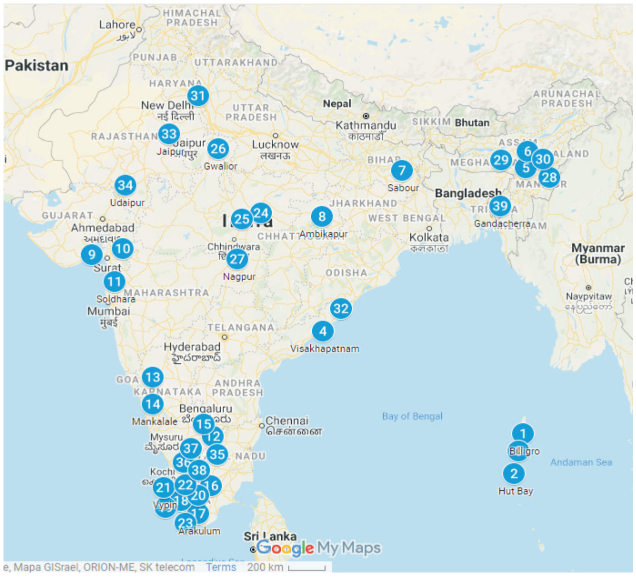
Mean and standard deviation were calculated for each parameter for male and female bee samples for each state separately. All the data were subjected to square root transformation before further analysis.

We adopted two methods of statistical analysis by using SPSS software (version 16) to identify discrete morphological groups of bees from these 18 states. The data were first subjected to factor analysis which included analysis of variation, principal component analysis (PCA) on a correlation matrix of all measured variables and a scatter plot by using regression factor score 1 and factor score 2. The second method of analysis was Canonical Discriminant analysis (CDA). A scatter plot was prepared by using the first two discriminate functions to study clustering of samples.

RESULTS AND DISCUSSION

Female bees

Variations in 36 morphological parameters in 17 states and Andaman Islands are presented in Table 2. Bees from Meghalaya were the biggest measuring 4.86 mm in length followed by bees from Andaman (4.35 mm), Manipur (4.23



1.Billigroround;2.Hut Bay;3.Jirkatang;4.Visakhapatnam;5.Dima Hasao;6.Karbi Anglong;7.Sabour;8.Ambikapur; 9.Navsari; 10.Dediapada; 11.Soldhara; 12.GKVK; 13.Dharwad; 14.Mankalale;15. Hessaraghatta; 16.Moolmattom; 17.Arakulum; 18.Aruvithura; 19.Vallamkulam;20.Murikassiry;21.Vypin;22.Kanjar; 23. Kadammanitta; 24.Jabalpur; 25.Karak Bel;26.Gwalior;27. Nagpur; 28.Thawai;29.Kyrdemkulai; 30. Medziphema; 31.New Delhi;32.Paralekhemundi; 33.Jaipur; 34.Udaipur; 35.Salem; 36.Nellithurai; 37.Mettupalayam; 38.Coimbatore;39.Gandacherra

Figure 1: Places of collection of stingless bees of the genus *Tetragonula*

mm) and Tripura (4.04 mm). Smallest bees (3.39 mm) were found in Andhra Pradesh. Bees from Andaman Islands had the widest head measuring 1.88 mm followed by bees from Meghalaya (1.83 mm). Head width was smaller in the bees from Maharashtra (1.48 mm) and New Delhi (1.49 mm). Longest forewings (4.74 mm in length) and hind basitarsus (0.74 mm) were recorded in the bees from Meghalaya but longest hind tibia was in the bees from Andaman Islands (1.77 mm) followed by bees from Meghalaya (1.74 mm).

Principal Component Analysis (PCA) of 346 female bees resulted in 5 components with Eigen values more than 1.00 which explained the variation among the female stingless bees to the extent of 78.13 per cent (Table 3). In the Principal Component 1, morphological parameters *viz*.SCL, HTL, HW, EL, FWL, MNL, HTW, FL, HL, FWD, HBTW, MCL, HBTL, BL, MSCL, MSCW, MNW, FWW, EW and UIOD had higher component loading that ranged from 0.613 to 0.931 (Table 4) and all these parameters together contributed for 46.01% variation (Table 3). Principal component 2 included 10 parameters which together influenced 19.91% variation. Both these components explained the variation to the extent of 65.92% cumulatively (Table 3). Scatter plot drawn by using regression factor score 1 and 2 (Fig 2) revealed the following six clusters.

Cluster 1: Bees from Andaman Islands

Cluster 2: Bees from Assam, Manipur and Meghalaya

Cluster 3: Bees from Nagaland and Tripura

Cluster 4: Bees from Bihar, Gujarat, Karnataka, Kerala, Tamil Nadu, Maharashtra

Cluster 5: Bees from Maharashtra and Karnataka

Table 1: Landmarks used for measuring various parameters in morphometry studies of stingless bees of the genus *Tetragonula*

SN	Abbre viation	Parameters	Land marks for measuring parameters
1	BL	Length of body	Anterior margin of face to posterior margin of metasoma measured from lateral longitudinal axis of the body
2	HW	Width of head including eyes	Outer margin of left compound eye to outer margin of right compound eye measured from dorsal side of head on transverse axis
3	HL	Length of head	Apical margin of clypeus to anterior margin of median ocellus measured from frontal side
4	EL	Length of eye	Distance between dorsal and ventral margin of eye measured on the mid-vertical axis of the eye
5	EW	Width of eye	Distance between two anterior and posterior margins on the mid-longitudinal axis of the eye
6	UIOD	Upper inter-ocular distance	Distance between inner margins of both compound eyes on the dorsal side
7	DMO	Diameter of median ocellus	Distance between outer margins of median ocellus on transverse axis
8	IOD	Inter-ocellar distance	Distance between inner margins of two dorsal ocelli on transverse axis
9	OOD	Ocello-ocular distance	Distance between outer margin of right dorsal ocellus and inner margin of right compound eye
10	CLL	Length of clypeus	Distance between apical and basal margin of clypeus
11	CLW	Maximum width of clypeus	Maximum distance between two lateral margins
12	MSL	Malar space length	Distance between ventral margin of left compound eye and basal margin of mandible
13	SCL	Length of scape	Distance between basal and apical margin of scape excluding basal bulb
14	SCW	Width of scape	Maximum distance between lateral margins
15	FL	Length of pedicel + flagellum	Basal margin of pedicel to apical margin of terminal segment of flagellum
16	FFL	Length of flagellomere 1	Maximum length between basal and apical margin measured from lateral longitudinal axis
17	SFL	Length of flagellomere 2	Maximum length between basal and apical margin measured from lateral longitudinal axis
18	TFL	Length of flagellomere 3	Maximum length between basal and apical margin measured from lateral longitudinal axis
19	TFW	Width of flagellomere 3	Maximum diameter
20	MNL	Length of mandible	Distance between basal to apical margin of mandibular tooth
21	MNW	Width of mandible	Maximum distance between two lateral margins near the basal margin
22	FWL	Length of forewing + tegula	Basal margin of tegula to outermost margin of forewing along its longitudinal axis
23	FWW	Width of forewing	Maximum width between costal and anal margin measured along its transverse axis
24	PTL	Length of pterostigma	Distance between basal margin to apical margin of pterostigma
25	MCL	Length of marginal cell	Distance between basal margin to apical margin along with longitudinal axis
26	MCW	Width of marginal cell	Maximum distance between anterior and posterior margin along with transverse axis
27	FWD	Wing diagonal	Distance between bifurcation of M-Cu bifurcation and basal tip of marginal cell
28	HAM	Number of hamuli	Number of hamuli on right hindwing
29	MSCL	Length of mesoscutum	Distance between anterior and posterior on mid-dorsal longitudinal axis
30	MSCW	Maximum width of mesoscutum	Maximum distance between two lateral margins along with transverse axis
31	SCTL	Length of scutellum	Maximum distance between basal and apical margins along mid-dorsal line
32	SCTW	Width of scutellum	Maximum distance between two lateral margins along transverse axis
33	HTL	Length of hind tibia	Maximum distance between basal and apical margins along with longitudinal axis
34	HTW	Width of hind tibia	Maximum distance between two lateral margins along with transverse axis
35	HBTL	Length of hind basitarsus	Maximum distance between basal and apical margins along with longitudinal axis
36	HBTW	Width of hind basitarsus	Maximum distance between lateral margins along with transverse axis

Cluster 6: Bees from Andhra Pradesh, Chhattisgarh, Madhya Pradesh, New Delhi and Rajasthan.

In CDA, eight functions were extracted with Eigen values more than 1.00 which explained the variation to the extent of 96.9% (Table 5). Forewing length (FWL) had the highest loading factor of 0.716 followed by scape width (SCW) with loading factor of 0.468 in the first function indicating their influence in variation of the bee samples (Table 6). Other parameters like HW, IOD, SCL,FFL, SFL, SCTL and HTL had next higher significant loading factors ranging from 0.304 to 0.424.

Results of CDA scatter plot drawn by using function 1 and 2 showed the following 8 clusters (Fig 3).

Cluster 1: Bees from Andaman Islands

Cluster 2: Bees from Meghalaya

Cluster 3: Bees from Assam

Cluster 4: Bees from Manipur

Cluster 5: Bees from Tripura

Cluster 6: Bees from Nagaland

Cluster 7. Bees from Bihar, Gujarat, Karnataka, Kerala, Maharashtra, Tamil Nadu, Odisha

Cluster 8: Bees from Andhra Pradesh, Chhattisgarh, Madhya Pradesh, New Delhi and Rajasthan

Classification and cross validation of results of CDA indicated that 97.4% grouped samples were correctly classified. In cross validation, 90.2% of grouped samples of bees were correctly classified (Table 7).

Male bees

As many as 222 male bee samples collected and associated with female bees were studied for morphological variations. Male bees from Meghalaya were the biggest with 5.20 mm in length and 1.83 mm in head width followed by bees from Andaman Islands with 4.59 mm in length and 1.69 mm in

Table 2: Morphometry of female stingless bees of the genus *Tetragonula* from 18 states of India

SN	Parameter/State	AN	AP	AS	BH	CG	GJ	KA	KL	MP	MH	MN	MG	NG	ND	OD	RJ	TN	TR
		Morphometry (Mean mm ± Standard deviation)																	
1	BL	4.35 ± 0.13	3.39 ± 0.18	3.99 ± 0.21	3.77 ± 0.08	3.65 ± 0.23	3.68 ± 0.06	3.80 ± 0.39	3.65 ± 0.2	3.70 ± 0.16	3.55 ± 0.21	4.23 ± 0.12	4.86 ± 0.21	3.99 ± 0.31	3.53 ± 0.1	3.76 ± 0.18	3.77 ± 0.18	3.58 ± 0.18	4.04 ± 0.14
2	HW	1.88 ± 0.03	1.51 ± 0.03	1.77 ± 0.12	1.53 ± 0.03	1.53 ± 0.07	1.62 ± 0.03	1.60 ± 0.06	1.57 ± 0.04	1.55 ± 0.03	1.48 ± 0.05	1.81 ± 0.02	1.83 ± 0.04	1.73 ± 0.06	1.49 ± 0.04	1.59 ± 0.03	1.50 ± 0.06	1.57 ± 0.03	1.70 ± 0.05
3	HL	1.39 ± 0.02	1.17 ± 0.02	1.30 ± 0.07	1.15 ± 0.04	1.18 ± 0.04	1.17 ± 0.03	1.18 ± 0.05	1.14 ± 0.03	1.19 ± 0.03	1.14 ± 0.06	1.30 ± 0.03	1.43 ± 0.03	1.24 ± 0.02	1.17 ± 0.03	1.16 ± 0.03	1.22 ± 0.07	1.15 ± 0.05	1.26 ± 0.03
4	EL	1.30 ± 0.03	1.05 ± 0.02	1.20 ± 0.08	1.07 ± 0.03	1.08 ± 0.02	1.06 ± 0.02	1.10 ± 0.03	1.08 ± 0.04	1.07 ± 0.02	1.01 ± 0.04	1.23 ± 0.03	1.25 ± 0.04	1.17 ± 0.02	1.08 ± 0.02	1.07 ± 0.04	1.06 ± 0.03	1.13 ± 0.06	1.13 ± 0.03
5	EW	0.51 ± 0.02	0.40 ± 0.07	0.45 ± 0.04	0.35 ± 0.01	0.41 ± 0.01	0.45 ± 0	0.42 ± 0.05	0.44 ± 0.02	0.41 ± 0.02	0.36 ± 0.02	0.47 ± 0.03	0.45 ± 0.01	0.46 ± 0.02	0.39 ± 0.03	0.42 ± 0.02	0.38 ± 0.03	0.42 ± 0.02	0.44 ± 0.02
6	UIOD	1.15 ± 0.02	1.04 ± 0.03	1.12 ± 0.04	1.00 ± 0.04	1.05 ± 0.04	1.02 ± 0.02	1.01 ± 0.04	1.01 ± 0.02	1.06 ± 0.02	0.97 ± 0.08	1.15 ± 0.02	1.08 ± 0.03	1.09 ± 0.02	1.08 ± 0.02	0.99 ± 0.03	1.08 ± 0.04	0.99 ± 0.04	1.12 ± 0.03
7	DMO	0.15 ± 0.01	0.17 ± 0.01	0.17 ± 0.02	0.15 ± 0	0.16 ± 0.02	0.15 ± 0	0.15 ± 0.01	0.14 ± 0.02	0.18 ± 0.01	0.15 ± 0	0.15 ± 0	0.21 ± 0.02	0.15 ± 0	0.18 ± 0.01	0.15 ± 0	0.16 ± 0.01	0.15 ± 0	0.15 ± 0
8	IOD	0.40 ± 0	0.41 ± 0.02	0.38 ± 0.02	0.37 ± 0.02	0.42 ± 0.01	0.39 ± 0.02	0.35 ± 0.03	0.35 ± 0.01	0.41 ± 0.02	0.37 ± 0.03	0.41 ± 0.02	0.37 ± 0.02	0.39 ± 0.02	0.41 ± 0.02	0.36 ± 0.02	0.44 ± 0.03	0.38 ± 0.03	0.40 ± 0
9	OOD	0.24 ± 0.02	0.24 ± 0.01	0.22 ± 0.02	0.19 ± 0.01	0.24 ± 0.02	0.20 ± 0.01	0.20 ± 0.01	0.20 ± 0.01	0.24 ± 0.01	0.18 ± 0.02	0.25 ± 0.02	0.21 ± 0.01	0.20 ± 0	0.24 ± 0.02	0.20 ± 0.01	0.26 ± 0.02	0.20 ± 0	0.22 ± 0.03
10	CLL	0.39 ± 0.02	0.33 ± 0.01	0.37 ± 0.05	0.30 ± 0	0.36 ± 0.04	0.31 ± 0.02	0.30 ± 0.03	0.30 ± 0	0.36 ± 0.04	0.33 ± 0.03	0.37 ± 0.02	0.40 ± 0.03	0.31 ± 0.02	0.35 ± 0.02	0.30 ± 0.01	0.36 ± 0.03	0.29 ± 0.01	0.31 ± 0.02
11	CLW	0.71 ± 0.06	0.73 ± 0.02	0.80 ± 0.07	0.70 ± 0	0.72 ± 0.03	0.62 ± 0.02	0.68 ± 0.05	0.66 ± 0.03	0.74 ± 0.03	0.67 ± 0.07	0.70 ± 0.03	0.82 ± 0.03	0.68 ± 0.03	0.74 ± 0.02	0.65 ± 0.03	0.72 ± 0.05	0.68 ± 0.03	0.68 ± 0.03
12	MSL	0.05 ± 0	0.05 ± 0	0.06 ± 0.02	0.05 ± 0.01	0.05 ± 0	0.05 ± 0	0.05 ± 0.01	0.04 ± 0.01	0.05 ± 0	0.05 ± 0	0.05 ± 0	0.04 ± 0.01	0.05 ± 0	0.06 ± 0.01	0.05 ± 0	0.05 ± 0.01	0.05 ± 0	0.05 ± 0
13	SCL	0.76 ± 0.03	0.55 ± 0.01	0.68 ± 0.05	0.56 ± 0.02	0.53 ± 0.02	0.63 ± 0.01	0.60 ± 0.05	0.61 ± 0.03	0.54 ± 0.02	0.54 ± 0.04	0.72 ± 0.02	0.72 ± 0.02	0.69 ± 0.02	0.54 ± 0.01	0.61 ± 0.02	0.55 ± 0.04	0.55 ± 0	0.68 ± 0.02
14	SCW	0.10 ± 0	0.13 ± 0.01	0.10 ± 0.02	0.10 ± 0	0.12 ± 0.01	0.10 ± 0	0.10 ± 0.01	0.10 ± 0.03	0.13 ± 0.01	0.10 ± 0	0.11 ± 0.01	0.10 ± 0	0.10 ± 0	0.13 ± 0	0.08 ± 0.02	0.13 ± 0.01	0.10 ± 0	0.10 ± 0
15	FL	1.50 ± 0.03	1.15 ± 0.08	1.47 ± 0.09	1.24 ± 0.02	1.14 ± 0.03	1.15 ± 0.03	1.24 ± 0.09	1.17 ± 0.03	1.19 ± 0.03	1.15 ± 0.08	1.38 ± 0.02	1.56 ± 0.05	1.23 ± 0.02	1.19 ± 0.02	1.15 ± 0.04	1.21 ± 0.05	1.35 ± 0.05	1.26 ± 0.03
16	FFL	0.10 ± 0	0.10 ± 0.01	0.08 ± 0.01	0.07 ± 0	0.10 ± 0	0.07 ± 0	0.08 ± 0.01	0.07 ± 0	0.10 ± 0.01	0.07 ± 0.01	0.07 ± 0	0.09 ± 0.01	0.07 ± 0	0.10 ± 0	0.07 ± 0	0.10 ± 0.01	0.08 ± 0	0.07 ± 0
17	SFL	0.15 ± 0	0.13 ± 0	0.13 ± 0.01	0.10 ± 0	0.13 ± 0	0.10 ± 0.01	0.10 ± 0	0.10 ± 0	0.13 ± 0	0.10 ± 0	0.12 ± 0.01	0.14 ± 0	0.12 ± 0	0.13 ± 0	0.10 ± 0	0.13 ± 0.01	0.10 ± 0	0.12 ± 0.01
18	TFL	0.15 ± 0	0.13 ± 0	0.13 ± 0.02	0.10 ± 0	0.13 ± 0	0.10 ± 0.01	0.10 ± 0.01	0.10 ± 0.01	0.13 ± 0	0.10 ± 0	0.12 ± 0.02	0.14 ± 0	0.12 ± 0	0.13 ± 0	0.10 ± 0	0.13 ± 0.01	0.10 ± 0	0.12 ± 0.01
19	TFW	0.15 ± 0	0.15 ± 0	0.14 ± 0.01	0.13 ± 0	0.15 ± 0.01	0.12 ± 0	0.13 ± 0.01	0.12 ± 0	0.15 ± 0	0.12 ± 0	0.14 ± 0.02	0.14 ± 0	0.12 ± 0	0.15 ± 0	0.12 ± 0	0.15 ± 0	0.13 ± 0	0.14 ± 0.02
20	MNL	0.77 ± 0.03	0.59 ± 0.03	0.73 ± 0.08	0,54 ± 0,04	0.59 ± 0,02	0.63 ± 0.03	0.59 ± 0.06	0.63 ± 0.03	0.59 ± 0.01	0.58 ± 0.04	0.71 ± 0.03	0.79 ± 0.01	0.65 ± 0.02	0.59 ± 0.02	0.62 ± 0.02	0.60 ± 0.03	0.55 ± 0	0.67 ± 0.02

Table 2: Continue...

SN	Parameter/State	AN	AP	AS	BH	CG	GJ	KA	KL	MP	MH	MN	MG	NG	ND	OD	RJ	TN	TR
		Morphometry (Mean mm ± Standard deviation)																	
21	MNW	0.30 ± 0.03	0.25 ± 0.01	0.30 ± 0.03	0.24 ± 0.01	0.23 ± 0.01	0.25 ± 0	0.25 ± 0.04	0.24 ± 0.02	0.23 ± 0.01	0.27 ± 0.03	0.30 ± 0	0.30 ± 0.01	0.25 ± 0	0.25 ± 0.01	0.26 ± 0.02	0.25 ± 0.02	0.23 ± 0	0.26 ± 0.02
22	FWL	4.34 ± 0.08	3.44 ± 0.08	4.44 ± 0.54	3.62 ± 0.16	3.62 ± 0.1	3.64 ± 0.11	3.82 ± 0.18	3.74 ± 0.19	3.44 ± 0.06	3.60 ± 0.17	4.38 ± 0.05	4.74 ± 0.1	4.09 ± 0.11	3.47 ± 0.11	3.75 ± 0.1	3.56 ± 0.17	3.62 ± 0.13	4.15 ± 0.05
23	FWW	1.47 ± 0.05	1.28 ± 0.04	1.56 ± 0.14	1.37 ± 0.03	1.36 ± 0.05	1.23 ± 0.06	1.32 ± 0.07	1.24 ± 0.05	1.31 ± 0.03	1.33 ± 0.09	1.47 ± 0.04	1.57 ± 0.07	1.42 ± 0.04	1.32 ± 0.08	1.25 ± 0.05	1.30 ± 0.07	1.20 ± 0	1.34 ± 0.02
24	PTL	0.60 ± 0.01	0.60 ± 0.01	0.68 ± 0.08	0.55 ± 0.01	0.59 ± 0.03	0.52 ± 0.03	0.56 ± 0.03	0.55 ± 0.01	0.55 ± 0.01	0.54 ± 0.02	0.66 ± 0.02	0.68 ± 0.03	0.60 ± 0	0.60 ± 0.01	0.55 ± 0.03	0.52 ± 0.04	0.57 ± 0.03	0.59 ± 0.02
25	MCL	1.42 ± 0.03	1.21 ± 0.02	1.48 ± 0.21	1.17 ± 0.06	1.25 ± 0.04	1.18 ± 0.05	1.25 ± 0.06	1.23 ± 0.05	1.22 ± 0.03	1.17 ± 0.06	1.39 ± 0.03	1.50 ± 0.03	1.28 ± 0.05	1.24 ± 0.04	1.20 ± 0.07	1.23 ± 0.06	1.25 ± 0.05	1.31 ± 0.07
26	MCW	0.38 ± 0.02	0.35 ± 0.01	0.36 ± 0.04	0.29 ± 0.03	0.36 ± 0.02	0.30 ± 0	0.32 ± 0.03	0.30 ± 0.01	0.35 ± 0	0.29 ± 0.05	0.37 ± 0.02	0.39 ± 0.01	0.35 ± 0	0.36 ± 0.02	0.30 ± 0.02	0.32 ± 0.03	0.30 ± 0	0.36 ± 0.02
27	FWD	1.26 ± 0.03	1.02 ± 0.03	1.20 ± 0.13	0.95 ± 0.04	1.05 ± 0.04	0.94 ± 0.03	1.02 ± 0.06	0.98 ± 0.03	1.01 ± 0.03	0.93 ± 0.08	1.15 ± 0.03	1.33 ± 0.04	1.06 ± 0.03	1.05 ± 0.02	0.97 ± 0.03	1.02 ± 0.05	1.10 ± 0.1	1.16 ± 0.02
28	HAM	5.00 ± 0	5.00 ± 0	5.69 ± 0.63	5.00 ± 0	5.00 ± 0	5.00 ± 0	5.06 ± 0.25	5.00 ± 0	5.02 ± 0.15	5.00 ± 0	5.40 ± 0.52	6.00 ± 0	5.00 ± 0	5.00 ± 0	5.00 ± 0	5.24 ± 0.43	5.33 ± 0.58	5.00 ± 0
29	MSCL	1.04 ± 0.05	0.91 ± 0.04	1.12 ± 0.06	0.97 ± 0.1	0.91 ± 0.04	0.96 ± 0.04	0.98 ± 0.05	0.91 ± 0.03	0.92 ± 0.04	0.95 ± 0.1	1.08 ± 0.03	1.18 ± 0.04	1.00 ± 0.05	0.89 ± 0.03	0.92 ± 0.04	0.92 ± 0.06	1.00 ± 0	0.98 ± 0.03
30	MSCW	1.18 ± 0.03	1.01 ± 0.02	1.22 ± 0.03	1.09 ± 0.05	1.07 ± 0.04	1.04 ± 0.03	1.06 ± 0.05	1.01 ± 0.02	1.08 ± 0.03	1.05 ± 0.06	1.22 ± 0.03	1.24 ± 0.03	1.13 ± 0.03	1.06 ± 0.02	1.01 ± 0.04	1.09 ± 0.05	1.08 ± 0.03	1.10 ± 0.03
31	SCTL	0.39 ± 0.03	0.34 ± 0.02	0.35 ± 0.09	0.26 ± 0.01	0.35 ± 0.02	0.33 0.03	0.28 ± 0.03	0.30 ± 0.01	0.34 ± 0.02	0.25 ± 0	0.38 ± 0.02	0.35 ± 0	0.34 ± 0.02	0.35 ± 0.02	0.30 ± 0.02	0.33 ± 0.02	0.26 ± 0.02	0.35 ± 0
32	SCTW	0.84 ± 0.05	0.77 ± 0.02	0.98 ± 0.03	0.83 ± 0.03	0.83 ± 0.07	0.60 ± 0.03	0.74 ± 0.13	0.66 ± 0.07	0.81 ± 0.04	0.86 ± 0.04	0.76 ± 0.05	1.03 ± 0.05	0.61 ± 0.02	0.79 ± 0.02	0.66 ± 0.04	0.84 ± 0.05	0.95 ± 0	0.70 ± 0.06
33	HTL	1.77 ± 0.04	1.35 ± 0.06	1.74 ± 0.16	1.40 ± 0.04	1.32 ± 0.05	1.45 ± 0.06	1.44 ± 0.05	1,48 ± 0.06	1.33 ± 0.04	1.33 ± 0.08	1.69 ± 0.04	1.74 ± 0.02	1.54 ± 0.05	1.39 ± 0.03	1.49 ± 0.04	1.34 ± 0.06	1.43 ± 0.03	1.59 ± 0.04
34	HTW	0.63 ± 0.02	0.50 ± 0	0.62 ± 0.04	0.51 ± 0.03	0.53 ± 0.02	0.53 ± 0.02	0.53 ± 0.03	0.53 ± 0.03	0.52 ± 0.02	0.49 ± 0.04	0.63 ± 0.03	0.60 ± 0.03	0.58 ± 0.02	0.53 ± 0.01	0.53 ± 0.02	0.52 ± 0.03	0.48 ± 0.03	0.59 ± 0.02
35	HBTL	0.68 ± 0.03	0.53 ± 0.02	0.60 ± 0.12	0.47 ± 0.03	0.48 ± 0.03	0.48 ± 0.04	0.50 ± 0.06	0.50 ± 0.02	0.50 ± 0.04	0.51 ± 0.04	0.63 ± 0.03	0.74 ± 0.04	0.54 ± 0.02	0.52 ± 0.02	0.52 ± 0.03	0.52 ± 0.03	0.52 ± 0.03	0.54 ± 0.02
36	HBTW	0.35 ± 0.01	0.28 ± 0.01	0.35 ± 0.05	0.26 ± 0.01	0.29 ± 0.01	0.28 ± 0.02	0.28 ± 0.02	0.30 ± 0.01	0.29 ± 0.01	0.26 ± 0.01	0.35 ± 0	0.38 ± 0.02	0.31 ± 0.02	0.29 ± 0.01	0.29 ± 0.02	0.29 ± 0.01	0.26 ± 0.02	0.32 ± 0.03

AN. Andaman and Nicobar Islands; AP. Andhra Pradesh; AS. Assam; BH. Bihar; CG. Chhattisgarh; GJ. Gujarat; KA. Karnataka; KL. Kerala; MP. Madhya Pradesh; MH. Maharashtra; MN. Manipur. MG. Meghalaya; NG. Nagaland; ND. New Delhi; OD. Odisha; RJ. Rajasthan; TN. Tamil Nadu; TR. Tripura

Table 3: Eigen values and percentage of variance in different Principal Components in the analysis of female stingless bees of the genus *Tetragonula* from 18 states of India

Comp onent	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Var iance	Cumu lative %	Total	% of Var iance	Cumu lative %	Total	% of Var iance	Cumu lative %
1	16.564	46.012	46.012	16.564	46.012	46.012	14.775	41.042	41.042
2	7.169	19.915	65.926	7.169	19.915	65.926	7.502	20.838	61.88
3	1.899	5.276	71.202	1.899	5.276	71.202	2.502	6.951	68.831
4	1.442	4.006	75.208	1.442	4.006	75.208	2.069	5.746	74.577
5	1.052	2.923	78.131	1.052	2.923	78.131	1.279	3.554	78.131
6	0.85	2.36	80.49						
7	0.673	1.87	82.361						
8	0.566	1.572	83.932						
9	0.536	1.49	85.422						
10	0.478	1.328	86.75						
11	0.464	1.289	88.039						
12	0.385	1.07	89.109						
13	0.372	1.034	90.143						
14	0.322	0.896	91.039						
15	0.291	0.81	91.848						
16	0.275	0.765	92.613						
17	0.257	0.713	93.326						
18	0.237	0.658	93.984						
19	0.209	0.58	94.564						
20	0.193	0.537	95.101						
21	0.181	0.502	95.604						
22	0.179	0.496	96.1						
23	0.157	0.436	96.536						
24	0.142	0.394	96.93						
25	0.139	0.387	97.316						
26	0.132	0.367	97.683						
27	0.118	0.328	98.011						
28	0.113	0.314	98.325						
29	0.106	0.295	98.62						
30	0.1	0.277	98.897						
31	0.092	0.255	99.152						
32	0.088	0.245	99.397						
33	0.07	0.195	99.592						
34	0.067	0.185	99.777						
35	0.047	0.132	99.909						
36	0.033	0.091	100						

Extraction Method: Principal Component Analysis.

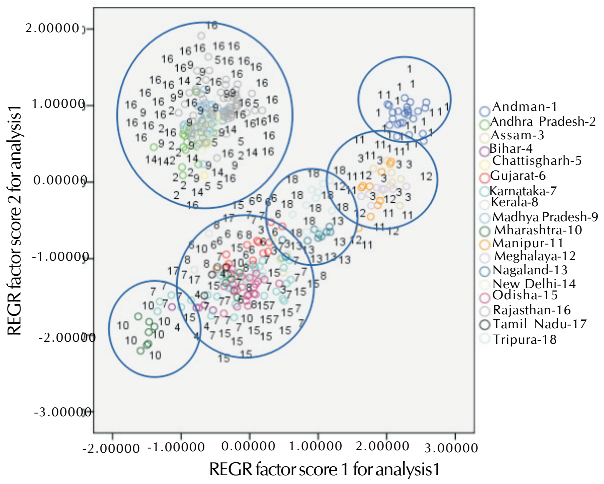


Figure 2: Factor analysis scatter plot showing clusters of female stingless bees of the genus *Tetragonula* from 18 states of India

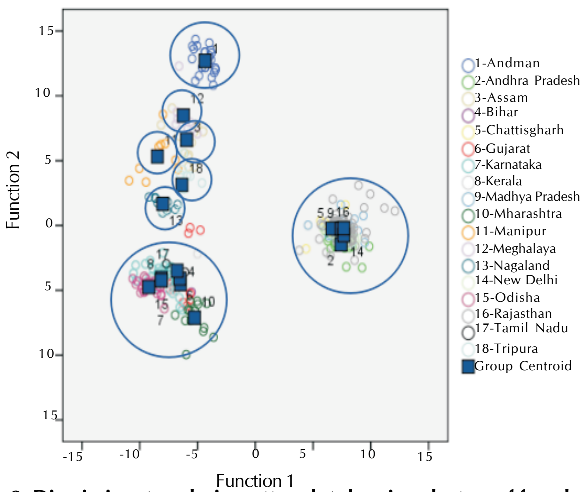


Figure 3: Discriminant analysis scatter plot showing clusters of female stingless bees of the genus *Tetragonula* from 18 states of India

head width (Table 8). Males from Kerala were the smallest with 3.43 mm in length and 1.43 mm in head width. Males from Meghalaya had the longest wings, hind tibia and hind basitarsus measuring 4.70, 1.60 and 0.63 mm, respectively.

Table 4: Rotated component matrix in Principal Component analysis of female stingless bees of the genus *Tetragonula* from 18 states of India

Parameter	Component				
	1	2	3	4	5
SCL	0.931				
HTL	0.926				
HW	0.925				
EL	0.924				
FWL	0.911				
MNL	0.897				
HTW	0.883				
FL	0.834		0.328		
HL	0.831	0.317			
FWD	0.815			0.306	
HBTW	0.803				
MCL	0.796			0.339	
HBTL	0.787				
BL	0.785				
MSCL	0.747		0.436		
MSCW	0.719		0.436		
MNW	0.7				
FWW	0.694			0.434	
EW	0.693		-0.307		
UIOD	0.613	0.594			
SFL	0.316	0.868			
TFW		0.868			
FFL		0.867			
TFL	0.334	0.854			
OOD		0.85			
IOD		0.787			
SCW	-0.357	0.734			
CLL	0.328	0.66			
SCTL	0.496	0.626			
SCTW		0.423	0.754		
HAM	0.304		0.643		
CLW		0.484	0.525	0.435	
PTL	0.566			0.716	
DMO		0.507		0.547	
MCW	0.52	0.453		0.532	
MSL					0.889

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 6 iterations.

Similarly, bees from north east India and Andaman Islands had next longer forewings (3.85 to 4.24 mm). Bees from the remaining states had shorter forewings that measured 3.43 to 3.74 mm.

Principal component analysis extracted five functions with Eigen value of more than 1.00 (Table 9). The first component with highest Eigen value of 14.185 explained the variation to the extent of 47.28% while the first five components together contributed for 67.89% variation. In the Principal Component 1, morphological parameters like forewing diagonal length (FWD) and hind tibial length (HTL) had significantly higher component loading factors of 0.741 and 0.717, respectively (Table 10). Other parameters like FL, MCW, HL, HW, PTL, OOD, FWW, HTW, FWL, TFW, HBTW, UIOD and MCL had next higher loading factors that ranged from 0.546 to 0.696. Principal component 2 included 7 morphological parameters while Principal component 3, 4 and 5 had 4, 3 and 1 parameters, respectively.

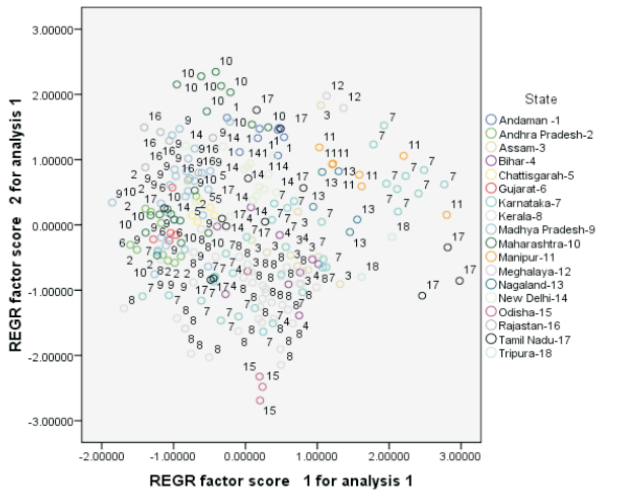


Figure 4: Factor analysis scatter plot showing clusters of male stingless bees of the genus *Tetragonula* from 18 states of India

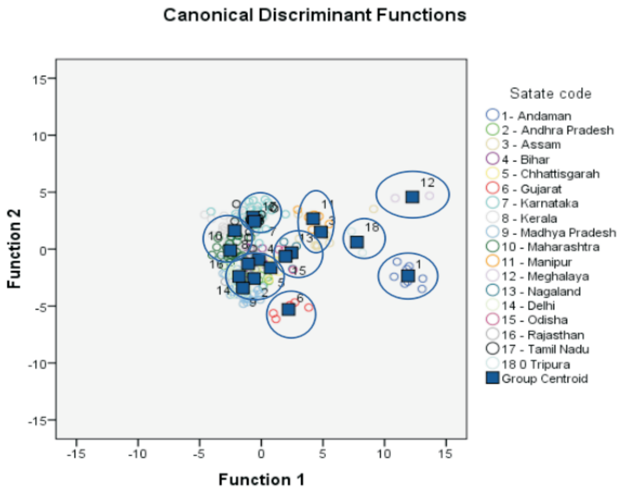


Figure 5: Discriminant analysis scatter plot showing clusters of male stingless bees of the genus *Tetragonula* from 18 states of India

Table 5: Eigen values and Canonical correlations of different functions in Discriminant analysis of female stingless bees of the genus *Tetragonula* from 18 states of India

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
1	56.833a	56.9	56.9	0.991
2	23.918a	24	80.9	0.98
3	6.366a	6.4	87.3	0.93
4	2.742a	2.7	90	0.856
5	2.653a	2.7	92.7	0.852
6	1.638a	1.6	94.3	0.788
7	1.324a	1.3	95.6	0.755
8	1.230a	1.2	96.9	0.743
9	.857a	0.9	97.7	0.679
10	.572a	0.6	98.3	0.603
11	.502a	0.5	98.8	0.578
12	.333a	0.3	99.1	0.5
13	.283a	0.3	99.4	0.47
14	.255a	0.3	99.7	0.45
15	.172a	0.2	99.8	0.383
16	.103a	0.1	99.9	0.305
17	.052a	0.1	100	0.222

a. First 17 canonical discriminant functions were used in the analysis.

Table 6: Standardized Canonical Discriminant function coefficients in the analysis of female stingless bees of the genus *Tetragonula* from 18 states

Para meter	Function 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
BL	-0.011	0.043	0.037	-0.373	-0.264	0.494	-0.169	0.266	-0.41	-0.124	0.006	-0.139	0.13	-0.001	0.038	-0.189	-0.373
HW	-0.359	0.183	-0.174	0.087	0.116	0.136	-0.174	-0.291	0.522	-0.015	-0.398	0.281	0.227	-0.381	-0.004	-0.049	0.422
HL	0.048	-0.019	-0.297	-0.202	-0.09	-0.279	-0.406	-0.172	-0.185	0.162	-0.162	0.071	-0.215	-0.398	-0.03	0.473	0.057
EL	-0.135	0.22	-0.033	-0.106	-0.254	0.046	0.458	-0.594	-0.26	-0.044	0.41	0.085	0.177	0.238	0.218	-0.149	-0.163
EW	-0.135	0.093	-0.015	-0.012	-0.122	0.087	-0.1	0.033	0.159	-0.17	-0.082	-0.211	0.33	0.416	0.015	0.062	0.298
UIOD	0.042	-0.076	-0.385	0.337	0.329	-0.057	0.005	0.122	-0.333	-0.235	0.17	-0.305	-0.317	0.164	-0.574	-0.067	0.272
DMO	0.258	-0.109	0.236	0.132	-0.461	0.333	-0.297	0.322	-0.061	-0.15	0.282	0.392	-0.205	-0.001	-0.122	0.127	0.033
IOD	0.411	-0.101	-0.219	-0.012	0.431	0.098	0.057	-0.098	0.108	0.275	-0.341	0.445	0.027	0.223	0.389	0.028	-0.107
OOD	0.097	0.08	-0.198	-0.121	-0.009	0.133	0.399	0.329	-0.099	0.133	0.127	0.031	0.414	-0.214	0.22	-0.064	0.111
CLL	0.112	-0.005	0.155	-0.154	0.26	-0.073	-0.253	-0.255	-0.068	-0.162	0.33	0.075	0.129	0.255	-0.352	0.165	0.023
CLW	0.114	-0.364	0.325	0.214	-0.175	0.079	0.021	0.221	0.066	-0.397	-0.056	-0.205	-0.006	-0.242	0.278	-0.397	0.268
MSL	0.032	0.033	0.12	0.109	0.267	-0.26	0.207	0.031	0.16	-0.281	-0.022	0.331	-0.085	0.05	0.111	0.031	0.417
SCL	-0.304	0.274	-0.272	0.061	0.033	-0.038	-0.188	-0.098	0.092	0.152	0.029	-0.062	-0.011	-0.067	-0.098	-0.526	-0.154
SCW	0.468	-0.095	0.15	0.069	0.206	0.173	0.155	-0.153	0.377	0.287	0.003	-0.319	-0.147	0.029	-0.253	-0.078	-0.204
FL	-0.111	0.324	0.186	-0.295	-0.147	0.128	0.479	-0.109	0.402	-0.035	0.449	0.319	-0.261	-0.087	-0.105	-0.175	0.103
FFL	0.431	-0.105	-0.387	-0.315	-0.436	0.017	-0.007	-0.314	0.309	0.097	0.129	-0.232	0.021	0.041	0.293	0.345	-0.178
SFL	0.364	0.762	0.101	0.21	0.161	-0.074	-0.495	0.019	-0.078	0.007	-0.14	0.071	-0.095	0.09	0.166	-0.295	0.033
TFL	0.178	0.088	-0.113	-0.027	-0.097	-0.024	0.325	-0.178	-0.062	-0.077	-0.077	-0.155	-0.286	-0.158	-0.066	0.108	0.177
TFW	0.284	0.387	0.19	0.082	0.051	-0.22	-0.03	0.191	-0.011	0.113	-0.179	-0.004	0.278	-0.456	-0.167	0.107	-0.298
MNL	0.121	0.122	0.141	-0.185	0.03	-0.279	-0.56	0.348	0.559	-0.344	0.025	-0.34	0.178	0.51	-0.113	-0.021	-0.306
MNW	0.013	-0.204	0.207	0.148	0.199	-0.611	0.008	-0.071	-0.179	0.264	0.176	-0.125	0.095	-0.363	-0.146	0.475	0.215
FWL	-0.716	0.192	-0.029	-0.029	0.495	0.199	-0.072	0.015	-0.582	0.051	-0.54	-0.155	0.278	-0.188	0.198	0.28	-0.085
FWW	0.245	-0.051	0.327	-0.157	0.328	0.054	-0.328	-0.502	0.1	-0.038	0.217	-0.226	-0.261	-0.025	0.404	0.003	-0.206
PTL	-0.127	0.123	0.239	0.766	0.001	-0.057	-0.075	-0.217	-0.127	0.329	0.073	-0.126	0.377	0.146	0.274	-0.014	-0.262
MCL	0.23	-0.085	0.116	-0.219	0.173	0.066	0.179	-0.02	0.394	-0.133	-0.183	-0.229	-0.118	0.199	0.221	0.215	0.402
MCW	0.121	-0.108	0.06	0.265	-0.381	0.276	-0.038	-0.11	-0.322	-0.016	-0.069	0.117	0.14	-0.106	-0.287	0.143	0.304
FWD	0.1	0.003	-0.208	-0.185	-0.665	-0.088	0.684	0.48	-0.183	0.195	-0.527	0.136	-0.266	0.474	-0.318	0.188	-0.033
HAM	0.013	-0.264	0.419	-0.121	0.051	0.315	0.221	0.355	0.162	0.261	0.221	0.138	-0.03	0.025	0.105	0.022	0.24
MSCL	-0.268	-0.132	0.082	0.139	-0.07	0.03	-0.207	-0.082	0.456	0.588	-0.497	0.287	0.043	-0.231	-0.132	-0.069	-0.15
MSCW	-0.086	0.289	0.106	-0.02	0.226	0.725	0.019	-0.116	-0.062	0.041	0.472	-0.176	0.025	0.278	-0.087	0.29	-0.049
SCTL	0.356	-0.201	-0.399	0.219	0.15	-0.075	0.105	0.2	0.129	-0.234	0.155	0.428	0.265	0.018	0.005	-0.131	-0.303
SCTW	0.02	0.035	0.669	-0.111	0.162	-0.485	0.018	-0.048	-0.127	-0.456	-0.353	0.123	0.394	0.133	-0.072	-0.296	-0.087
HTL	-0.425	0.265	0.138	0.365	-0.207	-0.36	0.23	0.405	0.153	-0.17	0.168	0.142	-0.392	-0.145	0.176	0.155	-0.423
HTW	-0.014	-0.063	-0.082	0.05	0.168	0.083	0.131	0.064	-0.104	-0.398	0.059	0.064	-0.044	-0.236	0.078	0.282	-0.095
HBTL	-0.073	-0.187	-0.273	-0.111	0.018	-0.322	-0.25	0.091	-0.445	0.655	0.417	0.085	0	0.095	-0.059	-0.388	0.397
HBTW	0.033	0.058	0.258	-0.219	0.078	0.203	0.037	0.457	0.155	0.115	-0.014	-0.377	0.071	-0.082	-0.057	-0.108	0.183

Parameters with bold letters have significant loading factors in the first function

Table 7: Classification and cross validation of results in Discriminant analysis of female stingless bees of the genus *Tetragonula* from 18 states of India

		State code	Predicted Group Membership																		Total
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Original	Count	1	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24
		2	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20
		3	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
		4	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
		5	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	10
		6	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	15
		7	0	0	0	0	0	0	28	3	0	0	0	0	0	0	0	0	0	0	31
		8	0	0	0	0	0	0	1	11	0	0	0	0	0	0	1	0	0	0	13
		9	0	0	0	0	1	0	0	0	41	0	0	0	0	0	0	0	0	0	42
		10	0	0	0	0	0	0	0	0	0	14	0	0	0	0	0	0	0	0	14
		11	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	10
		12	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	8
		13	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	10
		14	0	0	0	0	0	0	0	0	0	0	0	0	0	25	0	0	0	0	25
		15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	0	0	0	23
		16	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	67	0	0	70
		17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3
		18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	10
		Ungrouped cases	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	%	1	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
		2	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
		3	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
		4	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
		5	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	100
		6	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	100
		7	0	0	0	0	0	0	90.3	9.7	0	0	0	0	0	0	0	0	0	0	100
		8	0	0	0	0	0	0	7.7	84.6	0	0	0	0	0	0	7.7	0	0	0	100
		9	0	0	0	0	2.4	0	0	0	97.6	0	0	0	0	0	0	0	0	0	100
		10	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	100
		11	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	100
		12	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	100
		13	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100
		14	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	100
		15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	100
		16	0	0	0	0	0	0	0	0	4.3	0	0	0	0	0	0	95.7	0	0	100
		17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	100
		18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	100
		Ungrouped cases	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	100

Grouping of states on a scatter plot using regression factor score 1 and 2 did not result in male bee samples grouping into distinct clusters as observed in female bees indicating wide range of variation among male bees that may perhaps belong to many sibling species (Fig 4). However, a few samples of bees from Assam, Meghalaya, Tripura, Manipur, Karnataka, Tamil Nadu, Rajasthan and Maharashtra appeared to be distinct from the rest of the bee populations.

CDA extracted 9 functions with more than 1.00 Eigen value explaining the variation to the extent of 91.20% (Table 11). In the first function, among 13 morphological parameters that influenced the variation significantly, hind tibial width (HTW), scape width (SCW), hind tibial length (HTL), hind basitarsus length (HBTL) and forewing width FWD) had higher loading factor ranging from 0.508 to 0.595) (Table 12).

The scatter plot drawn based on function 1 and 2 resulted in formation of the following 9 clusters (Fig. 5)

Cluster 1: Bees from Andaman Islands

Cluster 2: Bees from Meghalaya

Cluster 3: Bees from Tripura

Cluster 4: Bees from Assam, Manipur

Cluster 5: Bees from Nagaland

Cluster 6: Bees from Gujarat

Cluster 7: Bees from Andhra Pradesh, Bihar, Chhattisgarh, Madhya Pradesh, New Delhi, Odisha

Cluster 8: Bees from Maharashtra, Rajasthan

Cluster 9: Bees from Karnataka, Kerala, Tamil Nadu

Original grouped cases were correctly classified to the extent of 98.20% while 85.60% of cross validated grouped cases were correctly classified (Table 13).

Relation between important morphological traits like HW/FWD, HW/HTL, FWD/HTL and HTL/HTW as used by Sakagami

Table 7: Continued....

	State Code	Predicted group membership 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Total
Cross -validateda Count	1	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24
	2	0	19	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	20
	3	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
	4	0	0	0	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0	5
	5	0	0	0	0	9	0	0	0	1	0	0	0	0	0	0	0	0	0	10
	6	0	0	0	0	0	13	0	1	0	0	0	0	0	0	1	0	0	0	15
	7	0	0	0	2	0	0	24	4	0	0	0	0	0	0	1	0	0	0	31
	8	0	0	0	0	0	0	3	8	0	0	0	0	0	0	2	0	0	0	13
	9	0	0	0	0	1	0	0	0	40	0	0	0	0	1	0	0	0	0	42
	10	0	0	0	0	0	0	0	0	0	14	0	0	0	0	0	0	0	0	14
	11	0	0	0	0	0	0	0	0	0	0	9	0	1	0	0	0	0	0	10
	12	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	8
	13	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	10
	14	0	1	0	0	0	0	0	0	0	0	0	0	0	24	0	0	0	0	25
	15	0	0	0	0	0	2	0	3	0	0	0	0	0	0	18	0	0	0	23
	16	0	2	0	0	0	0	0	0	4	0	0	0	0	0	0	64	0	0	70
	17	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	3
	18	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	9	10
%	1	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
	2	0	95	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	100
	3	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
	4	0	0	0	80	0	0	20	0	0	0	0	0	0	0	0	0	0	0	100
	5	0	0	0	0	90	0	0	0	10	0	0	0	0	0	0	0	0	0	100
	6	0	0	0	0	0	86.7	0	6.7	0	0	0	0	0	0	6.7	0	0	0	100
	7	0	0	0	6.5	0	0	77.4	12.9	0	0	0	0	0	0	3.2	0	0	0	100
	8	0	0	0	0	0	0	23.1	61.5	0	0	0	0	0	0	15.4	0	0	0	100
	9	0	0	0	0	2.4	0	0	0	95.2	0	0	0	0	2.4	0	0	0	0	100
	10	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	100
	11	0	0	0	0	0	0	0	0	0	0	90	0	10	0	0	0	0	0	100
	12	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	100
	13	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100
	14	0	4	0	0	0	0	0	0	0	0	0	0	0	96	0	0	0	0	100
	15	0	0	0	0	0	8.7	0	13	0	0	0	0	0	0	78.3	0	0	0	100
	16	0	2.9	0	0	0	0	0	0	5.7	0	0	0	0	0	0	91.4	0	0	100
	17	0	0	0	0	0	0	33.3	0	0	0	0	0	0	0	0	0	66.7	0	100
	18	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	90	100

a. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.
b. 97.4% of original grouped cases correctly classified. c. 90.2% of cross-validated grouped cases correctly classified.

(1978) is presented in the Fig 6 for both female (A,B, C, D) and male bees (E, F, G, H). Interestingly there was a linear relationship and the values of these parameters increased gradually from southern to north-eastern states in both female and male bees. Consequently, bees from Meghalaya and Assam clustered at the outermost part of the graph followed by bees from Andaman Islands, Manipur, Nagaland and Tripura. However, some male bee samples from Tamil Nadu and Karnataka clustered very close to the bees of Meghalaya and Assam on the graph indicating occurrence of more than one species in these states (Fig 6. E,F,G H).

Body length of female *Tetragonula* bees reported from India by many researchers vary. Danaraddi and Viraktamath (2009), Ramya (2014), Sajan Jose (2015), Vijayakumar and Jeyaraaj (2014) reported body length varying from 3.41 to 5.07 in T. iridipennis from southern India. According to Makkar et al (2018) body length of this species in Punjab was 3.65 mm. Sakagami (1978) reported body length of 3.6 to 3.9 mm and head width of 1.53 to 1.88 in female bees of *T. iridipennis* from Sri Lanka and different parts of India (Dehradun, Kolkata, Nagpur, Mumbai, Pune, Lonavala, Bengaluru, Chennai, Kodaikanal, Krumbangaram, Pathanapuram and Aluva Khiaskam) . Patel and Pastagia (2016) reported mean body length of 3.67 mm in *T. laeviceps*. However, Rathor *et al.* (2013) reported maximum body length of 6.12 mm in *T. gressitti*. This appears to be the largest *Tetragonula* bee reported from India.

According to a single report of the morphometry of male stingless bee of *T. iridipennis* from Nellithurai, Tamil Nadu, the body length ranged from 2.5 to 3.5 mm, head width 1.38 to1.43 mm, forewing length 3.1 to 3.8 mm, forewing diagonal length 0.88 to 0.95 mm and hind tibial length 0.96 to 1.23 mm (Vijayakumar and Jeyaraaj, 2014). However, corresponding values for the same parameters from three locations of Tamil Nadu (Coimbatore, Nellithurai and Mettupalyam) were 3.68, 1.52, 3.69, 1.03 and 1.35 mm, respectively in our studies. Male bees of T. iridipennis from the type locality (Sri Lanka) measured 3.8 to 4.00 mm in body length; 1.70 to 1.80 mm in head width; 3.7 to 4.30 mm in forewing length; 1.10 to 1.20 mm in forewing diagonal length

Table 8: Morphometry of male stingless bees of the genus *Tetragonula* from 18 states of India

SN	Parameter/State	AN 1	AP 2	AS 3	BH 4	CG 5	GJ 6	KA 7	KL 8	MP 9	MH 10	MN 11	MG 12	NG 13	ND 14	OD 15	RJ 16	TN 17	TR 18
1	BL	4.59 ± 0.12	3.84 ± 0.17	3.89 ± 0.5	3.63 ± 0.1	3.63 ± 0.12	3.84 ± 0.09	3.85 ± 0.22	3.43 ± 0.15	3.88 ± 0.22	3.94 ± 0.28	4.24 ± 0.05	5.20 ± 0.14	4.34 ± 0.33	3.91 ± 0.22	3.52 ± 0.19	3.90 ± 0.16	3.68 ± 0.23	4.13 ± 0.18
2	HW	1.69 ± 0.02	1.47 ± 0.04	1.64 ± 0.09	1.48 ± 0.03	1.48 ± 0.01	1.50 ± 0.06	1.54 ± 0.06	1.43 ± 0.09	1.46 ± 0.04	1.47 ± 0.05	1.73 ± 0.03	1.83 ± 0.04	1.67 ± 0.02	1.52 ± 0.03	1.48 ± 0.03	1.48 ± 0.03	1.52 ± 0.11	1.65 ± 0
3	HL	1.22 ± 0.03	1.04 ± 0.03	1.20 ± 0.06	1.09 ± 0.02	1.08 ± 0.01	1.06 ± 0.02	1.13 ± 0.04	1.07 ± 0.05	1.08 ± 0.03	1.07 ± 0.04	1.22 ± 0.05	1.33 ± 0.04	1.22 ± 0.04	1.11 ± 0.03	1.08 ± 0.03	1.11 ± 0.02	1.11 ± 0.06	1.20 ± 0
4	UIOD	0.96 ± 0.04	0.88 ± 0.02	0.98 ± 0.05	0.92 ± 0.03	0.90 ± 0.01	0.88 ± 0.03	0.90 ± 0.05	0.87 ± 0.04	0.89 ± 0.04	0.90 ± 0.04	1.00 ± 0.03	1.05 ± 0	0.96 ± 0.04	0.90 ± 0.02	0.88 ± 0.03	0.90 ± 0.03	0.91 ± 0.05	0.93 ± 0.04
5	IOD	0.37 ± 0.02	0.37 ± 0.01	0.38 ± 0.03	0.36 ± 0.01	0.37 ± 0	0.36 ± 0.02	0.35 ± 0.03	0.34 ± 0.02	0.38 ± 0.01	0.37 ± 0.04	0.40 ± 0.01	0.38 ± 0	0.36 ± 0.02	0.39 ± 0.01	0.29 ± 0.01	0.39 ± 0.02	0.36 ± 0.02	0.35 ± 0
6	OOD	0.15 ± 0.01	0.14 ± 0.02	0.18 ± 0.02	0.17 ± 0.02	0.13 ± 0	0.15 ± 0.01	0.16 ± 0.02	0.15 ± 0.01	0.14 ± 0.01	0.13 ± 0.01	0.16 ± 0.02	0.15 ± 0	0.16 ± 0.01	0.15 ± 0.01	0.19 ± 0.01	0.13 ± 0.02	0.15 ± 0.03	0.17 ± 0
7	CLL	0.35 ± 0.02	0.35 ± 0.03	0.40 ± 0.03	0.35 ± 0	0.29 ± 0.01	0.30 ± 0	0.31 ± 0.03	0.31 ± 0.02	0.31 ± 0.02	0.32 ± 0.03	0.34 ± 0.02	0.50 ± 0	0.33 ± 0.03	0.30 ± 0.01	0.32 ± 0.03	0.31 ± 0.02	0.31 ± 0.03	0.30 ± 0
8	CLW	0.68 ± 0.04	0.54 ± 0.03	0.55 ± 0.07	0.52 ± 0.03	0.56 ± 0.02	0.56 ± 0.02	0.55 ± 0.05	0.51 ± 0.03	0.58 ± 0.04	0.59 ± 0.04	0.59 ± 0.04	0.75 ± 0	0.63 ± 0.03	0.55 ± 0.01	0.57 ± 0.03	0.56 ± 0.02	0.57 ± 0.02	0.58 ± 0.04
9	SCL	0.50 ± 0	0.45 ± 0.01	0.51 ± 0.04	0.46 ± 0.02	0.48 ± 0.01	0.45 ± 0	0.48 ± 0.03	0.46 ± 0.04	0.47 ± 0.03	0.44 ± 0.01	0.53 ± 0.03	0.55 ± 0	0.51 ± 0.02	0.45 ± 0	0.45 ± 0.03	0.45 ± 0.01	0.45 ± 0.04	0.50 ± 0
10	SCW	0.15 ± 0.01	0.12 ± 0	0.13 ± 0.01	0.13 ± 0	0.12 ± 0.01	0.14 ± 0.01	0.11 ± 0.01	0.11 ± 0.01	0.12 ± 0.01	0.10 ± 0	0.13 ± 0	0.15 ± 0	0.15 ± 0	0.12 ± 0	0.14 ± 0.01	0.10 ± 0	0.11 ± 0.02	0.14 ± 0.01
11	FL	1.91 ± 0.02	1.52 ± 0.03	1.67 ± 0.14	1.65 ± 0.09	1.54 ± 0.05	1.45 ± 0.09	1.66 ± 0.13	1.64 ± 0.1	1.52 ± 0.05	1.50 ± 0.06	1.80 ± 0.06	2.20 ± 0	1.71 ± 0.08	1.56 ± 0.05	1.67 ± 0.08	1.54 ± 0.04	1.62 ± 0.07	1.90 ± 0
12	FFL	0.08 0	0.05 ± 0.02	0.06 ± 0.01	0.07 ± 0.02	0.06 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	0.05 ± 0	0.06 ± 0.01	0.05 ± 0.01	0.08 ± 0	0.08 ± 0	0.05 ± 0	0.05 ± 0.01	0.05 ± 0	0.07 ± 0	0.07 ± 0.01	0.07 ± 0
13	SFL	0.15 ± 0	0.14 ± 0.01	0.15 ± 0.04	0.14 ± 0.01	0.14 ± 0.01	0.13 ± 0	0.14 ± 0.01	0.13 ± 0.01	0.13 ± 0.01	0.12 ± 0.01	0.16 ± 0.01	0.20 ± 0	0.15 ± 0	0.13 ± 0.01	0.13 ± 0.01	0.14 ± 0.01	0.14 ± 0.01	0.14 ± 0.01
14	TFL	0.15 ± 0	0.14 ± 0	0.15 ± 0.03	0.14 ± 0.01	0.14 ± 0.01	0.13 ± 0	0.14 ± 0.01	0.13 ± 0.01	0.13 ± 0	0.13 ± 0.01	0.16 ± 0.02	0.18 ± 0	0.15 ± 0	0.12 ± 0.01	0.13 ± 0.01	0.13 ± 0	0.14 ± 0.01	0.15 ± 0
15	TFW	0.15 ± 0	0.13 ± 0.01	0.14 ± 0.01	0.13 ± 0	0.13 ± 0	0.13 ± 0	0.14 ± 0.01	0.13 ± 0	0.13 ± 0	0.14 ± 0.01	0.16 ± 0.02	0.15 ± 0	0.13 ± 0	0.13 ± 0.01	0.13 ± 0	0.13 ± 0	0.14 ± 0.02	0.15 ± 0
16	MNL	0.50 ± 0.03	0.40 ± 0.01	0.45 ± 0.02	0.38 ± 0.03	0.40 ± 0.02	0.42 ± 0.01	0.40 ± 0.02	0.39 ± 0.03	0.40 ± 0.02	0.39 ± 0.01	0.47 ± 0.02	0.50 ± 0	0.43 ± 0.01	0.39 ± 0.01	0.40 ± 0	0.40 ± 0	0.41 ± 0.02	0.41 ± 0.01

Table 8 : Continued

SN	Para meter/State	AN 1	AP 2	AS 3	BH 4	CG 5	GJ 6	KA 7	KL 8	MP 9	MH 10	MN 11	MG 12	NG 13	ND 14	OD 15	RJ 16	TN 17	TR 18
17	MNW	0.26 ± 0.02	0.18 ± 0.02	0.23 ± 0.01	0.17 ± 0.02	0.20 ± 0.01	0.20 ± 0	0.19 ± 0.01	0.19 ± 0.02	0.20 ± 0.02	0.18 ± 0.01	0.23 ± 0.02	0.25 ± 0	0.20 ± 0.01	0.18 ± 0.01	0.20 ± 0	0.19 ± 0.01	0.18 ± 0.02	0.20 ± 0
18	MSCL	1.13 ± 0.03	0.94 ± 0.04	1.02 ± 0.14	0.93 ± 0.03	0.96 ± 0.03	0.93 ± 0.04	0.97 ± 0.07	0.91 ± 0.07	0.98 ± 0.05	0.97 ± 0.06	1.09 ± 0.06	1.23 ± 0.04	1.05 ± 0	0.99 ± 0.03	0.80 ± 0	0.99 ± 0.03	0.93 ± 0.07	1.05 ± 0
19	MSCW	1.28 ± 0.05	1.03 ± 0.04	1.19 ± 0.2	1.08 ± 0.04	1.08 ± 0.03	1.05 ± 0.05	1.08 ± 0.09	1.01 ± 0.05	1.07 ± 0.04	1.07 ± 0.06	1.21 ± 0.02	1.35 ± 0.07	1.15 ± 0.04	1.05 ± 0.06	1.02 ± 0.03	1.08 ± 0.04	1.01 ± 0.09	1.20 ± 0.07
20	FWL	4.24 ± 0.08	3.57 ± 0.19	3.85 ± 0.25	3.60 ± 0.09	3.54 ± 0.05	3.59 ± 0.16	3.70 ± 0.3	3.54 ± 0.1	3.45 ± 0.1	3.60 ± 0.16	4.09 ± 0.13	4.70 ± 0.14	4.24 ± 0.11	3.67 ± 0.13	3.43 ± 0.06	3.74 ± 0.13	3.69 ± 0.2	4.10 ± 0
21	FWW	1.40 ± 0.04	1.18 ± 0.06	1.32 ± 0.09	1.22 ± 0.03	1.20 ± 0	1.10 ± 0	1.27 ± 0.05	1.17 ± 0.09	1.21 ± 0.05	1.18 ± 0.08	1.31 ± 0.02	1.45 ± 0	1.35 ± 0.05	1.23 ± 0.03	1.07 ± 0.06	1.22 ± 0.04	1.25 ± 0.11	1.35 ± 0
22	PTL	0.63 ± 0.03	0.54 ± 0.03	0.61 ± 0.03	0.56 ± 0.03	0.56 ± 0.02	0.52 ± 0.03	0.57 ± 0.07	0.56 ± 0.04	0.55 ± 0.01	0.55 ± 0.01	0.67 ± 0.07	0.65 ± 0	0.63 ± 0.03	0.55 ± 0	0.57 ± 0.03	0.53 ± 0.03	0.58 ± 0.04	0.68 ± 0.04
23	MCL	1.35 ± 0.06	1.15 ± 0.03	1.27 ± 0.09	1.12 ± 0.04	1.20 ± 0	1.16 ± 0.05	1.21 ± 0.06	1.16 ± 0.05	1.11 ± 0.04	1.18 ± 0.05	1.29 ± 0.03	1.58 ± 0.04	1.24 ± 0.02	1.15 ± 0.05	1.13 ± 0.03	1.17 ± 0.05	1.21 ± 0.04	1.25 ± 0
24	MCW	0.34 ± 0.01	0.26 ± 0.01	0.30 ± 0.02	0.28 ± 0.02	0.28 ± 0.01	0.26 ± 0.01	0.29 ± 0.04	0.28 ± 0.04	0.26 ± 0.02	0.27 ± 0.02	0.31 ± 0.02	0.34 ± 0.01	0.34 ± 0.02	0.28 ± 0.02	0.29 ± 0.01	0.27 ± 0.02	0.29 ± 0.04	0.35 ± 0
25	HAM	5.00 ± 0	5.00 ± 0	5.00 ± 0	5.10 ± 0.32	5.00 ± 0	5.00 ± 0	5.00 ± 0	5.00 ± 0	5.00 ± 0	5.00 ± 0	5.00 ± 0	5.50 ± 0.71	5.00 ± 0	5.00 ± 0	5.00 ± 0	5.14 ± 0.38	5.00 ± 0	6.00 ± 0
26	FWD	1.18 ± 0.03	0.93 ± 0.04	1.06 ± 0.06	0.97 ± 0.02	0.96 ± 0.03	0.95 ± 0.04	1.01 ± 0.08	0.97 ± 0.04	0.93 ± 0.03	0.95 ± 0.06	1.17 ± 0.03	1.25 ± 0	1.09 ± 0.02	0.97 ± 0.02	0.90 ± 0	0.92 ± 0.06	1.03 ± 0.1	1.20 ± 0
27	HTL	1.32 ± 0.04	1.25 ± 0.04	1.40 ± 0.13	1.28 ± 0.06	1.25 ± 0	1.27 ± 0.07	1.31 ± 0.07	1.27 ± 0.03	1.21 ± 0.04	1.29 ± 0.06	1.49 ± 0.04	1.60 ± 0	1.43 ± 0.03	1.24 ± 0.07	1.25 ± 0	1.23 ± 0.02	1.35 ± 0.12	1.30 ± 0
28	HTW	0.42 ± 0.03	0.48 ± 0.01	0.51 ± 0.05	0.49 ± 0.02	0.47 ± 0.01	0.45 ± 0	0.50 ± 0.04	0.49 ± 0.03	0.47 ± 0.03	0.47 ± 0.03	0.56 ± 0.02	0.58 ± 0.04	0.55 ± 0.04	0.50 ± 0.02	0.45 ± 0	0.46 ± 0.02	0.50 ± 0.06	0.48 ± 0.04
29	HBTL	0.55 ± 0	0.46 ± 0.02	0.53 ± 0.05	0.47 ± 0.03	0.46 ± 0.01	0.44 ± 0.02	0.48 ± 0.05	0.42 ± 0.04	0.43 ± 0.03	0.48 ± 0.05	0.49 ± 0.03	0.63 ± 0.04	0.49 ± 0.02	0.48 ± 0.02	0.37 ± 0.03	0.49 ± 0.03	0.49 ± 0.05	0.43 ± 0.04
30	HBTW	0.25 ± 0	0.23 ± 0	0.26 ± 0.04	0.24 ± 0.02	0.26 ± 0.02	0.23 ± 0	0.24 ± 0.03	0.23 ± 0.02	0.21 ± 0.02	0.23 ± 0.02	0.26 ± 0.01	0.35 ± 0	0.25 ± 0	0.23 ± 0.02	0.23 ± 0	0.22 ± 0.02	0.25 ± 0.02	0.25 ± 0

AN. Andaman and Nicobar Islands; AP. Andhra Pradesh; AS. Assam; BH. Bihar; CG. Chhattisgarh; GJ. Gujarat; KA. Karnataka; KL. Kerala; MP. Madhya Pradesh; MH. Maharashtra; MN. Manipur; MG. Meghalaya; NG. Nagaland; ND. New Delhi; OD. Odisha; RJ. Rajasthan; TN. Tamil Nadu; TR. Tripura

Table 9: Eigen values and percentage of variance in Principal Components in the analysis of male stingless bees of the genus *Tetragonula* from 18 states of India

Component	Initial Eigenvalues Total	% of Variance	Cumulative %	Extraction Sums of Squared Loadings Total	% of Variance	Cumulative %	Rotation Sums of Squared Loadings Total	% of Variance	Cumulative %
1	14.185	47.283	47.283	14.185	47.283	47.283	7.465	24.884	24.884
2	2.199	7.331	54.614	2.199	7.331	54.614	4.718	15.725	40.609
3	1.617	5.39	60.004	1.617	5.39	60.004	3.993	13.311	53.92
4	1.257	4.189	64.193	1.257	4.189	64.193	2.806	9.352	63.273
5	1.109	3.698	67.891	1.109	3.698	67.891	1.385	4.618	67.891
6	0.958	3.193	71.084						
7	0.89	2.966	74.05						
8	0.817	2.722	76.771						
9	0.799	2.664	79.436						
10	0.727	2.425	81.861						
11	0.579	1.931	83.792						
12	0.552	1.84	85.632						
13	0.467	1.557	87.188						
14	0.422	1.407	88.596						
15	0.406	1.354	89.95						
16	0.364	1.213	91.163						
17	0.334	1.112	92.275						
18	0.31	1.033	93.308						
19	0.255	0.851	94.159						
20	0.239	0.795	94.954						
21	0.233	0.775	95.729						
22	0.191	0.638	96.368						
23	0.188	0.628	96.995						
24	0.164	0.545	97.541						
25	0.16	0.535	98.075						
26	0.15	0.501	98.576						
27	0.136	0.454	99.03						
28	0.108	0.359	99.389						
29	0.103	0.343	99.732						
30	0.08	0.268	100						

Extraction Method: Principal Component Analysis.

and 1.40 to 1.60 mm in hind tibial length (Sakagami, 1978). As there are distinct differences in the morphometry of *T. iridipennis* bees reported by Vijayakumar and Jeyaraaj (2014) and Sakagami (1978), occurrence of *T. iridipennis* in India needs to be confirmed.

Body length is a difficult parameter to measure accurately as the abdomen is bent down in most specimens or the abdomen distended when preserved in alcohol or shrunk when preserved dry. Hence, utmost care needs to be taken while measuring this parameter to avoid human error.

Contrarily variation in head width, forewing length, hind tibial length and hind basitarsus length was in the same range as reported from Karnataka, Kerala, Tamil Nadu, Gujarat, Punjab and Arunachal Pradesh by various researchers. However, values reported for head width and hind tibial length by Ramya (2014) from Karnataka (0.80 to 0.99 and 0.84 mm, respectively) and Divya (2016) from Kerala (1.16 to 1.34 and 1.04 to 1.26 mm, respectively) are lower and we infer that these researchers erred while measuring.

Rasmussen (2013) has provided detailed morphometry of primary types of Tetragonula bees namely, *T. iridipennis, T. praeterita, T. ruficornis* and *T. bengalensis* from Indian subcontinent. Body length of these primary types was 3.55, 3.33, 3.45 and 3.55 mm, respectively. Bees from Andhra Pradesh, Maharashtra, New Delhi and Tamil Nadu had the similar body length while bees from other states were longer (3.65 to 4.86 mm) than these primary types. In contrary, the head width, which was 1.60, 1.52, 1.66 and 1.70 mm, respectively in these types, was similar to the head width of bees from southern(Karnataka. Kerala, Tamil Nadu), central (Andhra Pradesh, Bihar, Chhattisgarh, Maharashtra, Madhya Pradesh, Gujarat, Odisha and Rajasthan) and northern (New Delhi) states. But head width of the bees from northeastern states (Assam, Manipur, Meghalaya, Nagaland and Tripura) and Andaman Islands ranged from 1.70 to 1.88 mm. Similar trend was noticed in respect of forewing length, forewing diagonal width, hind tibial length and hind basitarsus length.

We used two different methods of analysis (PCA and CDA) in our studies and both methods showed the presence of wide variation in the population of stingless bees from these 18 states. Interestingly bees from individual states of North-Eastern India formed separate clusters indicating rich diversity of stingless bees in this area. Similarly, bees from Andaman Islands formed distinct and separate cluster in both PCA and CDA which indicates that these bees belong to a distinct species. Bees from Central India (Andhra Pradesh, Bihar, Chhattisgarh, Gujarat, Maharashtra, Madhya Pradesh, Odisha, Rajasthan) together with north India (New Delhi) formed a separate overlapping cluster. Similarly, bees of southern India (Karnataka, Kerala, Tamil Nadu) formed distinct cluster.

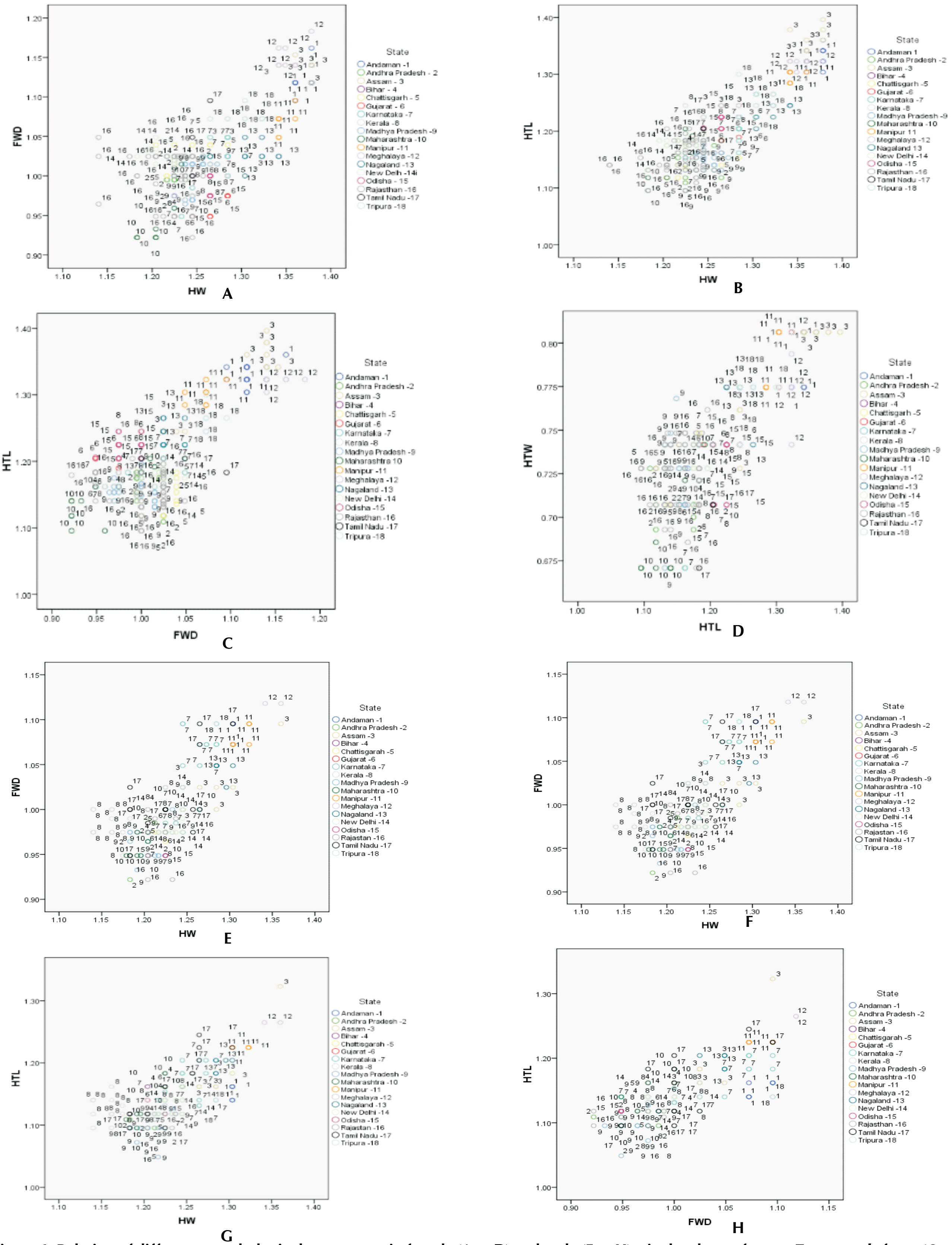


Figure 6: Relation of different morphological parameters in female (A to D) and male (E to H) stingless bees of genus *Tetragonula* from 18 state of India(HW -head with,FWD-forewing widt,HTL -hind tibla length,HTW- hind tibila width

Table 10: Rotated component matrix in Principal Component analysis of male stingless bees of the genus *Tetragonula* from 18 states of India

Parameter	Component				
	1	2	3	4	5
FWD	0.741	0.307			
HTL	0.717			0.416	
FL	0.696		0.305		0.327
MCW	0.672				
HL	0.671	0.373	0.42		
HW	0.658	0.406	0.486		
PTL	0.649				
OOD	0.63	-0.392			
FWW	0.629	0.414	0.324		
HTW	0.621				-0.383
FWL	0.619	0.474			
TFW	0.616	0.317			
HBTW	0.597	0.31		0.452	
UIOD	0.555	0.436	0.441		
MCL	0.546	0.35		0.392	
IOD		0.745			
CLW		0.71	0.31		
MSCL	0.315	0.706			
BL		0.697	0.381		
HBTL		0.589		0.483	
MSCW	0.449	0.577	0.36		
FFL		0.465		-0.302	0.392
MNW			0.84		
MNL			0.817		
SCL	0.459		0.619		
SCW	0.315		0.543		
CLL			0.305	0.695	
SFL	0.322			0.669	
TFL	0.487		0.324	0.588	
HAM					0.676

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 7 iterations.

Table 11: Eigen values and Canonical correlations of different functions in Discriminant analysis of male stingless bees of the genus *Tetragonula* from 18 states of India

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
1	11.873a	35.7	35.7	0.96
2	6.201a	18.6	54.3	0.928
3	2.939a	8.8	63.1	0.864
4	2.513a	7.5	70.7	0.846
5	1.921a	5.8	76.4	0.811
6	1.388a	4.2	80.6	0.762
7	1.292a	3.9	84.5	0.751
8	1.190a	3.6	88.1	0.737
9	1.048a	3.1	91.2	0.715
10	.712a	2.1	93.3	0.645
11	.604a	1.8	95.1	0.614
12	.523a	1.6	96.7	0.586
13	.443a	1.3	98.1	0.554
14	.251a	0.8	98.8	0.448
15	.175a	0.5	99.3	0.386
16	.156a	0.5	99.8	0.368
17	.067a	0.2	100	0.25

a. First 17 canonical discriminant functions were used in the analysis.

Association of males and females with already known species is a challenging task as the females of different species are remarkably similar and males are not known for most of the described species from India. Identification of species based on morphometry, pilosity, body coloration of only female bees may lead to errors and confusion rather than resolving the problem of identification. Though our studies do not help in identification of the species, but it brings out the extent of variation in female and associated male stingless bees of *Tetragonula* for the first time in India and forms a sound basis for further detailed investigations. Our results indicate that the *Tetragonula* bees occurring in India may belong to many unknown species which are yet to be described. Further investigations are needed to identify the species with the help of male genitalia and DNA sequences. We endorse the views of Rasmussen (2013) that it is premature to describe and propose new species of *Tetragonula* without males.

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Table 12 : Standardized Canonical Discriminant function coefficients in the analysis of male stingless bees of the genus Tetragonula from 18 states

	Function																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
BL	-0.107	-0.305	-0.471	0.007	0.184	0.124	0.083	-0.428	-0.235	0.356	-0.2	0.271	0.568	0.106	0.151	-0.057	0.025
HW	0.396	0.022	0.105	0.917	0.334	-0.391	-0.138	-0.152	-0.089	-0.317	-0.305	-0.119	0.53	-0.07	0.361	0.208	0.172
HL	0.127	0.221	0.053	0.146	0.602	0.114	-0.044	-0.093	-0.103	0.089	0.321	0.165	-0.51	-0.581	-0.391	0.249	-0.53
UIOD	0.05	0.298	0.174	-0.051	-0.321	0.251	0.309	0.242	-0.245	0.071	-0.185	0.052	-0.107	-0.21	-0.084	0.196	0.48
IOD	-0.302	-0.658	0.112	0.606	0.22	-0.236	0.11	0.115	0.449	-0.201	0.114	0.057	0.255	-0.023	0.079	0.144	-0.142
OOD	0.031	0.096	0.185	0.334	0.068	0.044	-0.319	-0.041	-0.477	0.095	0.307	0.318	0.519	0.104	0.289	-0.029	-0.202
CLL	0.163	0.02	0.193	0.027	-0.278	0.549	0.134	0.397	-0.241	0.13	-0.574	-0.203	0.05	0.021	0.063	0.025	-0.263
CLW	-0.048	-0.167	-0.474	-0.438	-0.528	0.248	0.176	-0.275	-0.354	0.361	0.268	0.249	-0.265	0.38	0.128	0.182	-0.102
SCL	0.063	0.021	-0.095	-0.108	0.416	0.357	-0.294	-0.204	-0.014	0.258	-0.144	0.323	-0.416	0.227	-0.429	-0.326	-0.005
SCW	0.588	-1.055	0.715	-0.069	-0.075	-0.147	0.048	-0.228	0.042	-0.104	0.117	-0.06	-0.013	0.159	-0.298	0.04	-0.014
FL	0.15	0.153	0.158	-0.837	-0.096	0.056	0.095	0.052	-0.015	0.308	-0.077	-0.412	0.543	-0.205	-0.43	0.271	0.153
FFL	0.419	0.055	0.023	0.234	-0.189	-0.173	0.379	0.524	0.069	0.239	0.286	0.269	-0.048	-0.077	-0.104	-0.293	0.013
SFL	-0.3	-0.037	0.026	0.02	-0.112	0.369	0.161	0.135	0.657	0.233	0.575	0.186	0.919	-0.339	-0.008	-0.105	-0.093
TFL	0.459	0.202	0.216	0.21	0.107	-0.013	-0.115	0.014	-0.12	-0.077	-0.151	-0.035	-0.831	0.51	0.248	-0.388	0.389
TFW	-0.179	-0.11	-0.217	-0.306	0	-0.378	-0.008	0.229	-0.12	-0.237	-0.388	0.215	0.333	-0.191	-0.241	-0.087	0.197
MNL	0.351	-0.132	-0.047	-0.197	-0.535	-0.434	0.301	0.261	0.124	0.303	0.308	-0.104	0.027	-0.17	0.225	0.043	-0.36
MNW	0.438	0.115	-0.181	0.025	0.051	0.227	-0.488	-0.01	0.504	-0.369	-0.037	0.16	0.033	-0.043	0.194	0.119	0.177
FWL	-0.017	-0.016	-0.132	0.062	0.163	0.423	-0.123	-0.805	0.155	0.03	0.069	-0.473	-0.327	-0.456	0.389	-0.672	0.263
FWW	-0.508	0.132	-0.557	0.002	-0.081	0.329	-0.047	0.564	0.118	-0.082	0.628	-0.368	-0.292	0.589	0.249	0.088	-0.2
PTL	-0.258	0.136	-0.212	0.099	-0.061	-0.188	-0.157	0.347	0.184	0.142	-0.024	-0.135	-0.023	-0.091	0.467	0.68	0.302
MCL	0.299	0.328	-0.167	-0.02	-0.476	0.147	0.11	-0.246	0.149	-0.405	0.011	0.288	0.068	0.036	-0.092	0.114	-0.238
MCW	0.377	-0.156	0.196	-0.305	0.035	-0.116	0.039	-0.027	-0.18	0.163	0.106	-0.1	-0.127	-0.408	0.2	0.072	0.123
FWD	0.398	0.232	-0.081	-0.162	0.468	-0.62	-0.084	0.134	0.008	0.014	-0.225	-0.166	0.207	0.801	-0.066	-0.236	-0.264
HAM	0.296	0.042	0.206	-0.242	0.626	0.042	0.625	0.052	0.028	-0.339	-0.042	0.218	-0.102	0.034	0.171	0.061	-0.087
MSCL	-0.014	-0.102	-0.216	0.157	0.274	-0.114	-0.08	-0.093	-0.007	-0.08	-0.51	-0.388	0.15	0.148	-0.431	0.035	-0.147
MSCW	0.084	-0.159	0.052	-0.102	0.151	0.138	-0.474	0.672	-0.196	0.203	-0.366	0.141	-0.594	-0.352	-0.077	-0.36	0.214
HTL	-0.544	0.642	0.347	0.432	-0.642	-0.732	0.472	-0.371	0.081	-0.055	-0.17	0.125	-0.174	0.005	-0.114	-0.282	-0.255
HTW	-0.595	0.249	-0.033	0.188	0.072	0.471	0.033	-0.12	0.391	0.459	-0.004	-0.074	0.111	0.067	0.046	0.214	0.106
HBTL	0.581	-0.145	0.007	0.248	-0.132	0.078	-0.011	0.191	-0.43	-0.428	0.351	-0.306	-0.01	0.1	-0.202	0.062	0.353
HBTW	-0.028	0.154	0.187	-0.5	-0.065	0.209	0.094	-0.08	0.225	-0.334	0.345	0.487	-0.113	0.107	-0.195	0.353	0.256

Table 13: Classification and cross validation of results of analysis of male stingless bees of the genus *Tetragonula* from 18 states of India

		State	Predicted Group Membership																		Total
		code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Original	Count	1	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
		2	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
		3	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
		4	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
		5	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	5
		6	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	5
		7	0	0	0	0	0	0	35	0	0	0	0	0	0	0	0	0	0	0	35
		8	0	0	0	0	0	0	0	36	0	1	0	0	0	0	0	0	1	0	38
		9	0	0	0	0	0	0	0	0	27	0	0	0	0	1	0	0	0	0	28
		10	0	0	0	0	0	0	0	0	0	19	0	0	0	0	0	0	0	0	19
		11	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	7
		12	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2
		13	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	5
		14	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	15
		15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	3
		16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	7
		17	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	12	0	13
		18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
	%	1	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
		2	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
		3	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
		4	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
		5	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	100
		6	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	100
		7	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	100
		8	0	0	0	0	0	0	0	94.7	0	2.6	0	0	0	0	0	0	2.6	0	100
		9	0	0	0	0	0	0	0	0	96.4	0	0	0	0	3.6	0	0	0	0	100
		10	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	100
		11	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	100
		12	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	100
		13	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100
		14	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	100
		15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	100
		16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	100
		17	0	0	0	0	0	0	7.7	0	0	0	0	0	0	0	0	0	92.3	0	100
		18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	100

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Table 13: Continued ....

		State Code	Predicted group membership 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Total
Cross-validateda	Count	1	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
		2	0	9	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	10
		3	0	0	8	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	10
		4	0	0	0	8	0	0	0	1	0	0	0	0	0	0	0	0	0	1	10
		5	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	5
		6	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	5
		7	0	1	0	0	0	0	30	1	0	0	0	0	0	0	0	1	2	0	35
		8	0	1	0	0	0	0	0	30	0	3	0	0	0	0	1	0	3	0	38
		9	0	0	0	0	0	0	0	1	25	0	0	0	0	1	0	1	0	0	28
		10	0	0	0	0	0	0	0	1	0	18	0	0	0	0	0	0	0	0	19
		11	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	7
		12	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2
		13	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	5
		14	0	0	0	0	0	0	0	0	2	0	0	0	0	13	0	0	0	0	15
		15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	3
		16	0	0	0	1	1	0	0	0	1	0	0	0	0	1	0	3	0	0	7
		17	0	0	0	0	0	0	2	0	0	1	1	0	0	0	0	0	9	0	13
		18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
	%	1	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
		2	0	90	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	100
		3	0	0	80	0	0	0	0	0	0	0	0	10	0	0	0	0	10	0	100
		4	0	0	0	80	0	0	0	10	0	0	0	0	0	0	0	0	0	10	100
		5	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	100
		6	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	100
		7	0	2.9	0	0	0	0	85.7	2.9	0	0	0	0	0	0	0	2.9	5.7	0	100
		8	0	2.6	0	0	0	0	0	78.9	0	7.9	0	0	0	0	2.6	0	7.9	0	100
		9	0	0	0	0	0	0	0	3.6	89.3	0	0	0	0	3.6	0	3.6	0	0	100
		10	0	0	0	0	0	0	0	5.3	0	94.7	0	0	0	0	0	0	0	0	100
		11	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	100
		12	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	100
		13	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100
		14	0	0	0	0	0	0	0	0	13.3	0	0	0	0	86.7	0	0	0	0	100
		15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	100
		16	0	0	0	14.3	14.3	0	0	0	14.3	0	0	0	0	14.3	0	42.9	0	0	100
		17	0	0	0	0	0	0	15.4	0	0	7.7	7.7	0	0	0	0	0	69.2	0	100
		18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	100

a. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.
b. 98.2% of original grouped cases correctly classified.
c. 85.6% of cross-validated grouped cases correctly classified.

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