



Description of five new species of *Tetragonula* (Hymenoptera: Apidae: Meliponini) from India

Shashidhar Viraktamath¹ · Jagruti Roy²

Received: 17 July 2021 / Accepted: 7 February 2022 / Published online: 11 April 2022

© The Author(s), under exclusive licence to Plant Science and Biodiversity Centre, Slovak Academy of Sciences (SAS), Institute of Zoology, Slovak Academy of Sciences (SAS), Institute of Molecular Biology, Slovak Academy of Sciences (SAS) 2022

Abstract

We describe five new species of *Tetragonula* namely, *Tetragonula vikrami* Viraktamath, sp. n. (from Karnataka), *T. sumae* Viraktamath, sp. n. (from Tamil Nadu), *T. ashishi* Viraktamath and Jagruti, sp. n. (from Maharashtra), *T. shishirae* Viraktamath sp. n. (from Rajasthan) and *T. shubhami* Viraktamath, sp. n. (from Chhattisgarh) with associated female and male bees. These new species are distinct in having robust penis valve. Besides, *T. sumae*, *T. ashishi*, *T. shishirae* and *T. shubhami* have robust gonostylus which is lamellate, broad and apically outwardly curved finger-like structure. *Tetragonula vikrami* resembles *T. iridipennis*, however, the five new species differ from the other known species of *Tetragonula* in morphometry, shape, size, and structure of gonostylus, penis valve and the structure of the sternum 5 and 6. The discovery of these five new species elevates the total number of stingless bee species to 22 and the number of species in the genus *Tetragonula* to 17 from India.

Keywords *Tetragonula vikrami* · *Tetragonula sumae* · *Tetragonula ashishi* · *Tetragonula shishirae* · *Tetragonula shubhami* · Stingless bees · Meliponini · India

Introduction

Stingless bees (Hymenoptera: Apidae: Meliponini) are receiving great attention from bee scientists throughout the world as they are one of the economically important as well as biologically intriguing groups of insects. They yield honey considered as having higher medicinal value than the honey from *Apis* bees (Cortopassi-Laurino et al. 2006) and costs rupees 1000–10,000 per liter (Kumar et al. 2012; Viraktamath et al. 2021). Stingless bees also play an important role in pollinating several plant species including cultivated crops (Heard 1999). In India, meliponiculture is practiced since ancient times and is very well developed in Karnataka, Kerala, Tamil Nadu, Gujarat and north-eastern states. Three genera of stingless bees occur in India namely, *Tetragonula* Moure, 1961, *Lepidotrigona* Schwarz, 1939 and

Lisotrigona Moure, 1961. Among these *Tetragonula* is the most dominant with 12 species followed by *Lisotrigona* and *Lepidotrigona* with four and one species each, respectively (Rasmussen 2013; Shanas and Faseeh 2019; Viraktamath and Rojeet 2021). India has diverse bioecological conditions and is considered one of the hotspots of biodiversity in the world. However, the diversity of Indian stingless bees is poorly known (Rasmussen 2013). Hence, to improve our knowledge, we made intensive collections of stingless bees from different parts of India. As a result of these efforts, we discovered five new species of the genus *Tetragonula* from Karnataka, Tamil Nadu, Maharashtra, Rajasthan and Chhattisgarh and these are described and illustrated with the associated male and female bees in this paper.

Materials and methods

We collected female and associated male bees from the natural colonies of stingless bees at Mankalale (Karnataka 14.1437° N, 75.0115° E), Nagpur (Maharashtra 21.1458° N, 79.0882° E), Udaipur (Rajasthan 24.5854° N, 73.7125° E), Pushpal (26.05° N, 74.02° E) and Bardebhata (Chhattisgarh

✉ Shashidhar Viraktamath
shashiv777@gmail.com

¹ Department of Entomology, University of Agricultural Sciences, Bengaluru, India

² Department of Zoology, Hislop College, Nagpur 440030, India

20.2675° N, 81.4927° E) by using a water trap (Viraktamath et al. 2020). All the bees trapped in water were transferred to vials containing 90% ethyl alcohol and labelled indicating the place, date and name of the collector. Bees collected were examined at the Department of Entomology, University of Agricultural Sciences, Bengaluru (UASB) and sexed under a stereoscopic binocular microscope (Jenco Model ZM-H-602). All the male and a few representative female bees were mounted on a card point and labelled for further detailed studies. The first author (SV) came across male and female bees of *Tetragonula* in the collections of UASB with a label indicating the place of collection as Salem (Tamil Nadu 11.6643° N, 78.1460° E). These were also included in the studies. The identity of the genus was confirmed by a combination of characters like the presence of sericeous area on the inner surface of hind basitarsus and projection of mesoscutellum over propodeum (Sakagami 1978; Rasmussen 2013).

We used 34 morphological parameters to study the detailed morphometry of male and female bees to describe species and the landmarks used for measuring these parameters were similar to those explained by Viraktamath and Rojeet (2021). We also calculated ten ratios of different morphological parameters (Sakagami 1978) for the description of the species. The morphometric data of female bees were subjected to Principal Component analysis and a PCA graph was prepared to understand the clustering of these five new species. The terminology used in the description is that of Sakagami (1978) and Rasmussen (2013). All the morphometry was studied by using a stereoscopic binocular microscope (Jenco) fitted with an ocular micrometer. The procedure to study the male genitalia, metasomal terga and sterna were similar to that described by Viraktamath and

Rojeet (2021). Images of the bees, genitalia and metasomal sterna were taken under Leica microscopes (M205C and DM2000) fitted with a digital camera (DFC425) having a range of magnification from 7.8 to 160× and 40 to 400×, respectively. The images were later processed by using Photoshop. We also measured the length and width of the penis valve, gonostylus and gonocoxite under these microscopes by using Leica measurement software. The landmarks for these parameters are presented in Fig. 1.

Holotypes and paratypes are deposited at the Department of Entomology (UASB). One paratype of each species will be deposited at the Department of Entomology (IARID) and Zoological Survey of India, Kolkata (ZSIK).

Tetragonula vikrami Viraktamath sp. n.

Diagnosis Male bees 4.00 ± 0.20 mm long with head width of 1.61 ± 0.04 mm while the female bees 4.07 ± 0.15 mm long and 1.65 ± 0.00 mm in head width. This species resembles *T. iridipennis* (Smith, 1854) in having dense white plumose hairs on clypeus and face and same range of body length in both male and female bees. However, this species differs from *T. iridipennis* in having mesoscutum with indistinct longitudinal bands of hairs (distinct bands in *T. iridipennis*); narrower head (1.55 – 1.65 as against 1.60 – 1.80 mm in *T. iridipennis*); $1.43\times$ longer second flagellomere (0.10 mm as against 0.07 mm in *T. iridipennis*); larger median ocellus (0.17 – 0.18 mm versus 0.15 mm in *T. iridipennis*); greater values of ratios of forewing length to width (2.97 in female bee as against 2.88 in *T. iridipennis* female); forewing diagonal length to head width (0.72 in male as against 0.69 in *T. iridipennis* male); lesser values

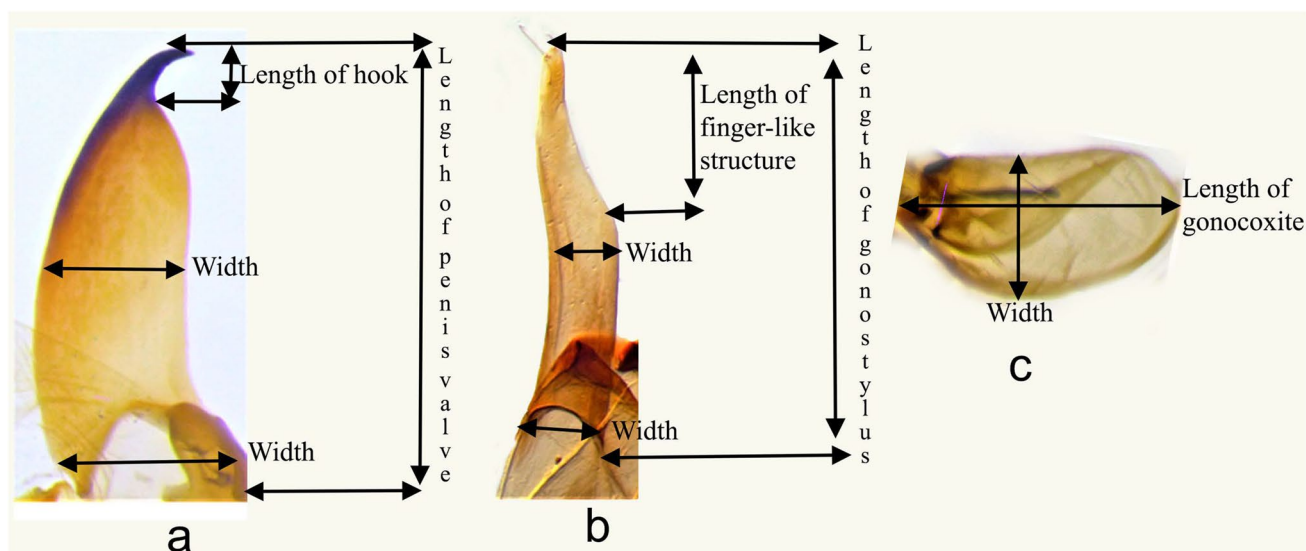


Fig. 1 Landmarks for measurement of penis valve (a), gonostylus (b) and gonocoxite (c)

of the ratios of hind tibia to forewing diagonal length (1.25 in male and 1.31 in female bees as against 1.37 and 1.49–1.53 mm in *T. iridipennis*, respectively). Male metasomal sternum 5 is with a gentle concavity medio-apically (Fig. 3a) while distinctly emarginated in *T. iridipennis* (Fig. 73 of Sakagami 1978; Fig. 14a); sternum 6 with a medio-apical process 3.62× longer than wide (0.07 mm), gradually narrowed, incurved to a narrow and blunt rounded apex (Fig. 3b, c) while in *T. iridipennis* the medio-apical process is 2.73× longer than wide, incurved terminating in broad rounded apex (Fig. 80 A and B of Sakagami 1978; Fig. 14b). The male genitalia resembles that of *T. iridipennis* superficially in having robust penis valves but differs in shape and size of gonostylus and penis valve. Gonostylus in this species is 0.05 mm wide at the base gradually widening to 0.06 mm and tapering to 0.02 mm and then dilated to 0.04 mm near the apex (Fig. 3d–f). In *T. iridipennis* the gonostylus is 0.03 mm wide at the base, gradually dilated to 0.10 mm and tapering to 0.02 mm with rounded apex without any dilation (Fig. 89 of Sakagami 1978; Fig. 14c). Similarly, penis valve is 0.20 mm at the base but narrowing to 0.15 mm after a short distance, later gradually narrowing to 0.10 mm before curving into a 0.02 mm wide, 0.10 mm long hook at the apex (Fig. 3e, f). In *T. iridipennis* the penis valve is 0.18 mm wide at the base, and abruptly tapering and gently curved at the apex (Fig. 89 of Sakagami 1978).

Description

Holotype: Male

Colouration Body shiny. Head black; scape brownish black except basal and apical region pale brown; pedicel brown, flagellomeres brown on upper side, ochraceous on lower side; clypeus black with concave apical margin; ocelli pale brown, shiny; compound eyes yellowish-brown (Fig. 2g). Mandibles dark reddish-brown at the basal 1/3rd, reddish-brown at apical 2/3rd (Fig. 2h) Mesosoma black; tegula black; wings with reddish-brown tinge; pterostigma, veins dark brown; legs brownish black except the terminal four tarsal segments light brown. Metasomal terga brownish-black with intersegmental areas light brown (Fig. 2e); sterna dark brown basally, yellowish-brown apically thus appearing banded.

Pilosity Clypeus, scape, lower 3/4th of face with dense white plumose hairs obscuring underlying integument (Fig. 2g); upper 1/4th of face, vertex, occipital area with brownish-black, short, erect hairs; post gena, post occipital margins with white intermixed with yellowish hairs; lower part of occipital area with a patch of white very fine hairs. Mesoscutum with indistinct longitudinal bands of hairs; mesoscutellar margin fringed with yellow intermixed with

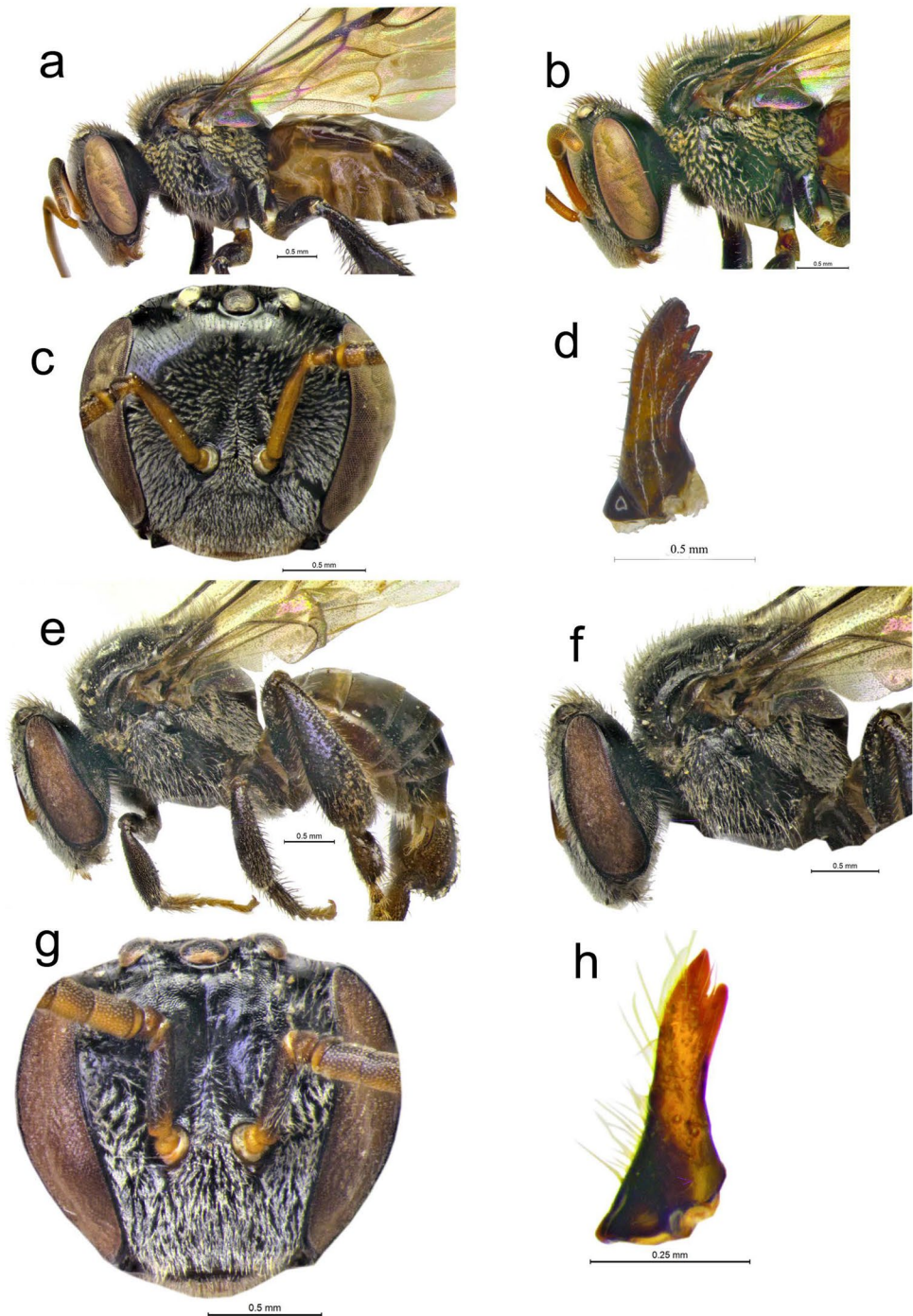
dark brown long hairs. Mesepisternum with long, white plumose hairs, the density increasing towards lower part; posterior area of metepisternum, lateral area of propodeum with dense white short plumose hairs obscuring underlying integument (Fig. 2f). All the legs with dark brown hairs except tarsi which are with yellow hairs; anterior margin of hind tibia with dark brown hairs; posterior margin with ochraceous long plumose hairs; upper surface with long ochraceous hairs. Metasomal terga with indistinct brown sparse hairs; sterna with white hairs, the density increasing towards terminal segments.

Morphometry Body 3.75 mm in length and 1.55 mm head width including compound eyes (Table 1); compound eye 2.75× longer than its width (0.40 mm); median ocellus 0.18 mm in diameter; upper interocular distance 1.00 mm; interocellar distance 2.22× that of cello-ocular distance (0.18 mm); malar space length 0.01 mm; scape 3.75× longer than its width (0.12 mm); first flagellomere 0.07 mm in length while second and third flagellomeres subequal in length; mandible 0.43 mm in length and 0.20 mm in width. Mesosoma narrower than head; forewing 4.00 mm in length and 1.30 mm in width; wing diagonal length 1.15 mm. Hind tibia 1.40 mm in length and 0.55 mm in width; hind basitarsus length 0.52 mm, width 0.28 mm.

Ratios of head length to head width 0.77; eye length to upper interocular distance 1.10; interocellar to cello-ocular distance 2.22; scape length to eye length 0.41; forewing length to width 3.08; forewing diagonal to head width 0.74; hind tibial length to head width 0.90; hind tibial length to wing diagonal length 1.22; hind tibial width to length 0.39; hind basitarsus width to hind tibial width 0.51 (Table 2).

Metasomal sterna and genitalia In sternum 5 the gradulus touches the antecosta (Fig. 3a); medio-apical margin with a very gentle concavity; antecostal curvature is distinctly convex in sternum 6; medio apical process 3.62× longer than wide, gradually narrowed, incurved and terminating in a narrow blunt rounded apex (Fig. 3b, c). Genitalia light yellowish-brown; gonocoxae oriented vertically (Fig. 3d). Gonostylus arising dorsally on gonocoxa, pale yellowish in the basal and apical region, dark brown in the middle region; gently curved inwards terminally (Fig. 3d, e); 1.03 mm in length; 0.05 mm wide at the base, slightly widening to 0.06 mm and later gradually narrowing to 0.02 mm and then dilated to 0.04 mm near the apex; apical margin with stout and long setae (Fig. 3f). Penis valve robust, with yellowish body and dark brown outwardly curved hook at the terminal end (Fig. 3d, e); 0.83 mm in length; 0.20 mm wide at the base, gradually narrowing to 0.10 mm before curving outwards into a 0.02 mm wide, 0.10 mm long hook at the apex.

Fig. 2 *Tetragonula vikrami* sp. n. Female paratype: **a** lateral habitus, **b** head and thorax closer lateral view, **c** head frontal view, **d** mandible. Male holotype: **e** lateral habitus, **f** head and thorax closer lateral view, **g** head frontal view, **h** mandible



Paratypes: Males

Resemble the holotype in coloration and pilosity. In some ocelli dark brown. Scape brownish black except basal part light brown.

Morphometry Mean body length 4.00 mm with head width 1.61 mm (Table 1); compound eyes 1.10 mm long and 0.41 mm wide; upper interocular distance 0.94 mm;

interocellar distance 0.38 mm; forewing 4.07 mm long, 1.32 mm wide; wing diagonal length 1.15 mm; hind tibiae 1.43 mm long, 0.55 mm wide while hind basitarsus 0.54 mm long and 0.29 mm wide.

Ratios of head length to width 0.76 (Table 2); eye length to upper interocular distance 1.19; interocellar to cello-ocular distance 2.13; forewing length to width 3.06; hind tibial length to head width 0.90; hind tibial length to forewing diagonal length 1.25.

Table 1 Morphometry of five new species of *Tetragonula* and *Tetragonula iridipennis*

↓Parameter / Species→	<i>Tetragonula vikrami</i> sp. n.			<i>Tetragonula sumae</i> sp. n.			<i>Tetragonula ashishi</i> sp. n.			<i>Tetragonula shishirae</i> sp. n.			<i>Tetragonula shubhami</i> sp. n.			<i>Tetragonula iridipennis</i> (Smith, 1854)	
	Holo-type Male	Paratypes Male [#] n=10	Female [#] n=10	Holo-type Male	Paratypes Male [#] n=3	Female [#] n=10	Holo-type Male	Paratypes Male [#] n=10	Female [#] n=10	Holo-type Male	Paratypes Male [#] n=2	Female [#] n=10	Holo-type Male	Paratypes Male [#] n=5	Female [#] n=10	Male*	Female**
Length of body	3.75	4.00 ± 0.20	4.07 ± 0.15	4.00	3.68 ± 0.26	3.58 ± 0.18	4.35	4.19 ± 0.18	3.74 ± 0.07	4.00	4.00 ± 0.00	3.81 ± 0.06	4.05	3.86 ± 0.21	3.50 ± 0.17	3.90	3.55
Width of head including eyes	1.55	1.61 ± 0.04	1.65 ± 0.00	1.58	1.57 ± 0.04	1.57 ± 0.03	1.50	1.51 ± 0.02	1.52 ± 0.02	1.52	1.49 ± 0.05	1.42 ± 0.09	1.47	1.47 ± 0.07	1.54 ± 0.06	1.78	1.60
Length of head	1.20	1.21 ± 0.02	1.25 ± 0.01	1.12	1.12 ± 0.02	1.15 ± 0.05	1.15	1.11 ± 0.03	1.19 ± 0.03	1.15	1.13 ± 0.04	1.25 ± 0.03	1.15	1.15 ± 0.00	1.20 ± 0.07	–	1.30
Length of eye	1.10	1.10 ± 0.00	1.10 ± 0.00	1.05	1.05 ± 0.00	1.13 ± 0.06	1.10	1.07 ± 0.03	1.05 ± 0.02	1.00	1.03 ± 0.02	1.07 ± 0.02	1.15	1.11 ± 0.04	1.05 ± 0.06	–	1.10
Width of eye	0.40	0.41 ± 0.01	0.39 ± 0.01	0.40	0.46 ± 0.01	0.42 ± 0.02	0.40	0.44 ± 0.04	0.36 ± 0.02	0.35	0.38 ± 0.02	0.38 ± 0.02	0.40	0.43 ± 0.02	0.35 ± 0.04	–	0.40
Upper interocular distance	1.00	0.94 ± 0.04	1.05 ± 0.00	0.90	0.90 ± 0.00	0.99 ± 0.04	0.93	0.93 ± 0.02	1.05 ± 0.01	0.95	0.93 ± 0.04	1.06 ± 0.03	0.93	0.93 ± 0.00	1.01 ± 0.03	–	1.00
Diameter of median ocellus	0.18	0.17 ± 0.01	0.17 ± 0.01	0.17	0.18 ± 0.01	0.13 ± 0.00	0.16	0.016 ± 0.01	0.16 ± 0.01	0.18	0.18 ± 0.00	0.16 ± 0.01	0.15	0.15 ± 0.01	0.15 ± 0.01	–	0.15
Inter ocellar distance	0.40	0.38 ± 0.01	0.38 ± 0.00	0.40	0.39 ± 0.01	0.38 ± 0.03	0.40	0.41 ± 0.01	0.40 ± 0.01	0.42	0.41 ± 0.01	0.45 ± 0.02	0.35	0.38 ± 0.02	0.41 ± 0.03	–	0.33
Ocellular distance	0.18	0.17 ± 0.01	0.20 ± 0.00	0.14	0.15 ± 0.02	0.20 ± 0.00	0.13	0.13 ± 0.01	0.20 ± 0.01	0.15	0.15 ± 0.00	0.26 ± 0.02	0.12	0.13 ± 0.01	0.21 ± 0.02	–	0.23
Maximum width of clypeus	0.35	0.32 ± 0.02	0.32 ± 0.01	0.30	0.33 ± 0.03	0.29 ± 0.01	0.35	0.35 ± 0.01	0.36 ± 0.01	0.35	0.33 ± 0.04	0.33 ± 0.02	0.35	0.38 ± 0.03	0.43 ± 0.05	–	0.33
Maximum width of clypeus	0.60	0.62 ± 0.02	0.74 ± 0.02	0.60	0.60 ± 0.01	0.68 ± 0.03	0.60	0.63 ± 0.02	0.74 ± 0.02	0.60	0.60 ± 0.00	0.74 ± 0.02	0.63	0.66 ± 0.04	0.57 ± 0.04	–	0.70
Malar space length	0.01	0.01 ± 0.01	0.05 ± 0.00	0.01	0.01 ± 0.00	0.05 ± 0.00	0.01	0.01 ± 0.00	0.01 ± 0.01	0.00	0.00	0.02 ± 0.01	0.01	0.01 ± 0.00	0.05 ± 0.00	–	0.03
Length of scape	0.45	0.49 ± 0.01	0.60 ± 0.00	0.45	0.45 ± 0.00	0.55 ± 0.00	0.45	0.45 ± 0.00	0.58 ± 0.01	0.48	0.47 ± 0.02	0.55 ± 0.01	0.45	0.45 ± 0.01	0.55 ± 0.04	–	0.57
Width of scape	0.12	0.12 ± 0.01	0.10 ± 0.00	0.10	0.10 ± 0.00	0.10 ± 0.00	0.10	0.10 ± 0.00	0.10 ± 0.00	0.10	0.10 ± 0.00	0.13 ± 0.01	0.12	0.12 ± 0.00	0.10 ± 0.00	–	0.10
Length of pedicel + flagellum	1.70	1.77 ± 0.06	1.38 ± 0.04	1.70	1.68 ± 0.05	1.35 ± 0.05	1.60	1.55 ± 0.06	1.22 ± 0.04	1.55	1.55 ± 0.00	1.23 ± 0.03	1.60	1.57 ± 0.04	1.23 ± 0.07	–	1.24
Length of flagellomere 1	0.07	0.06 ± 0.01	0.10 ± 0.00	0.08	0.08 ± 0.01	0.08 ± 0.00	0.06	0.06 ± 0.01	0.08 ± 0.01	0.07	0.07 ± 0.00	0.11 ± 0.01	0.05	0.06 ± 0.01	0.08 ± 0.00	–	0.09

Table 1 (continued)

↓Parameter / Species →	<i>Tetragonula vikrami</i> sp. n.			<i>Tetragonula sumae</i> sp. n.			<i>Tetragonula ashishi</i> sp. n.			<i>Tetragonula shishirae</i> sp. n.			<i>Tetragonula shubhami</i> sp. n.			<i>Tetragonula iridipennis</i> (Smith, 1854)	
	Holo-type Male	Paratypes Male [#] n=10	Female [#] n=10	Holo-type Male	Paratypes Male [#] n=3	Female [#] n=10	Holo-type Male	Paratypes Male [#] n=10	Female [#] n=10	Holo-type Male	Paratypes Male [#] n=2	Female [#] n=10	Holo-type Male	Paratypes Male [#] n=5	Female [#] n=10	Male*	Female**
Length of flagellomere 2	0.17	0.15 ± 0.02	0.10 ± 0.00	0.13	0.12 ± 0.01	0.10 ± 0.00	0.13	0.13 ± 0.01	0.10 ± 0.00	0.15	0.15 ± 0.00	0.14 ± 0.01	0.15	0.15 ± 0.00	0.10 ± 0.00	–	0.07
Length of flagellomere 3	0.16	0.15 ± 0.00	0.10 ± 0.00	0.13	0.12 ± 0.01	0.10 ± 0.00	0.13	0.13 ± 0.01	0.10 ± 0.00	0.13	0.13 ± 0.00	0.14 ± 0.01	0.15	0.15 ± 0.01	0.10 ± 0.00	–	0.10
Width of flagellomere 3	0.15	0.15 ± 0.00	0.13 ± 0.00	0.15	0.14 ± 0.02	0.13 ± 0.00	0.15	0.15 ± 0.01	0.13 ± 0.00	0.13	0.13 ± 0.00	0.14 ± 0.01	0.14	0.14 ± 0.00	0.12 ± 0.00	–	0.12
Length of mandible	0.43	0.45 ± 0.04	0.59 ± 0.03	0.45	0.44 ± 0.01	0.55 ± 0.00	0.40	0.40 ± 0.01	0.62 ± 0.04	0.40	0.40 ± 0.00	0.63 ± 0.00	0.40	0.43 ± 0.02	0.60 ± 0.03	–	0.62
Width of mandible	0.20	0.20 ± 0.02	0.25 ± 0.02	0.18	0.19 ± 0.01	0.23 ± 0.00	0.18	0.18 ± 0.00	0.29 ± 0.02	0.18	0.18 ± 0.00	0.27 ± 0.01	0.18	0.18 ± 0.00	0.24 ± 0.03	–	0.19
Length of forewing + tegula	4.00	4.07 ± 0.18	3.98 ± 0.08	3.90	3.85 ± 0.06	3.62 ± 0.13	3.80	3.73 ± 0.11	3.76 ± 0.02	3.60	3.70 ± 0.14	3.71 ± 0.05	3.90	3.77 ± 0.17	3.72 ± 0.14	4.00	3.80
Width of forewing	1.30	1.32 ± 0.04	1.32 ± 0.06	1.20	1.21 ± 0.03	1.20 ± 0.00	1.30	1.27 ± 0.04	1.42 ± 0.03	1.25	1.25 ± 0.00	1.25 ± 0.06	1.20	1.23 ± 0.04	1.29 ± 0.07	–	1.32
Length of pre-ostigma marginal cell	0.65	0.67 ± 0.05	0.59 ± 0.02	0.55	0.55 ± 0.00	0.57 ± 0.03	0.55	0.55 ± 0.00	0.55 ± 0.00	0.50	0.53 ± 0.04	0.50 ± 0.05	0.55	0.55 ± 0.00	0.49 ± 0.02	–	0.48
Length of marginal cell	1.27	1.28 ± 0.03	1.30 ± 0.00	1.20	1.21 ± 0.03	1.25 ± 0.05	1.20	1.23 ± 0.03	1.21 ± 0.04	1.10	1.13 ± 0.04	1.17 ± 0.06	1.25	1.26 ± 0.04	1.21 ± 0.07	–	1.21
Width of marginal cell	0.32	0.32 ± 0.02	0.32 ± 0.02	0.25	0.27 ± 0.02	0.30 ± 0.00	0.29	0.28 ± 0.02	0.33 ± 0.03	0.25	0.26 ± 0.01	0.29 ± 0.02	0.30	0.29 ± 0.01	0.27 ± 0.03	–	0.30
Wing diagonal length	1.15	1.15 ± 0.04	1.07 ± 0.03	1.00	0.99 ± 0.03	1.10 ± 0.10	1.00	0.98 ± 0.04	0.99 ± 0.04	0.85	0.85 ± 0.00	1.02 ± 0.05	1.00	0.98 ± 0.04	1.02 ± 0.04	1.16	1.01
Hamuli	5.00	5.00 ± 0.00	5.00 ± 0.00	5.00	5.00 ± 0.00	5.33 ± 0.58	5.00	5.00 ± 0.04	5.00 ± 0.00	05	5.50 ± 0.71	5.8 ± 0.42	5.00	5.00 ± 0.00	5.03 ± 0.18	–	5.00
Length of mesoscutum	1.05	1.07 ± 0.04	1.04 ± 0.02	1.00	0.94 ± 0.05	1.00 ± 0.00	1.05	1.03 ± 0.04	1.05 ± 0.00	1.00	1.03 ± 0.04	1.00 ± 0.04	1.05	0.97 ± 0.06	0.98 ± 0.05	–	0.87
Maximum width of mesoscutum	1.20	1.21 ± 0.04	1.11 ± 0.02	1.10	1.10 ± 0.04	1.08 ± 0.03	1.10	1.11 ± 0.05	1.11 ± 0.02	1.10	1.13 ± 0.04	1.13 ± 0.03	1.10	1.08 ± 0.04	1.08 ± 0.08	–	1.01
Length of hind tibia	1.40	1.43 ± 0.03	1.50 ± 0.00	1.40	1.40 ± 0.04	1.43 ± 0.03	1.40	1.36 ± 0.03	1.40 ± 0.03	1.20	1.23 ± 0.04	1.27 ± 0.05	1.35	1.33 ± 0.03	1.47 ± 0.07	1.55	1.55
Width of hind tibia	0.55	0.55 ± 0.02	0.55 ± 0.00	0.52	0.52 ± 0.02	0.48 ± 0.03	0.50	0.50 ± 0.02	0.53 ± 0.02	0.45	0.45 ± 0.00	0.52 ± 0.02	0.52	0.52 ± 0.01	0.52 ± 0.03	–	0.54

Table 1 (continued)

Parameter / Species →	<i>Tetragonula vikrami</i> sp. n.		<i>Tetragonula sumae</i> sp. n.		<i>Tetragonula ashishi</i> sp. n.		<i>Tetragonula shishirae</i> sp. n.		<i>Tetragonula shubhami</i> sp. n.		<i>Tetragonula iridipennis</i> (Smith, 1854)	
	Holo-type Male	Paratypes Male [#] n=10	Holo-type Male	Paratypes Male [#] n=3	Holo-type Male	Paratypes Male [#] n=10	Holo-type Male	Paratypes Male [#] n=2	Holo-type Male	Paratypes Male [#] n=5	Holo-type Male	Paratypes Male [#] n=10
Length of hind basi-tarsus	0.52	0.54 ± 0.02	0.62 ± 0.03	0.55 ± 0.00	0.50	0.53 ± 0.03	0.53 ± 0.04	0.45 ± 0.00	0.57 ± 0.03	0.52	0.50 ± 0.03	0.52 ± 0.02
Width of hind basi-tarsus	0.28	0.29 ± 0.01	0.30 ± 0.00	0.26 ± 0.02	0.25	0.25 ± 0.00	0.26 ± 0.01	0.20 ± 0.00	0.27 ± 0.01	0.25	0.26 ± 0.01	0.27 ± 0.03

***Based on data from Sakagami (1978); Based on data of the primary type (Rasmussen 2013); # Mean (mm) ± Standard deviation

Paratypes: Females

Colouration Similar to male holotype except for the following variations. Scape uniformly yellowish brown; pedicel and upper flagellomeres darker brown while bright yellow on lower side compared to males. (Fig. 2c) Mandibles reddish brown with dark brown to black patches basally and apically; inner margin of mandible distinctly sinuate (Fig. 2d).

Pilosity Clypeus, entire face up to the median ocellus clothed with small, plumose white hairs with high density on clypeus and lower part of face (Fig. 2c); vertex, upper part of occiput with dark brown erect short hairs; lower part of occiput, post gena with fine white hairs. Mesoscutum with indistinct longitudinal bands of hairs; margins of mesoscutum fringed with brownish-grey hairs; mesoscutellar margin heavily fringed with yellowish intermixed with dark brown hairs; mesepisternum with white plumose hairs on the upper part while long simple hairs on the lower part (Fig. 2b), metepisternum, laterals of propodeum with dense short plumose white hairs obscuring the underlying integument. Legs with brown and dark brown hairs. Metasomal terga with short white hairs at basal margin, density of which increases towards terminal terga; sterna with white simple hairs having high density on the terminal sterna as well as on medial part of each sternum (Fig. 2a).

Morphometry Detailed morphometry of females is presented in Table 1. Body length 4.07 mm; head 1.32× wider than its length (1.25 mm); compound eyes 2.82× longer than its width (0.39 mm); upper interocular distance 1.05 mm; interocellar distance 0.38 mm; malar space length 0.05 mm; forewings 3.98 mm long, 1.32 mm wide; wing diagonal length 1.07 mm; hind tibiae 1.50 mm long, 0.55 mm wide; hind basitarsus 2.06× longer than its width (0.30 mm).

Ratios of head length to width 0.73 (Table 2); eye length to upper interocular distance 1.08; interocellar to cello-ocular distance 1,80; forewing length to width 2.97; forewing diagonal length to head width 0.67; hind tibial length to forewing diagonal length 1.31.

Material examined Holotype: Male: Karnataka: Mankalale. 25. iii. 2019. Coll. Bhat S. deposited at UASB. Paratypes: 44 males, 24 females with the same collection data deposited at UASB, one paratype male will be deposited each at IARID and ZSIK.

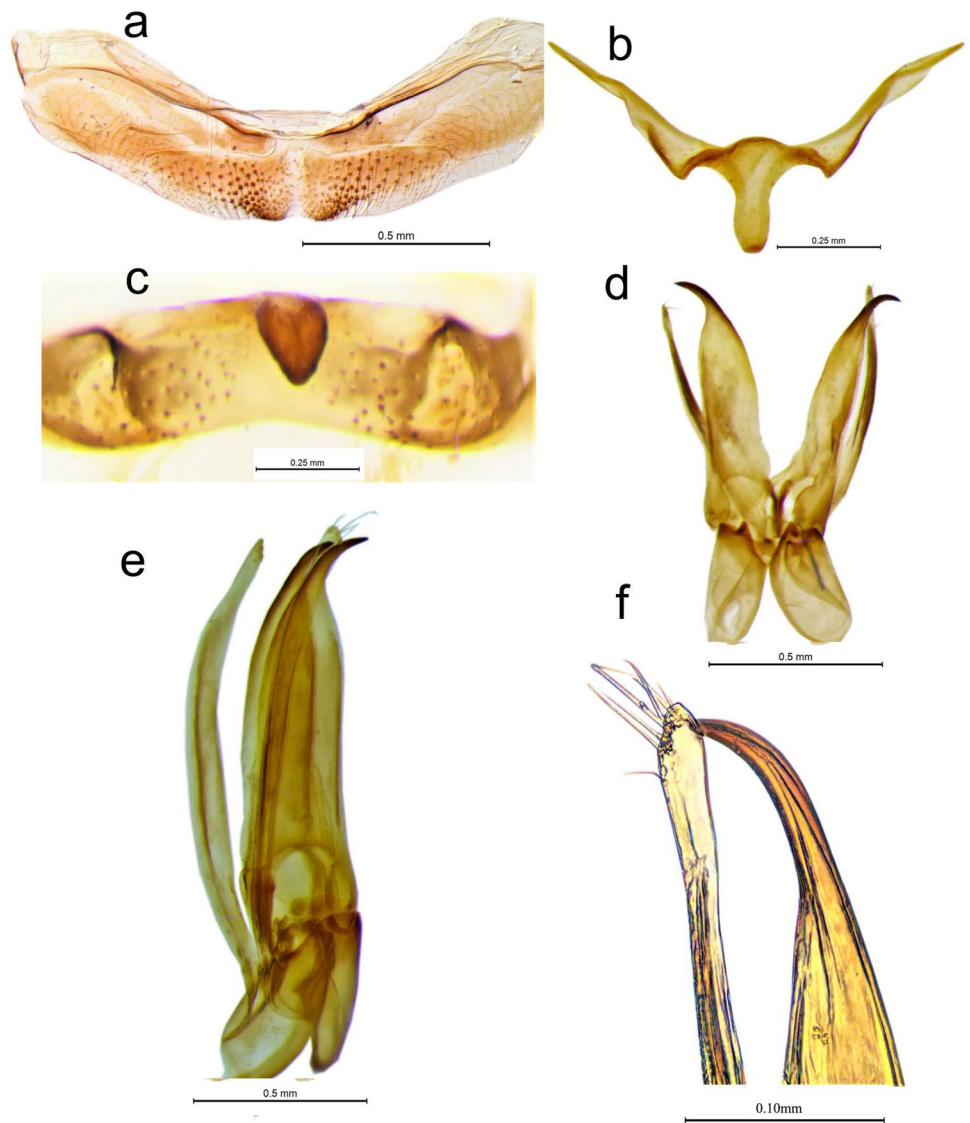
Name derivation This species is named as a tribute to Mr. Vikram a Covid-19 warrior who later became a victim of it.

Table 2 Ratios of body parts of *Tetragonula* and *Tetragonula iridipennis*

↓Ratio/Species→	<i>Tetragonula vikrami</i> sp. n.			<i>Tetragonula sumae</i> sp. n.			<i>Tetragonula ashishi</i> sp. n.			<i>Tetragonula shishirae</i> sp. n.			<i>Tetragonula shubhami</i> sp. n.			<i>Tetragonula iridipennis</i> (Smith, 1854)*	
	Holotype	Male n=5	Female n=5	Holotype	Male n=5	Female n=5	Holotype	Male n=5	Female n=5	Holotype	Male n=5	Female n=5	Holotype	Male n=5	Female n=5	Male	Female
Head length/Head width	0.77	0.76±0.01	0.73 ± 0.01	0.71	0.71±0.02	0.73 ± 0.01	0.77	0.74±0.02	0.78 ± 0.03	0.76	0.76±0.00	0.85 ± 0.04	0.78	0.78±0.04	0.80 ± 0.02	–	–
Eye length/Upper interocular distance	1.10	1.19±0.05	1.08 ± 0.06	1.17	1.17±0.00	1.15 ± 0.02	1.18	1.13±0.05	0.98 ± 0.03	1.05	1.11±0.08	1.00 ± 0.00	1.24	1.20±0.05	1.07 ± 0.03	1.08	0.97
Interocellar/Ocello-ocular distance	2.22	2.13±0.05	1.80 ± 0.07	2.86	2.68±0.41	1.89 ± 0.09	3.08	3.18±0.29	2.04 ± 0.10	2.80	2.74±0.09	1.73 ± 0.17	2.92	2.87±0.29	1.95 ± 0.11	–	1.78
Scape length/Eye length	0.41	0.41±0.03	0.50 ± 0.00	0.43	0.43±0.00	0.48 ± 0.02	0.41	0.43±0.02	0.54 ± 0.02	0.48	0.45±0.05	0.51 ± 0.02	0.39	0.41±0.01	0.51 ± 0.03	0.43	0.53
Forewing length/Forewing width	3.08	3.06±0.19	2.97 ± 0.06	3.25	3.23±0.13	3.02 ± 0.07	2.92	2.97±0.10	2.64 ± 0.05	2.88	2.96±0.11	2.98 ± 0.15	3.25	3.10±0.24	2.76 ± 0.07	–	–
Forewing diagonal length/Head width	0.74	0.72±0.05	0.67 ± 0.02	0.63	0.63±0.02	0.70 ± 0.04	0.67	0.66±0.05	0.66 ± 0.05	0.56	0.58±0.02	0.71 ± 0.06	0.68	0.67±0.05	0.66 ± 0.04	0.69	0.66
Hind tibial length/Head width	0.90	0.90±0.03	0.86 ± 0.04	0.89	0.89±0.01	0.92 ± 0.03	0.93	0.90±0.05	0.91 ± 0.03	0.79	0.83±0.05	0.91 ± 0.04	0.92	0.91±0.06	0.99 ± 0.03	0.90	0.94
Hind tibial length/Forewing diagonal length	1.22	1.25±0.06	1.31 ± 0.04	1.40	1.42±0.05	1.31 ± 0.10	1.40	1.38±0.07	1.39 ± 0.08	1.41	1.44±0.04	1.29 ± 0.08	1.35	1.36±0.05	1.50 ± 0.07	1.37	1.49
Hind tibial width/Hind tibial length	0.39	0.38±0.01	0.36 ± 0.03	0.37	0.37±0.01	0.34 ± 0.01	0.36	0.36±0.01	0.38 ± 0.01	0.38	0.36±0.03	0.40 ± 0.02	0.39	0.38±0.01	0.33 ± 0.01	0.38	0.36
Hind basitarsus width/Hind tibial width	0.51	0.50±0.04	0.49 ± 0.02	0.48	0.50±0.01	0.54 ± 0.05	0.50	0.51±0.01	0.50 ± 0.02	0.44	0.46±0.02	0.54 ± 0.02	0.48	0.49±0.04	0.50 ± 0.00	0.49	0.53
Length and width of medio-apical process of sternum 6		3.62		2.54		2.80		2.80		2.39		2.58		2.30			

*Based on data from Sakagami (1978)

Fig. 3 *Tetragonula vikrami* sp. n. **a** Male sternum 5, **b** male sternum 6 dorsal view, **c** male sternum 6 top view, **d** male genitalia dorsal view, **e** genitalia lateral view, **f** terminal part of gonostylus and penis valve closer view

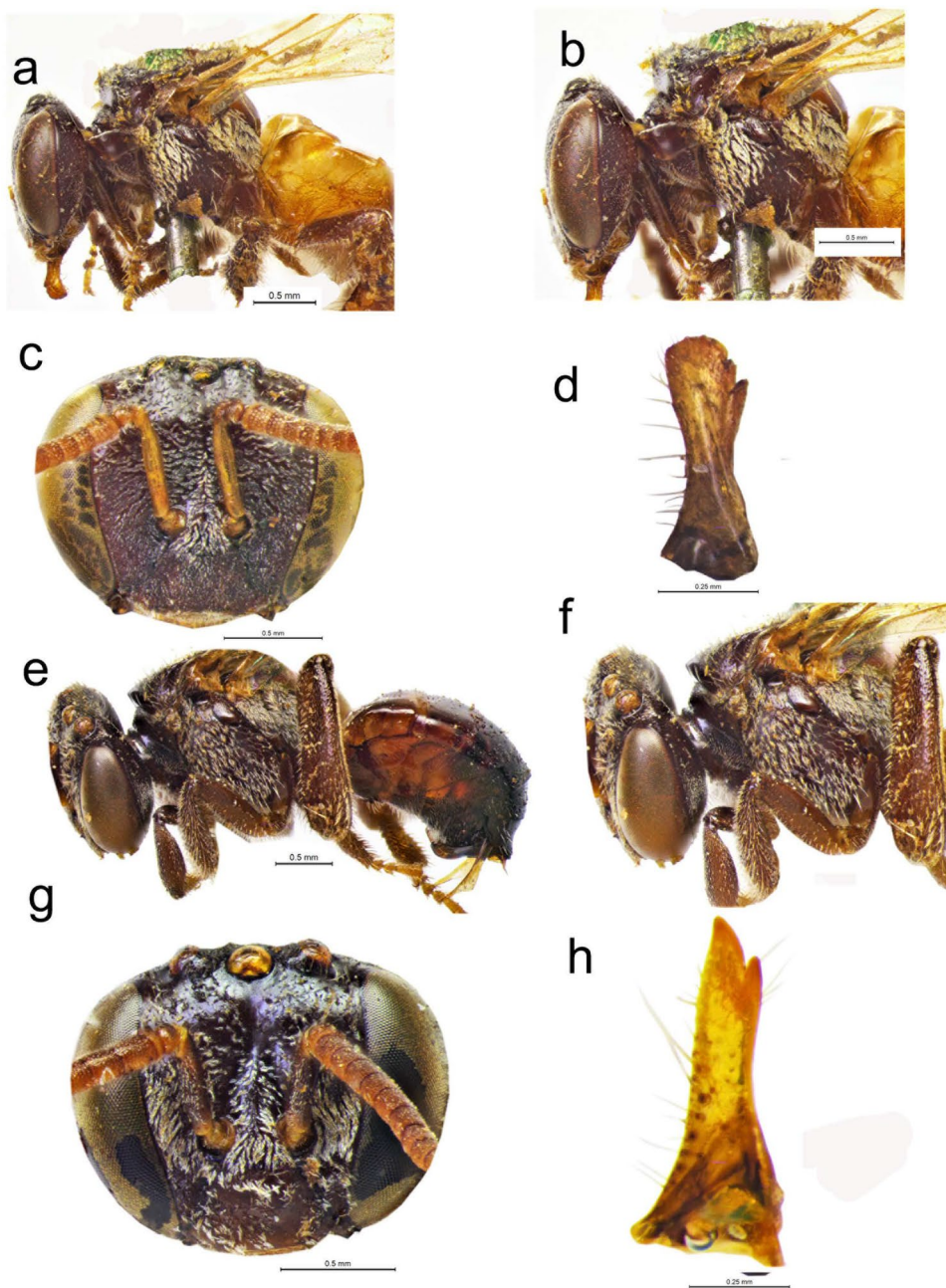


***Tetragonula sumae* Viraktamath sp. n.**

Diagnosis Male bees measure 3.68 ± 0.26 mm and 1.57 ± 0.04 mm in body length and head width, respectively. Female bees measure 3.58 ± 0.18 mm in body length and 1.57 ± 0.03 mm in head width. This species is characterized by the presence of dense plumose hairs on the clypeus, face, mesepisternum, metepisternum and lateral areas of propodeum; indistinct longitudinal bands of hairs on mesoscutum. The species differs from all other species of *Tetragonula* in having the gonostylus lamellate, broad, curved inwards longitudinally, terminating into an outwardly curved finger-like structure; penis valve being very robust terminating in an outwardly curved hook. Though *T. iridipennis*, *T. geissleri* Cockerell, 1918 and *T. hirashimai* Sakagami, 1978 have robust penis valves. Gonostylus is not lamellate and broad. Male genitalia resembles those of *T. ashishi* sp. n., *T. shishirae* sp. n.

and *T. shubhami* sp. n. However, *T. sumae* can be differentiated based on the longer gonostylus (0.90 mm as against 0.60, 0.58 and 0.65 mm in *T. ashishi*, *T. shishirae* and *T. shubhami*, respectively) with a shorter finger-like terminal structure (0.22 mm long while 0.35, 0.38 and 0.37 mm in *T. ashishi*, *T. shishirae* and *T. shubhami*, respectively) (Fig. 13b-gs). The penis valve 0.65 mm long as against 0.60, 0.58 and 0.65 mm long in *T. ashishi*, *T. shishirae* and *T. shubhami*, respectively. The penis valve terminates into a very short hook (0.05 mm long versus 0.08, 0.13, 0.10 mm in other three new species, respectively). (Fig. 13b-pv). *T. sumae* also differs from the other three new species in the structure of sternum 5 and 6. In *T. sumae*, the gradulus does not touch the antecosta in sternum 5 and apical margin convex medially with an elongate oval marking (Figs. 5a, 12b-s5) while in *T. ashishi*, the pregradulus is extensive and gradulus

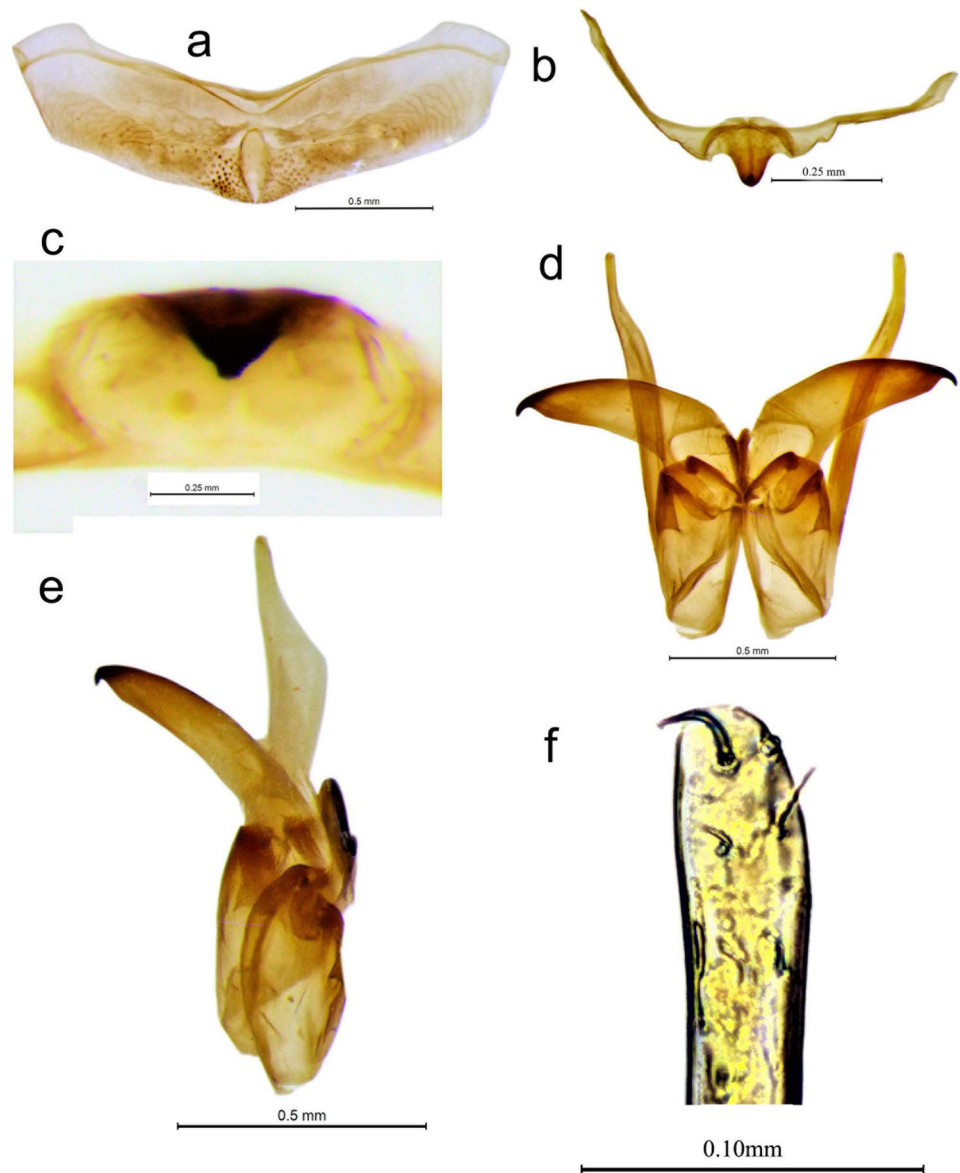
Fig. 4 *Tetragonula sumae* sp. n. Female paratype: **a** lateral habitus, **b** head and thorax closer lateral view, **c** head frontal view, **d** mandible. Male holotype: **e** lateral habitus, **f** head and thorax closer lateral view, **g** head frontal view, **h** mandible



touching the antecosta only in the medial region, the apical margin with a distinct broad concavity medially with an inverted V-shaped marking touching the antecosta (Fig. 12c-s5). In *T. shishirae* gradulus briefly touches the antecosta medially, apical margin with a distinct inverted “U” shaped notch medially (Fig. 12d-s5) while in *T. shubhami* Gradulus is very close to antecosta without touching it, apical margin without any notch (Fig. 12e-s5). The

antecosta in sternum 6 is gently convex medially in *T. sumae* (Fig. 12b-s6), convex medially, angularly bisinuate laterally in *T. ashishi* (Fig. 12c-s6), gently convex in *T. shishirae* (Fig. 12d-s6) and gently convex and bisinuate laterally in *T. shubhami* (Fig. 12e-s6). The medio-apical process of sternum 6 is 2.54× longer than wide in *T. sumae* while in *T. ashishi*, *T. shishirae* and *T. shubhami* it is 2.80, 2.39 and 2.58× longer than wide, respectively.

Fig. 5 *Tetragonula sumae* sp. n. **a** Male sternum 5, **b** male sternum 6 dorsal view, **c** male sternum 6 top view, **d** male genitalia dorsal view, **e** genitalia lateral view, **f** terminal part of gonostylus closer view



Description

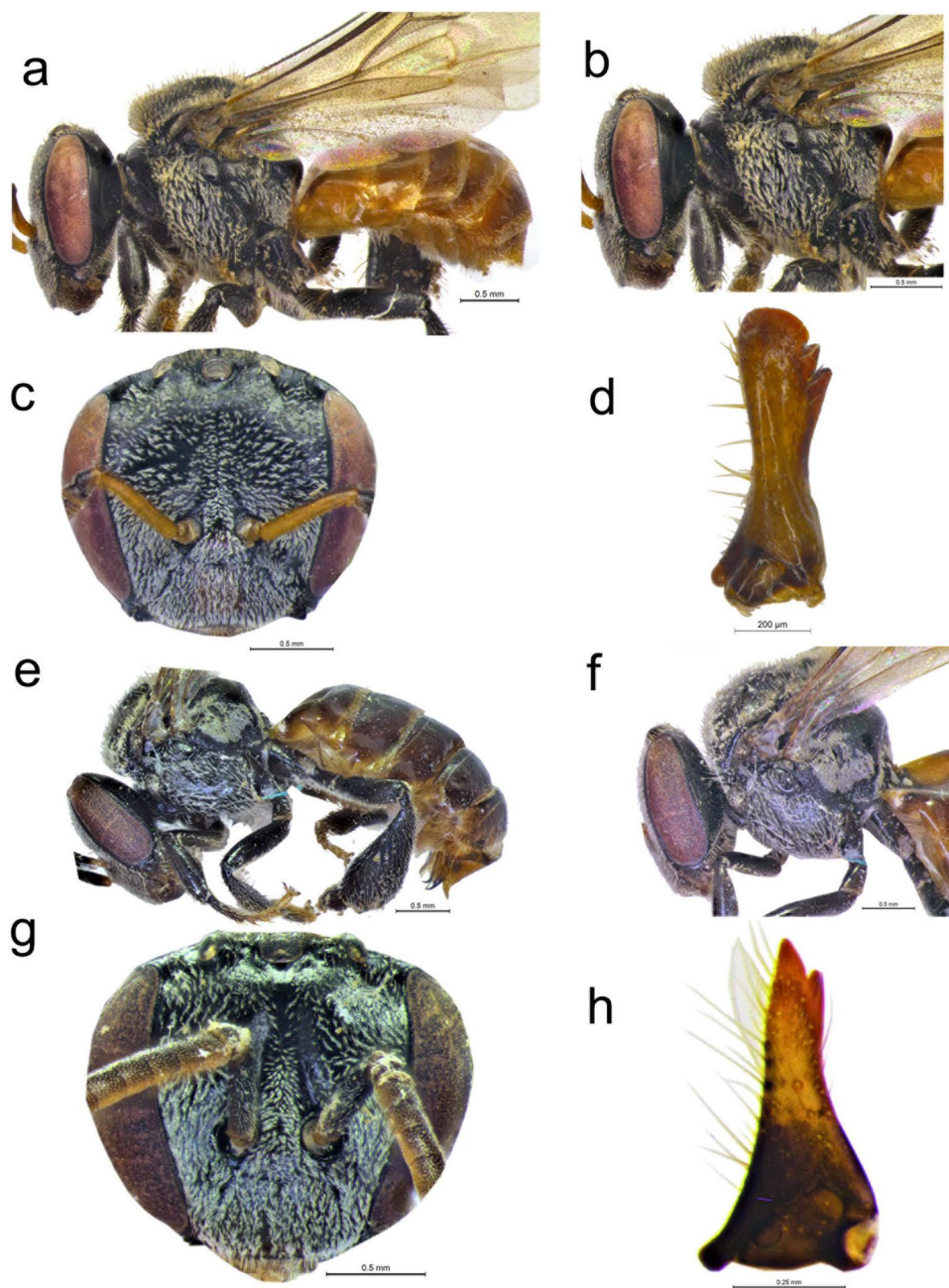
Holotype: Male

Colouration Body shiny. Head dark brown; ocelli transparent, yellowish-brown; compound eyes dull yellowish-brown; scape, pedicel dark reddish-brown; flagellomeres ochraceous both on upper and lower side (Fig. 4g); mandible yellowish with brown patches both at basally and apically (Fig. 4h). Mesosoma reddish-brown; tegulae reddish-brown; wing with brownish tinge; pterostigma, veins light yellowish-brown legs reddish-brown. The first three metasomal terga and four sterna light reddish brown while the remaining

terminal terga and sterna dark reddish-brown approaching black (Fig. 4e).

Pilosity Clypeus, face up to the ocellar triangle clothed with white plumose white hairs, with high intensity on clypeus and lower part of face (hairs worn out in patches on clypeus and face) (Fig. 4g); vertex, occiput, postgena with ochraceous long, erect hairs; lower part of occiput with a patch of ochraceous short hairs. Mesoscutum without distinct longitudinal bands of hairs but integument covered with ochraceous short hairs; mesoscutellum heavily fringed with long yellow hairs. Mesepisternum clothed with dense, long plumose white hairs; metepisternum, laterals of propodeum with thick felt of white, plumose short hairs obscuring the

Fig. 6 *Tetragonula ashishi* sp. n. Female paratype: **a** lateral habitus, **b** head and thorax closer lateral view, **c** head frontal view, **d** mandible. Male holotype: **e** lateral habitus, **f** head and thorax closer lateral view, **g** head frontal view, **h** mandible



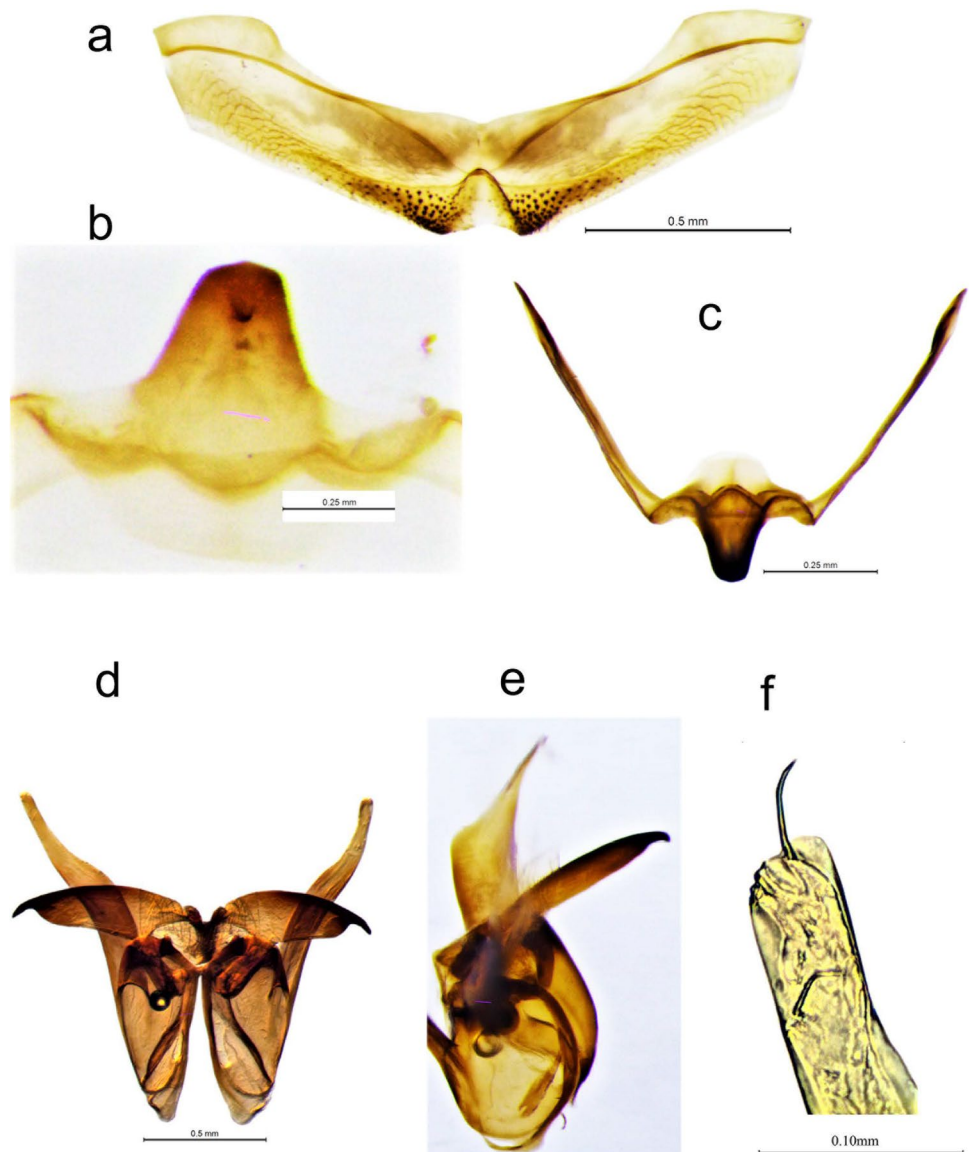
underlying integument (Fig. 4f). All legs with yellowish hairs; anterior, posterior margins and upper surface of hind tibia with short white setae. Metasomal terga with sparse white hairs; sterna with fine dense white hairs.

Morphometry Detailed morphometry of holotype is presented in Table 1. Body 4.00 mm long with head width 1.58 mm; head length 1.12 mm; upper interocular distance

0.90 mm while interocellar distance 0.40 mm; malar space length 0.01 mm; mandibles 2.5× longer than its width (0.18 mm); forewings 3.90 mm long, 1.20 mm wide; wing diagonal length 1.00 mm; hind tibia 2.54× longer than hind basitarsus (0.55 mm).

Ratios of head length to width 0.71; eye length to upper interocular distance 1.17; interocellar to cello-ocular distance 2.86; forewing length to width 3.25; forewing diagonal

Fig. 7 *Tetragonula ashishi* sp. n. **a** Male sternum 5, **b** male sternum 6 dorsal view, **c** male sternum 6 top view, **d** male genitalia dorsal view, **e** genitalia lateral view, **f** terminal part of gonostylus closer view



length to head width 0.63; hind tibial length to forewing diagonal length 1.40 (Table 2).

Genitalia Gradulus not touching the antecosta medially in sternum 5; apical margin gently convex medially with an elongate oval marking (Fig. 5a); antecosta of sternum 6 gently convex medially ((Fig. 5b), medio-apical process 2.54× longer than wide, tapering, incurved terminating in a broad bluntly rounded apex (Fig. 5c). Genitalia yellowish-brown with apical 1/4th gonocoxa borders dark brown (Fig. 5d); gonocoxae and gonostyli oriented vertically while penis valves transversely oriented; gonostylus lamellate arising laterally on gonocoxa, 0.90 mm long with two lateral margins curved inwards longitudinally throughout their length of 0.68 mm at which both layers gently curved outwards and then inwards forming a 0.22 mm long, 0.05 mm

wide finger-like structure terminating into a rounded apex (Fig. 5d–f); gonostylus 0.13 mm wide at the base but narrowing to 0.10 mm after a short distance and gradually widening to 0.13 mm where it curves outwards and later gradually narrowing to 0.05 mm near the apex which bears two long setae on both lateral sides (Fig. 5e, f). Penis valve robust, 0.65 mm long, 0.18 mm at the base then narrowed to 0.15 mm and to 0.10 mm where it curves outwards into a dark reddish-brown 0.05 mm long, 0.02 mm wide hook (Figs. 5d, 13b–pv).

Paratypes: Males

Resemble the holotype in coloration and pilosity except the following variations. Scape, pedicel reddish-brown in some males. Flagellomeres, compound eyes dark reddish-brown.

Morphometry Body 2.34× longer than its head width (1.57 mm) (Table 1); head length 1.12 mm; upper interocular distance 2.31× greater than interocellar distance (0.39 mm); median ocellus diameter 18× greater than malar space length; scape length 4.5× greater than its diameter (0.10 mm); forewing 3.85 mm long, 1.21 mm wide; wing diagonal length 0.99 mm; hind tibia 2.55× longer than hind basitarsus length (0.55 mm).

Ratios of head length to width 0.71 (Table 2); eye length to upper interocular distance 1.17; interocellar to cello-ocular distance 2.68; forewing length to width 3.23; hind tibial to forewing diagonal length 1.42.

Paratypes: Females

Coloration Body coloration similar to males (Fig. 4a–c) but one female lighter reddish-brown than the males. Mandibles dark brown at the basal half and light brown apical half (Fig. 4d).

Pilosity Similar to the male. In some white plumose hairs on the clypeus, face, mesepisternum, metepisternum and lateral sides of propodeum are quite dense obscuring underlying integument (Fig. 4b, c).

Morphometry Detailed morphometry is presented in Table 1. Females measure 3.58 mm in length and 1.57 mm in head width; head length 1.15 mm; compound eyes 1.13 mm long, 0.42 mm wide; upper interocular distance 2.61× greater than interocellar distance (0.38 mm); diameter of median ocellus 2.60× greater than malar space length (0.05 mm); scape 0.55 mm long, 0.10 mm wide; mandible 2.39× longer than its width (0.23 mm); forewing 3.62 mm long, 1.20 mm wide; wing diagonal length 1.10 mm; hind tibia 1.43 mm long, 0.48 mm wide while hind basitarsus 0.52 mm long and 0.26 mm wide.

Ratios of head length to width 0.73; eye length to upper interocular distance 1.15; interocellar to cello-ocular distance 1.89; forewing length to width 3.02 (Table 2).

Material examined Holotype: Male: Tamil Nadu: Salem. 15. vi. 1915, Coll. Dutt GR deposited at UASB. Paratypes: Three males and two females with the same collection data deposited at UASB.

Name derivation This species is named in honor of Mrs. Suma Viraktamath who is a constant source of inspiration, encouragement and support to the senior author (SV) to undertake this research on Indian stingless bees.

Tetragonula ashishi Viraktamath and Jagruti sp. n.

Diagnosis Male bees are 4.19 ± 0.18 mm long with 1.51 mm head width while the female bees 3.74 ± 0.07 mm long and 1.52 ± 0.02 mm in head width. This species is with dense, white plumose hairs on clypeus, lower half of face, mesepisternum, metepisternum, lateral areas of propodeum and distinct bands of longitudinal hairs on mesoscutum. The species can be distinguished from *T. sumae*, *T. shishirae* and *T. shubhami* by the shape, structure and size of male metasomal sterna 5 and 6 and genitalia (Figs. 12c–s5.s6, 13c–pv, c–gs). Pregradulus extensively developed in sternum 5, gradulus touching the antecosta medially; apical margin of sternum 5 with a distinct broad concavity medially and an inverted V-shaped marking touching the antecosta (Fig. 7a); the antecosta in sternum 6 distinctly convex medially and bisinuate laterally; the apico-medial process 2.80× longer than its width (Fig. 7b, c). The gonostylus 0.83 mm long including a 0.33 mm long and 0.05 mm wide outwardly curved finger-like structure. Penis valve 0.60 mm long terminating in a 0.08 mm long outwardly curved hook (Fig. 7d–f).

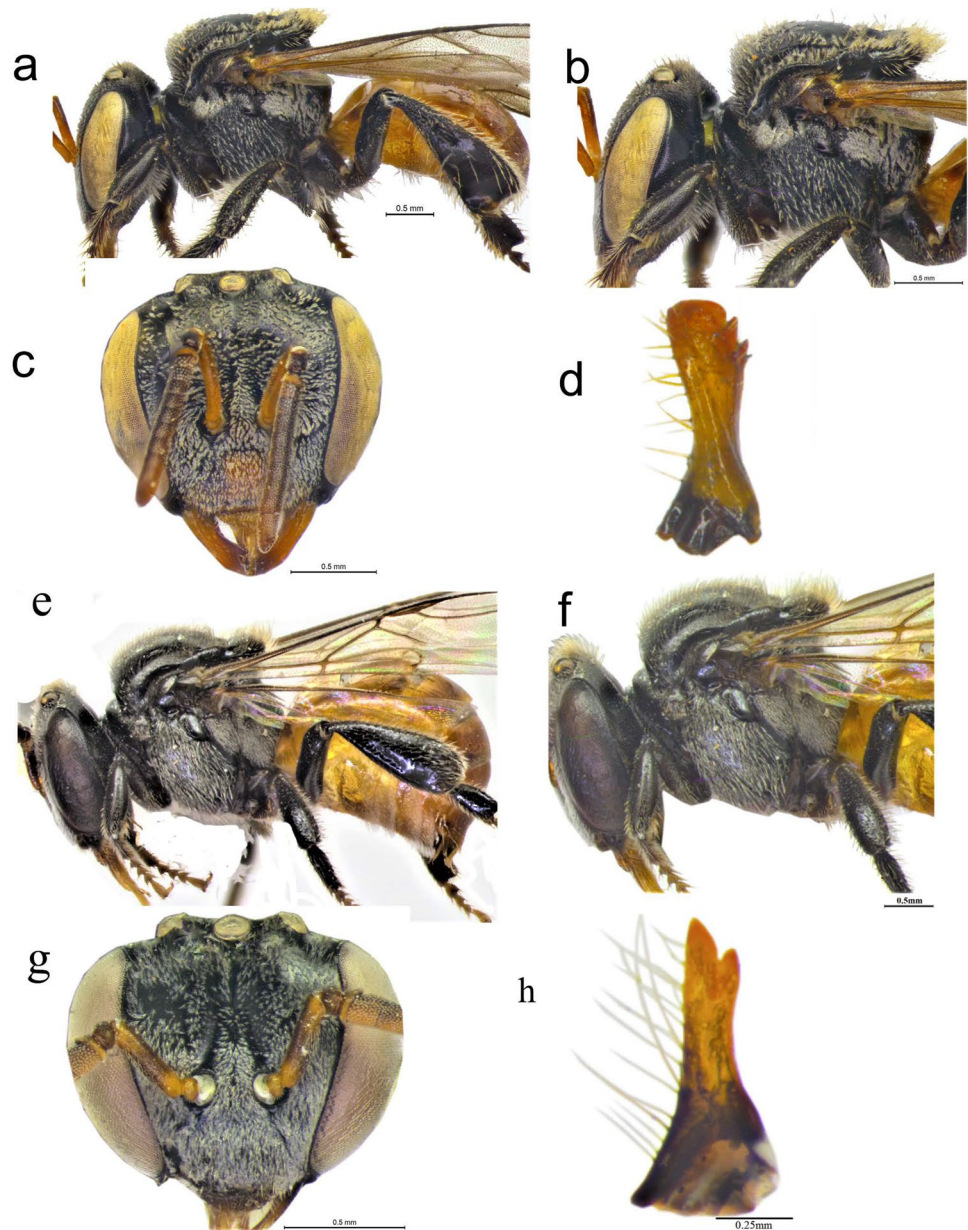
Description

Holotype: Male

Coloration Body shiny. Head black; scape, pedicel light brown with darker tinge on the dorsal side; flagellomeres dark brown on the upper side and yellow on the lower side; ocelli transparent dark brown; compound eyes reddish-brown (Fig. 6e, g); mandibles dark brown to black at the basal half, light brown at the apical half (Fig. 6h). Mesosoma black; tegula dark brown; wings with reddish-brown tinge; pterostigma, veins dark brown. Legs black except terminal four tarsal segments brown. Metasomal terga with dark brown basal half and light brown apical half thus appearing banded; sterna yellow (Fig. 6e).

Pilosity Clypeus, lower half of face clothed with dense white plumose hairs (Fig. 6g); upper half of face with less dense plumose white hairs; vertex, occiput with sparse brownish erect hairs; postgenal margin fringed with long yellowish hairs. Mesoscutum with distinct longitudinal bands of white hairs; lateral margins of mesoscutum fringed with short white hairs; mesoscutellar margin heavily fringed with long yellowish hairs. Mesepisternum, metepisternum and lateral part of propodeum with a felt of thick white plumose hairs (Fig. 6f). Legs with long white hairs except tarsi with yellow hairs; anterior and posterior margin, upper surface of hind tibia with short white hairs.

Fig. 8 *Tetragonula shishirae* sp. n. Female paratype: **a** lateral habitus, **b** head and thorax closer lateral view, **c** head frontal view, **d** mandible. Male holotype: **e** lateral habitus, **f** head and thorax closer lateral view, **g** head frontal view, **h** mandible



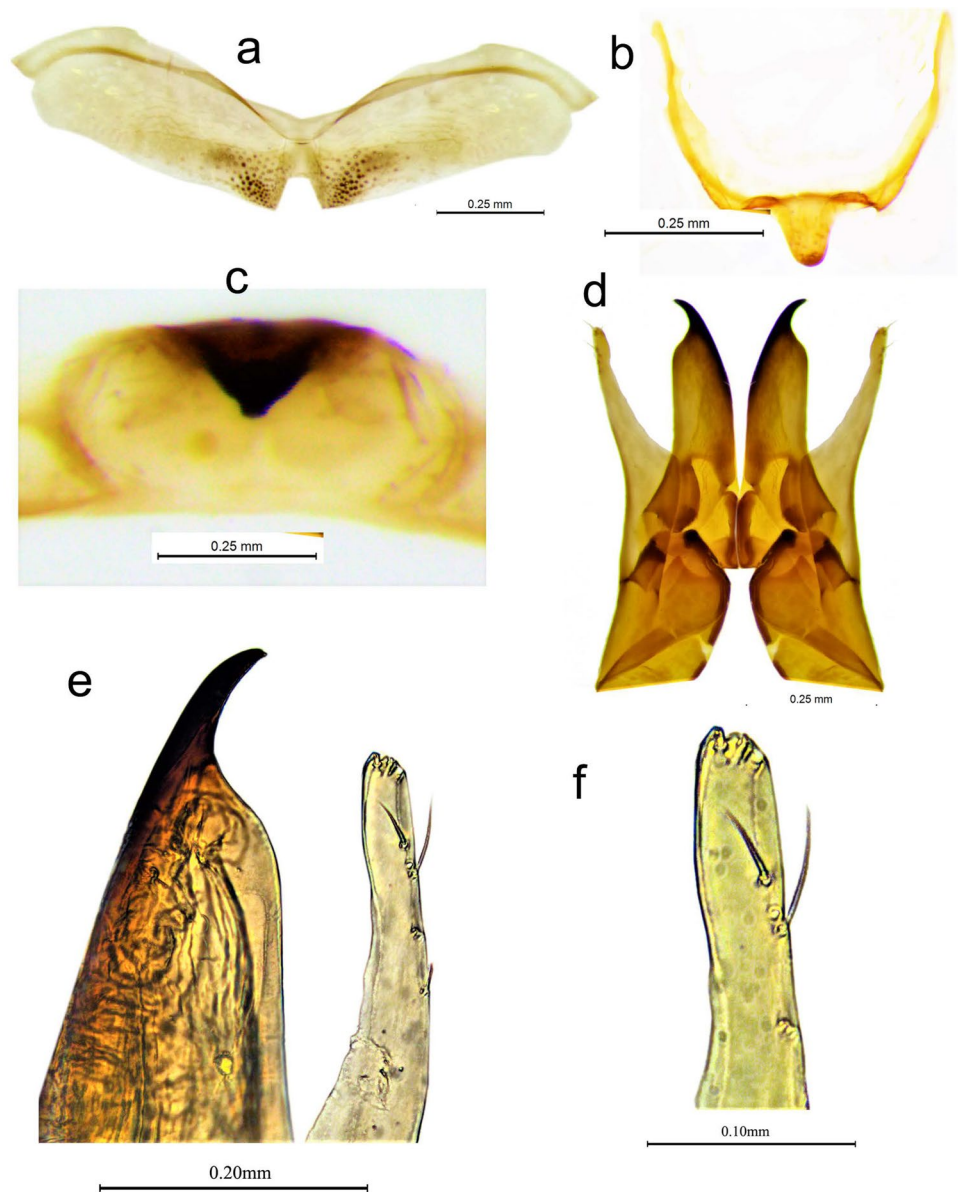
Morphometry Holotype male measures 4.35 mm in length, 1.50 and 1.15 mm in head width and length, respectively (Table 1); upper interocular distance 0.93 mm, interocellar and cello-ocular distance 0.40 and 0.13 mm, respectively; compound eye 1.10 long, 0.40 mm wide while the median ocellus diameter 0.16 mm; malar space length 0.01 mm while the scape 4.5× longer than its width (0.10 mm); mandible 0.40 mm long, 0.18 mm wide; forewing length 3.80 mm while width 1.30 mm; hind tibia 2.80× longer than the hind basitarsus (0.50 mm).

Ratios of head length to width 0.77; eye length to upper interocular distance 1.18; interocellar to cello-ocular distance 3.08; forewing length to width 2.92; forewing diagonal

length to head width 0.67; hind tibial length to forewing diagonal length 1.40 (Table 2).

Genitalia In sternum 5 pregradulus is extensive; gradulus touching the antecosta in the medial region; apical margin with a distinct broad concavity medially with an inverted V-shaped marking touching the antecosta (Fig. 7a); the antecosta in sternum 6 distinctly convex medially and bisinuate laterally; the apico-medial process 2.8× longer than its width terminating into an incurved narrowly rounded apex (Fig. 7b, c). Genitalia yellowish-brown with apical 1/4th of gonocoxae, lateral margins and terminal part of penis valves reddish dark brown;

Fig. 9 *Tetragonula shishirae* sp. n. **a** Male sternum 5, **b** male sternum 6 dorsal view, **c** male sternum 6 top view, **d** male genitalia dorsal view, **e** terminal part of gonostylus and penis valve, **f** terminal part of gonostylus closer view



gonocoxae oriented vertically, penis valves obliquely while penis valves transversely (Fig. 7d). Gonostylus arising laterally on gonocoxa, lamellate, with two lateral margins curved inwards longitudinally; 0.83 mm long, with an outward curve (at 0.48 mm length) of 0.33 mm long, 0.05 mm wide finger-like structure; basally 0.18 mm wide, maintaining the same width throughout till it curves outwards narrowing to 0.05 mm at apex (Fig. 7d, e). Penis valve very robust, 0.60 mm long, 0.23 mm wide at the base, narrowing to 0.20 mm after a short distance, later gradually narrowing to 0.18 mm where it turns outward forming a 0.08 mm long, 0.02 mm wide hook (Fig. 13c-pv).

Paratypes: Males

Similar to holotype in coloration and pilosity. In some males, metasomal sterna dark brown apical half and light brown basal half thus appearing banded.

Morphometry Males 4.19 mm in body length, 1.51 mm in head width and 1.11 mm head length (Table 1); compound eye 1.07 mm long, 0.44 mm wide; upper interocular distance 2.27× greater than interocellar distance (0.41 mm); median ocellus 1.6× greater than malar space length (0.01 mm); scape 0.45 mm long, 0.10 mm wide while the mandible 0.40 mm long and 0.18 mm wide; forewing length 3.73 mm,

width 1.27 mm; wing diagonal length 0.99 mm; Hind tibia 1.36 mm long, 0.50 mm wide while the hind basitarsus 0.53 mm long, 0.25 mm wide.

Ratios of head length to width 0.74 (Table 2); eye length to upper interocular distance 1.13; interocellar to cello-ocular distance 3.18; forewing length to width 2.97; forewing diagonal length to head width 0.66; hind tibial length to forewing diagonal length 1.38.

Paratypes: Females

Coloration Body shiny. Head black; scape yellowish-brown with a dark brown tinge in the middle; ocelli shiny, creamy white; flagellomeres dark brown on upper side, ochraceous on lower side; compound eyes yellow to reddish-brown (Fig. 6c); mandibles brown with dark brown patches basally and apically (Fig. 6d). Mesoscutum brownish-black; legs dark brown to black except tarsal four terminal segments light brown. Metasomal terga dark brown 3/4th, ochraceous at basal 1/4th thus appearing banded (Fig. 6a); sterna either uniformly dark brown or apical half dark brown and basal half ochraceous.

Pilosity Clypeus, face clothed with white plumose hairs with heavy density on clypeus and lower half of face (Fig. 6c); vertex, upper part of occiput with short, erect brown hairs; postgena, lower margin of occiput fringed with long yellow hairs. Mesoscutum with distinct longitudinal bands of white hairs; mesoscutellar margin heavily fringed with light brown intermixed with dark brown long hairs; mesepisternum, clothed with moderately dense white plumose hairs; lower margin fringed with long white hairs; metepisternum, lateral parts of propodeum with a felt of white, plumose hairs (Fig. 6b). Anterior margin of hind tibia with dark brown setae; long yellowish hairs on upper surface; posterior margin with ochraceous plumose setae with a few dark brown setae intermittently. Metasomal terga with sparse white hairs on the anterior segments and density increasing on terminal segments; sterna clothed with white fine hairs with higher density towards terminal segments and medially.

Morphometry Detailed morphometry of female paratypes is presented in Table 1. Body length 3.74 mm; head 1.19 mm long and 1.52 mm wide; compound eye 2.92× longer than its width (0.36 mm) while upper interocular distance 2.63× greater than interocellar distance; cello-ocular distance 0.20 mm; median ocellus 0.16 mm in diameter while malar space length 0.01 mm; scape 5.8× longer than its width (0.10 mm); mandible 0.62 mm long, 0.29 mm wide; forewing length 3.76, width 1.42 mm; hind tibia 1.40 mm long, 0.53 mm wide while the hind basitarsus 0.53 mm long, 0.26 mm wide.

Ratios of head length to width 0.78; eye length to upper interocular distance 0.98; interocellar to cello-ocular distance 2.04; forewing length to width 2.64 (Table 2).

Materials examined Holotype: Male: Maharashtra: Nagpur, 26. ix. 2019, Coll. Ashish Kumar J. deposited at UASB. Paratypes: 21 males, 50 females with same collection data but Coll. Jagruti Roy deposited at UASB; one male and one female will be deposited each at IARID and ZSIK.

Name derivation This species is named in honor of Dr. Ashish Kumar Jha who collected these bees and spared them for our studies.

Tetragonula shishirae Viraktamath sp. n.

Diagnosis Male and female bees measure 4.00 ± 0.01 and 3.81 ± 0.06 mm in body length while 1.49 ± 0.05 and 1.42 ± 0.09 mm in head width, respectively. Clypeus, face with white, plumose fine hairs; lower margin of compound eye closely appressed with the base of mandibles leaving no malar space; mesoscutum with indistinct longitudinal bands of hairs; mesepisternum with long plumose white hairs; metepisternum and lateral areas of propodeum with thick felt of white hairs; Gradulus in sternum 5 briefly touches the antecosta medially; apical margin with an inverted “U” shaped notch medially; antecosta of sternum 6 gently convex medially, bisinuate laterally with medio-apical process 2.39x longer than its width.

Description

Holotype: Male

Coloration Body shiny. Clypeus, face, vertex brownish-black; scape yellow with brown irregular marking in the middle; pedicel brown; flagellomeres blackish yellow on upper side while yellow on the lower side. Ocelli pale yellow (Fig. 8e–g); compound eyes dull yellowish-brown. Mandibles dark reddish-brown at the basal half and light brown at the apical half (Fig. 8h). Legs dark reddish-brown except terminal four segments of tarsi light brown. Tegulae dark brown; wings with brownish tinge; pterostigma, veins dark brown. Metasoma light brown.

Pilosity Clypeus, face covered with white, plumose, fine hairs with the high density on clypeus, lateral parts of antennal insertions (Fig. 8g). Vertex, occiput, postgena with white intermixed with dark brownish erect hairs. Mesoscutum with indistinct longitudinal white hairs; margins of mesoscutum, mesoscutellum heavily fringed with pale yellow hairs.

Mesepisternum with white, plumose long hairs; metepisternum and lateral parts of propodeum with thick felt of white, plumose short hairs obscuring underlying integument (Fig. 8f). Anterior and posterior margins of hind tibia fringed with pale yellow and white setae, respectively while upper margin with long white setae. Metasomal terga with sparse hairs while the sterna have dense, fine white hairs.

Morphometry Body 4.00 mm long with 1.52 mm head width (Table 1); head length 1.15 mm; compound eye 2.86× longer than its width (0.35 mm); upper interocular distance 0.95 mm; interocellar distance 0.42 mm; median ocellus diameter 0.18 mm; lower margin of compound eye closely appressed with the base of mandibles leaving no malar space; scape 4.8× longer than its width (0.10 mm); mandible 0.40 mm long, 0.18 mm wide; forewing length 3.60, width 1.25 mm; wing diagonal length 0.85 mm; hind tibia 2.67× longer than hind basitarsus (0.45 mm).

Ratios of head length to width 0.76 (Table 2); eye length to upper interocular distance 1.05; interocellar to cello-ocular distance 2.80; forewing length to width 2.88; forewing diagonal length to head width 0.56; hind tibial length to head width 0.79; hind tibial length to forewing diagonal length 1.41.

Genitalia Gradulus in sternum 5 briefly touching the antecosta medially, apical margin with a distinct inverted U-shaped notch medially (Fig. 9a); antecosta of sternum 6 gently convex medially and bisinuate laterally; medio-apical process 2.39× longer than its width with incurved broadly pointed apex (Fig. 9b, c). Genitalia yellowish-brown but gonocoxae and penis valves dark brown; gonocoxae oriented vertically (Fig. 9d); gonostylus lamellate, incurved longitudinally; 0.88 mm long; 0.15 mm wide at the base with similar width up to 0.50 length then distinctly curved outwards forming a 0.38 mm long, 0.05 mm wide finger-like structure terminating into a bluntly rounded apex (Figs. 9d, e, 13d-gs). Penis valve robust, 0.58 mm long with outwardly curved, 0.13 mm long dark reddish-brown hook; 0.23 mm wide at the base, then narrowed to 0.18 mm after a short distance and later to 0.15 mm at which it is suddenly narrowed to 0.05 mm wide hook (Figs. 9d, e, 13d-pv).

Variations Male paratypes resemble the holotype in general coloration and pilosity. However, in some males, scape, pedicel reddish-brown; flagellomeres, compound eyes dark reddish-brown.

Morphometry Detailed morphometry is presented in Table 1. Body length 4.00 mm, head width and length 1.49 and 1.13 mm, respectively; compound eye 2.71× longer than its width (0.38 mm); diameter of median ocellus 0.18 mm; upper interocular and interocellar distance 0.93

and 0.41 mm, respectively; lower margin of compound eye and mandible closely appressed without any malar space; mandible 0.40 mm long, 0.18 mm wide; forewing length 3.70, width 1.25 mm; wing diagonal length 0.85 mm; hind tibia 1.23 mm long, 0.45 mm wide while hind basitarsus 0.45 mm long and 0.20 mm wide.

Ratios of head length to width 0.76; eye length to upper interocular distance 1.11; interocellar to cello-ocular distance 2.74; forewing length to width 2.96; forewing diagonal length to head width 0.58; hind tibial to forewing diagonal length 1.44 (Table 2).

Paratypes: Females

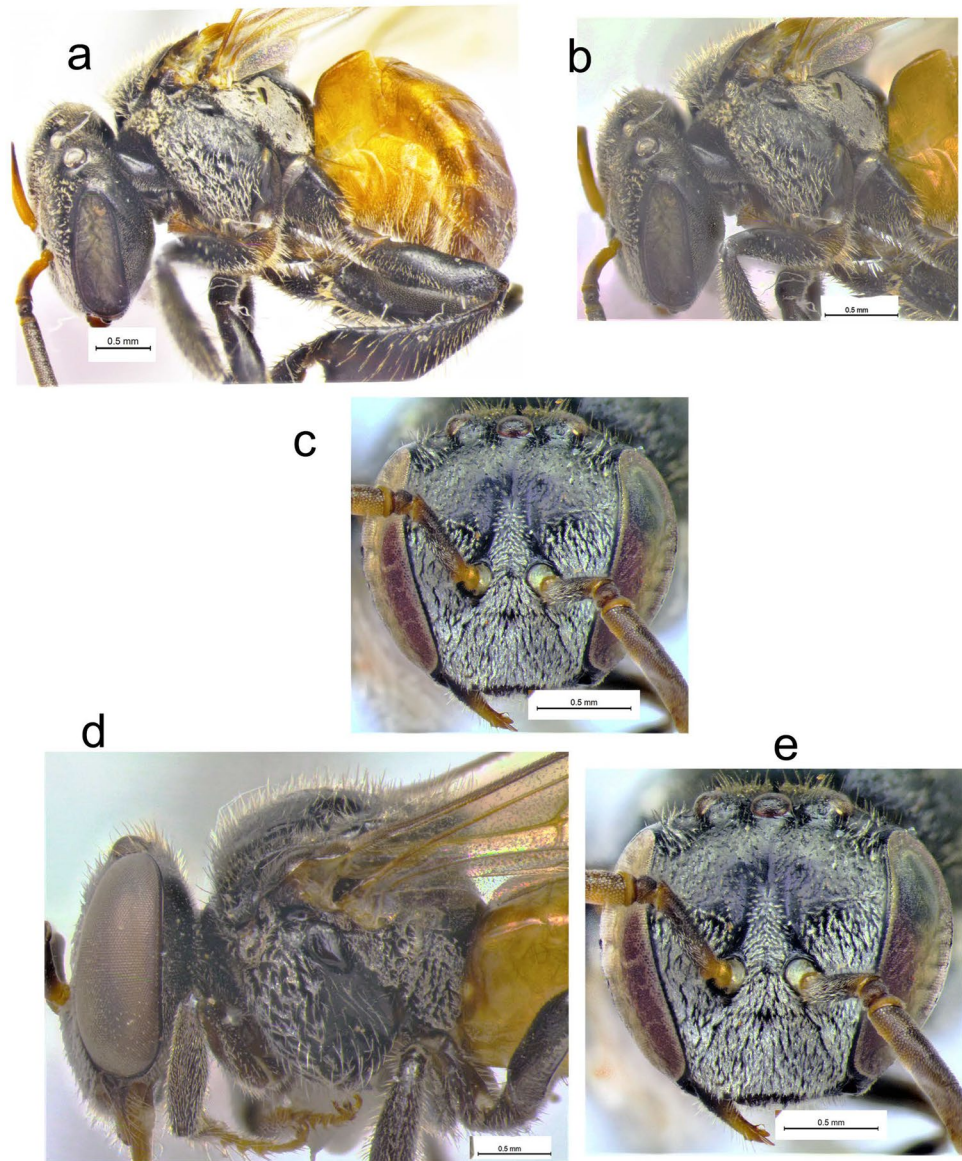
Coloration Body shiny. Head, mesosoma dark brown approaching to black. Clypeus light brown to dark reddish-brown; scape, pedicel ochraceous to reddish-brown; flagellomeres dark brown on the upper side but light brown on the lower side; ocelli shiny, yellowish; compound eyes yellow (Fig. 8a–c). Mandibles dark brown at the basal region, reddish-brown at the apical region (Fig. 8d). Legs dark brown except the terminal four tarsal segments brown. Tegulae dark brown; wings with reddish-brown tinge; pterostigma, veins brown. Metasoma yellowish-brown (Fig. 8a).

Pilosity Clypeus, entire face clothed with dense white plumose hairs; vertex, occiput with brown erect hairs (Fig. 8c); lower occiput, postgena with white hairs. Mesoscutum with distinct longitudinal bands of short white hairs; margins of mesoscutum, mesoscutellum fringed with yellowish hairs. Mesepisternum, metepisternum, lateral part of propodeum clothed with dense felt of short white hairs (Fig. 8b). Anterior margin of hind tibia fringed with brown intermixed with pale yellow setae, upper margin with long yellowish hairs; posterior margin with yellowish plumose setae with a few brown setae intermittently. Metasomal terga with sparse, fine white hairs while the sterna clothed with high density of fine white hairs.

Morphometry Females measure 3.81 mm in length, 1.42 mm in head width and 1.25 mm in head length (Table 1); compound eye 1.07 mm long, 0.38 mm wide; upper interocular distance 1.06 mm while interocellar distance 0.45 mm with cello-ocular distance 0.12 mm; diameter of median ocellus 15× greater than malar space length (0.01 mm); scape 0.55 mm long, 0.13 mm wide; forewing 3.71 mm long, 1.25 mm wide; wing diagonal length 1.02 mm; hind tibia 1.27 mm long and 0.52 mm wide while hind basitarsus 0.57 mm long and 0.27 mm wide.

Ratios of head length to width 0.85 (Table 2); eye length to upper interocular distance 1.00; interocellar

Fig. 10 *Tetragonula shubhami* sp. n. Female paratype: **a** lateral habitus, **b** head and thorax closer lateral view, **c** head frontal view. Male holotype: **d** head and thorax closer lateral view, **e** head frontal view



to cello-ocular distance 1.73; forewing length to width 2.98; hind tibial to forewing diagonal length 1.29.

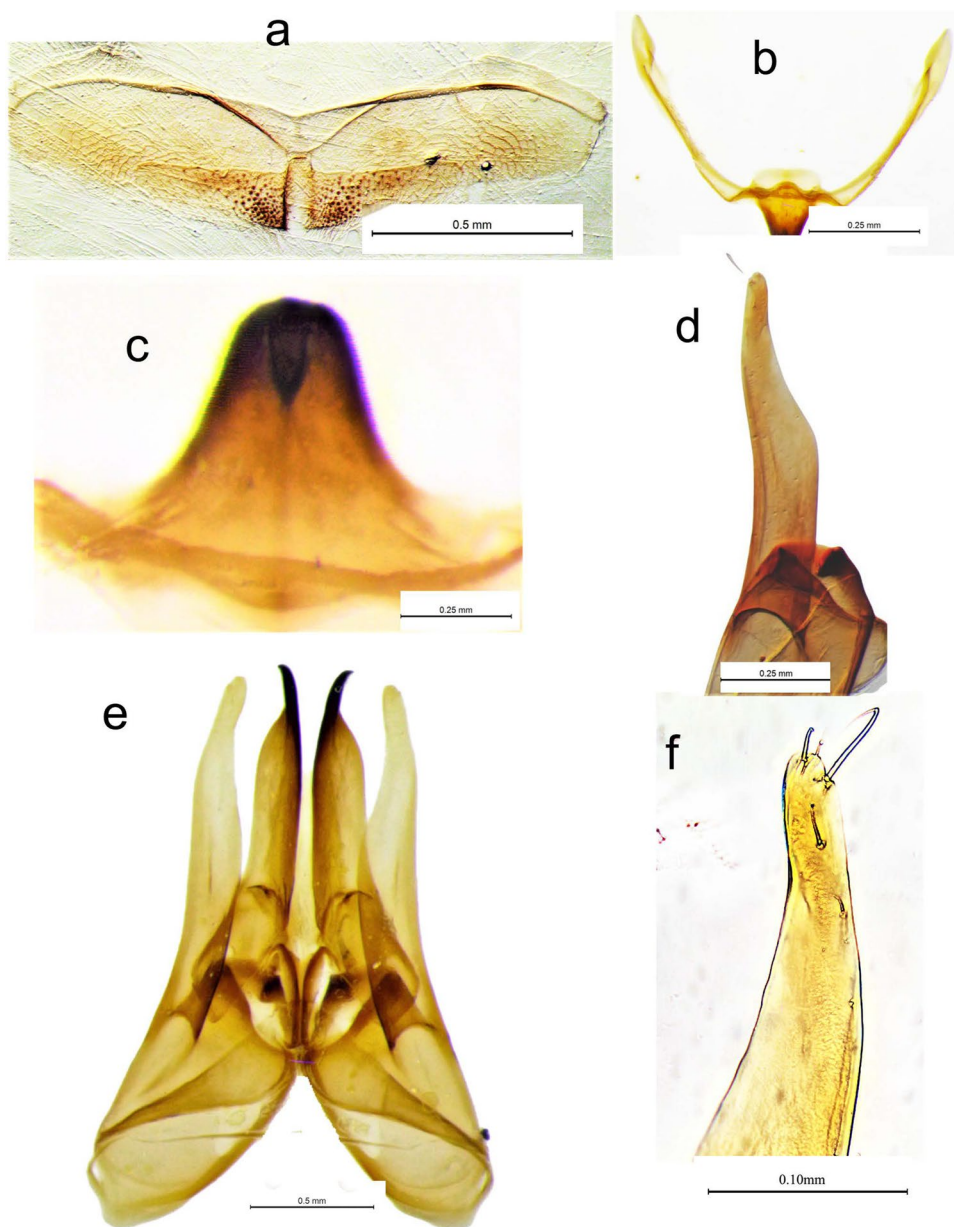
Materials examined Holotype: Male: Rajasthan: Udaipur, 11. iii. 2019, Coll. Shishira D. deposited at UASB. Paratypes: 02 males and 73 females with same collection data deposited at UASB; one female paratype will be deposited each at IARID and ZSIK.

Name derivation This species is named after Mrs. Shishira who collected these bees and spared them for our studies.

***Tetragonula shubhami* Viraktamath sp. n.**

Diagnosis Male bees 3.86 ± 0.21 mm long with a head width of 1.47 ± 0.07 mm while the female bees 3.50 ± 0.17 mm long and 1.54 ± 0.06 mm in head width. Clypeus, face, mesepisternum, metepisternum and lateral parts of propodeum covered with dense, thick white plumose hairs; mesoscutum with distinct longitudinal bands of white hairs; gradulus in sternum 5 does not touch antecosta, apical margin without any emargination but with an elongate “U” shaped marking (Fig. 11a); antecosta of sternum 6 gently convex and bisinuate laterally with apico-medial process 2.58× longer than its

Fig. 11 *Tetragonula shubhami* sp. n. **a** Male sternum 5, **b** male sternum 6 dorsal view, **c** male sternum 6 top view, **d** gonostylus, **e** genitalia dorsal view, **f** terminal part of gonostylus closer view



width (Fig. 11b). gonostylus arising laterally. Gonostylus lamellate, incurved longitudinally; 0.80 mm long, curved outwardly at 0.43 mm length into a 0.37 mm long, 0.05 mm wide finger-like structure (Figs. 11d, 13e-gs). Penis valve robust, 0.65 mm long terminating into a dark reddish-brown, 0.10 mm long hook (Figs. 11e, 13e-pv).

Description

Holotype: Male

Coloration Body shiny. Head, mesosoma dark reddish-brown approaching to black. Scape, pedicel dark

reddish-brown except basally and apically light brown; flagellomeres dark brown on the upper side, ochraceous on lower side; ocelli transparent, reddish-brown; compound eyes yellowish-brown with dark brown irregular markings (Fig. 10e). Mandibles dark reddish-brown at the basal 1/4th, light brown apical 3/4th. Tegula black; wings with reddish-brown tinge; pterostigma, veins brown. Legs dark brown except terminal four tarsal segments light brown. Metasomal terga yellowish apically but dark brown basally giving a banded appearance; sterna yellowish brown.

Pilosity Clypeus, lower half of face clothed with dense plumose thick white hairs obscuring underlying integument; upper half of face with a lesser density of plumose white

Fig. 12 Comparison of male sterna: **a** *Tetragonula vikrami* sp. n., **b** *Tetragonula sumae* sp. n., **c** *Tetragonula ashishi*, **d** *Tetragonula shishirae* **e** *Tetragonula shubhami*. Top row: s5 sternum 5; middle row: s6 sternum 6 dorsal view; bottom row: s6 sternum 6 top view. Not to scale. Images in a row are of uniform magnification

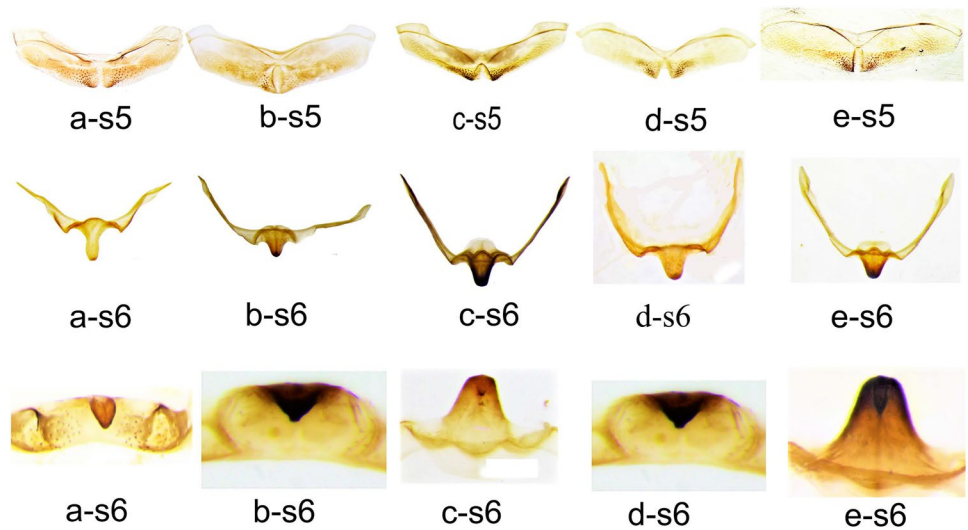
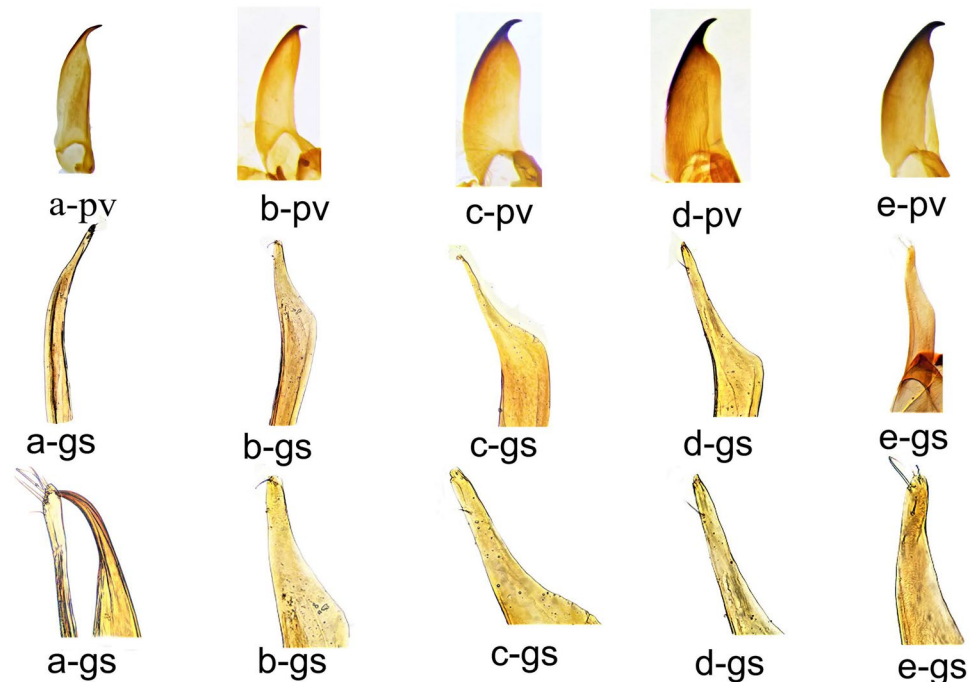


Fig. 13 Comparison of male genitalia structures: **a** *Tetragonula vikrami* sp. n., **b** *Tetragonula sumae* sp. n., **c** *Tetragonula ashishi*, **d** *Tetragonula shishirae* **e** *Tetragonula shubhami*. Top row: pv: penis valve lateral view; middle row: gs gonostylus lateral view; bottom row: gs gonostylus lateral closer view. Not to scale. Images in a row are of uniform magnification



hairs; vertex, occiput with short brown erect hairs (Fig. 10e); lower part of occiput, post gena with long white hairs. Mesoscutum with distinct longitudinal bands of white hairs; margins of mesoscutum fringed with yellow hairs while mesoscutellar margin with heavy fringe of white, long hairs. Legs dark reddish-brown except terminal four tarsal segments brown. Mesepisternum, upper part of metepisternum and lateral parts of propodeum with dense, plumose white hairs (Fig. 10d). Metasomal terga with short white hairs while sterna clothed with dense white long hairs.

Morphometry Detailed morphometry of the holotype is presented in Table 1. Body 4.05 mm long, head width and length 1.47 and 1.15 mm, respectively; compound eye 2.58× longer than its width (0.43 mm); upper interocular distance 2.66× greater than interocellar distance (0.35 mm); cello-ocular distance 0.12 mm; diameter of median ocellus 15× greater than malar space length (0.01 mm); scape 0.45 mm long, 0.12 mm wide; mandible 0.40 mm long, 0.18 mm wide; forewing length 3.90, width 1.20 mm; wing diagonal length 1.00 mm; hind tibia 2.60× longer than hind basitarsus (0.52 mm).

Table 3 Diagnostic characters of five new species of *Tetragonula*

↓Parameter/Species→	<i>Tetragonula vikrami</i> sp. n.	<i>Tetragonula sumae</i> sp. n.	<i>Tetragonula ashishi</i> sp. n.	<i>Tetragonula shishirae</i> sp. n.	<i>Tetragonula shubhami</i> sp. n.
Gradulus in male metasomal sternum 5	Touches antecosta medially	Does not touch antecosta	Touches antecosta medially	Briefly touches antecosta medially	Very close to antecosta without touching it
Apical margin	With a gentle concavity medially	Gently convex with elongate oval marking	With a distinct broad concavity medially with an inverted V-shaped marking	With a distinct inverted U-shaped notch	Without any invagination but with an elongate inverted U-shaped marking
Antecosta of male metasomal sternum 6	Convex medially	Gently convex	Distinctly convex medially, bisinuate laterally	Gently convex medially, gently bisinuate laterally	Gently convex medially and bisinuate laterally
Terminal part of the apico-medial process	Narrowed and blunt rounded apex	Broad and rounded apex	Narrow, rounded apex	Broadly pointed apex	Tapering, nearly pointed apex
Ratio of length to width of the apico-medial process	3.62	2.54	2.80	2.39	2.58
Length* of penis valve	0.83	0.65	0.60	0.58	0.65
Width* at the base	0.20	0.18	0.23	0.23	0.23
Width* at the middle	0.15	0.15	0.20	0.18	0.20
Length* of hook at the apex	0.10	0.05	0.08	0.13	0.10
Total length* of gonostylus	1.03	0.90	0.83	0.88	0.80
Length* from base to curving point	–	0.68	0.50	0.50	0.43
Length* of finger-like structure	–	0.22	0.33	0.38	0.37
Width* at the base	0.05	0.13	0.18	0.15	0.18
Width* at the middle	0.06	0.10	0.18	0.15	0.15
Width* at the apex	0.04	0.05	0.05	0.05	0.05

*in mm

Ratios of head length to width 0.78 (Table 2); eye length to upper interocular distance 1.24; interocular to cello-ocular distance 2.92; forewing length to width 3.25; forewing diagonal to head width 0.68; hind tibial to wing diagonal length 1.35.

Metasomal sterna and genitalia Gradulus in sternum 5 very close to antecosta medially without touching it, apical margin without any emargination but with an elongate inverted “U” shaped marking (Fig. 11a); antecosta gently convex medially, bisinuate laterally; medio-apical process 2.58× longer than wide, tapering with an incurved narrow nearly pointed apex (Fig. 11b, c). Genitalia yellowish-brown with apical margins of gonocoxae, basal margins of gonostyli, lateral and terminal 1/4th part of penis valves reddish dark brown shades. Gonocoxae oriented obliquely; gonostylus arising laterally, lamellate, incurved longitudinally; 0.80 mm long, curved outwardly at 0.43 mm length into a 0.37 mm long, 0.05 mm

wide finger-like structure (Figs. 11e, 13e-gs). Gonostylus 0.18 mm wide at the base, narrowed to 0.15 mm after a short distance and later to 0.13 mm wide at which it curves into a finger-like structure; long as well short setae arise on the terminal part (Fig. 11f). Penis valve robust, 0.65 mm long, 0.23 mm wide at the base, narrowing to 0.20 mm width after a short distance, then gradually widening to 0.22 mm and terminating into dark reddish-brown hook of a 0.10 mm length and 0.05 mm width (Figs. 11e, 13e-pv).

Paratypes: Males

Resemble the holotype in coloration and pilosity. Bees from Godre and Pushpal have dark brown compound eyes and ocelli.

Morphometry Males measure 3.86 mm in body length, 1.47 mm head width and 1.15 mm head length; compound

eye 1.11 mm long, 0.43 mm wide; upper interocular distance 0.93 mm; interocellar and cello-ocular distance 0.38 and 0.13 mm, respectively; median ocellus 15× greater in diameter than the malar space length (0.01 mm); scape 0.45 mm long, 0.12 mm wide; mandible 2.39× longer than its width (0.18 mm); forewing 3.77 mm long, 1.23 mm wide; wing diagonal length 0.98 mm; hind tibia and hind basitarsus 1.33 and 0.50 mm long and 0.52 and 0.26 mm wide, respectively (Table 1).

Ratios of head length to width 0.78; eye length to upper interocular distance 1.20; interocellar to cello-ocular distance 2.87; forewing length to width 3.10; forewing diagonal length to head width 0.67; hind tibial to forewing diagonal length 1.36 (Table 2).

Paratypes: Females

Coloration Body shiny. Head dark reddish-brown; clypeus brown to dark reddish-brown; scape, pedicel light brown; flagellomeres dark brown on the upper side, ochraceous on the lower side; compound eyes dark reddish-brown; ocelli transparent, ochraceous (Fig. 10c); mandibles dark reddish-brown at the basal ½, light brown at the apical half. Mesosoma, legs reddish-brown; tegulae brown; wings with a reddish tinge; pterostigma, veins light brown. Terga of anterior metasomal segments and sterna light brown while that of posterior segments dark brown; in some bees both terga and sterna of all segments dark brown (Fig. 10a).

Pilosity Clypeus, face up to ocellar triangle clothed with dense plumose white hairs; vertex, occiput, post gena with brown erect hairs (Fig. 10c). Mesoscutum with distinct bands of longitudinal white hairs; margins of mesoscutum fringed with short white hairs; mesoscutellar margin heavily fringed with long yellowish hairs. Mesepisternum, metepisternum and lateral parts of propodeum with thick felt of plumose white hairs (Fig. 10b). Anterior margin of hind tibia fringed with brown intermixed with pale yellow setae; posterior margin with pale yellow mixed with few brown setae; upper margin with long pale-yellow hairs. Metasomal terga with sparse white short hairs while sterna clothed with dense, long white hairs.

Morphometry Detailed morphometry of female paratypes is given in Table 1. Female body measures 3.50 mm in length, 1.54 and 1.20 mm in head width and length, respectively; compound eye 3.0× longer than its width (0.35 mm); upper interocular distance 1.01 mm while interocellar and cello-ocular distance 0.41 and 0.21 mm, respectively; median ocellus diameter 3× greater than the malar space length; scape 0.55 mm long, 0.10 mm wide; forewing 3.72 mm long, 1.29 mm wide; wing diagonal

length 1.02 mm; hind tibia and hind basitarsus 1.47 and 0.52 mm long, respectively.

Ratios of head length to width 0.80; eye length to upper interocular distance 1.07; interocellar to cello-ocular distance 1.95; forewing length to width 2.76; hind tibial length to forewing diagonal length 1.50 (Table 2).

Material examined Holotype: Male: Chhattisgarh: Bardebhata, 06. xi. 2019, Coll. Shubham Rao deposited at UASB. Paratypes: Four males, Chhattisgarh: Pushpal, 15. iv. 2020, Coll. Shubham Rao, one male, Chhattisgarh: Godre, 5. ix. 2019, Coll. Shubham Rao deposited at UASB. Fifty-nine females (10 mounted 49 in 95% alcohol vial), Chhattisgarh: Bardebhata, 06. xi. 2019, Coll. Shubham Rao deposited at UASB. One female paratype will be deposited each at IARID and ZSIK.

Name derivation This species is named after Mr. Shubham Rao who collected these bees and spared them for our studies.

Discussion

India has as many as 10 diverse biogeographical regions and is considered as one of the mega-diverse countries with about 8% of the known species of the world. More than 91,200 species of animals have been recorded so far in India (<https://www.cbd.int/countries/profile/?country=in>). Considering the diverse geographical diversity of India, the total number of stingless bees known is far less than expected. Of about 600 species of stingless bees in the world only 17 species (2.83% of the world species) are recorded in India so far (Rasmussen 2013; Viraktamath and Rojeet 2021). However, Rasmussen (2013) predicts occurrence of more species of stingless bees in India.

Poor representation of diversity of stingless bees from India is due to lack of intensive collections from different parts of India, heavily relying on relative characters like coloration and pilosity of female bees, lack of concerted efforts to collect female and associated male bees and study of male genitalia. Among three genera viz. *Tetragonula*, *Lisotrigona* and *Lepidotrigona* that occur in India, *Tetragonula* is the most dominant with 12 species known so far. As Rasmussen (2013) states the genus *Tetragonula* is a notoriously complex and includes several species complexes. Females of different species are remarkably similar, making it very difficult or nearly impossible to identify them (Sakagami 1978). Hence importance of male bees and use of male genitalia characters in addition to metasomal sternal structural characters are emphasized by several researchers (Schwarz 1939; Sakagami 1978; Rasmussen 2013; Attasopa et al. 2018). In our efforts to enrich our knowledge of the diversity of

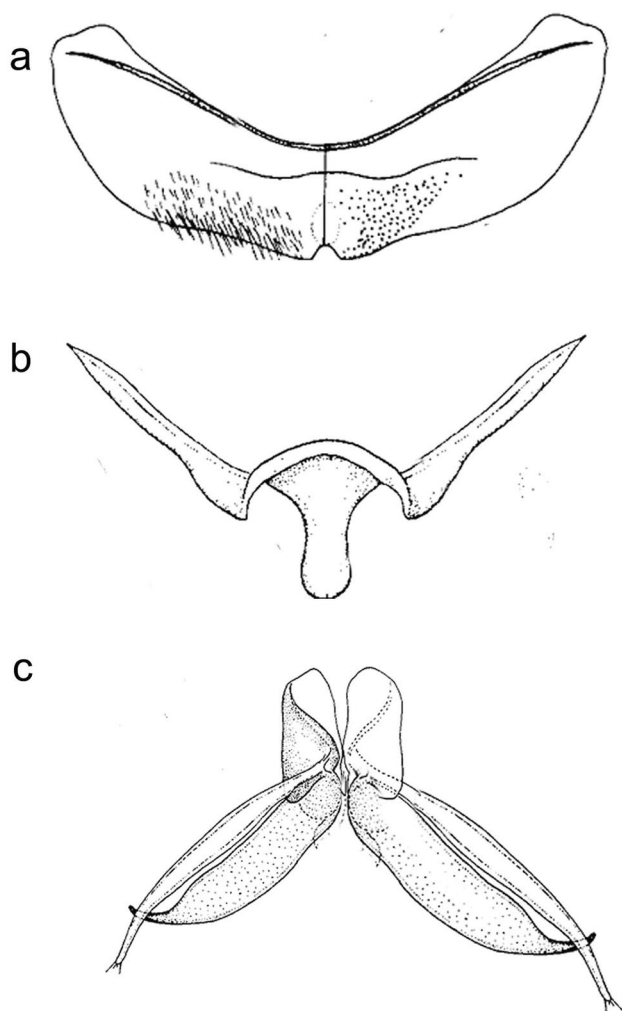


Fig. 14 Male characters of *Tetragonula iridipennis*: **a** Metasomal sternum 5, **b** metasomal sternum 5, **c** genitalia (Redrawn from Sakagami 1978)

stingless bees of India by intensive survey and examination of national collections, we came across five new species of *Tetragonula* which are described in this paper. We compared these new species with the published descriptions and images from Indo-Malayan, Australasian regions (Cockerell 1929; Schwarz 1939; Moure 1961; Sakagami 1975, 1978; Dollin et al. 1997; Rasmussen 2013; Rasmussen et al. 2017), identified species deposited at the national collections (ZSIK, IARID, UASB), images and descriptions of primary type specimens of *Tetragonula* species from Indian subcontinent (Rasmussen 2013) as well as with the recent collection of more than 30,000 bees by the senior author. We also consulted other specialists (Dr. Claus Rasmussen, Dr. Korrawat Attasopa and Dr. Michael Engel) through personal communication.

Five new species described here have overlapping coloration, pilosity among them but differ in morphometry

(Table 1) and body proportions (Table 2). Principal Component analysis of 34 morphometric parameters of female bees showed these five new species making distinct clusters (Online resource: Fig. 1S) All the five species are quite distinct from other species of *Tetragonula* occurring in Indo-Malayan and Australasia regions in having robust penis valves (Fig. 13a–e–pv). Besides, *T. sumae* sp. n., *T. ashishi* sp. n., *T. shishirae* sp. n. and *T. shubhami* sp. n. have robust gonostylus which is broad, lamellate, longitudinally curved inwards, terminating into an outwardly curved finger-like structure. However, these four new species can be differentiated based on the structure of male metasomal sterna 5 and 6; shape, structure and size of gonostylus and penis valve. Diagnostic characters of all the five species are presented in Figs. 12 and 13 and enumerated in Table 3.

Genitalia of *T. vikrami* sp. n. superficially resembles that of *T. iridipennis* but distinctly differs in the shape and size of gonostylus and penis valve. *T. vikrami* also differs from *T. iridipennis* in being larger (4.07 ± 0.15 long and 1.65 mm wide head as against the primary type of *T. iridipennis* with 3.55 mm body length and 1.60 mm head width), longer flagellomere II (0.10 as against 0.07 mm in *T. iridipennis*) longer forewings (3.98 mm against 3.80 mm long wings in *T. iridipennis*) longer marginal cell (1.30 mm vs 1.21 mm in *T. iridipennis*), longer hind basitarsus (0.62 ± 0.03 against 0.50 mm in *T. iridipennis*). The ratios of head length to width, hind tibial length to head width, hind tibial to forewing diagonal length and hind basitarsus to hind tibial width are smaller while those of eye length to upper inter-ocular distance and forewing length to width is greater than ratios in the primary type of *T. iridipennis* (Table 2). Interestingly, *T. vikrami* bees occurred in the same apiary where other stingless bee colonies of *Tetragonula* nr. *pagdeni* were kept often attacking the latter bee colonies in Mankalale (Karnataka).

All the five new species have been described with both female and associated male bees. Thus, the number of stingless bees from India is now elevated to 22 species and the number of species within the genus *Tetragonula* to 17. We speculate that *T. ashishi*, *T. shishirae* and *T. shubhami* may also occur in other states of central India while *T. vikrami* and *T. sumae* in south India. However, further intensive collections of male bees with securely associated female bees in these states are needed. We hope that future studies of these collections of stingless bees may further improve our knowledge of the diversity of Indian stingless bees.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s11756-022-01040-8>.

Acknowledgments We are grateful to Dr. C.A. Viraktamath, Emeritus Professor, Department of Entomology, UASB, for going through the manuscript and offering the most valuable comments, Dr. Claus Rasmussen and Dr. Attasopa Korrawat for examining the images of

the species and offering their comments. We express our gratitude to the Head, Department of Entomology, Indian Agricultural Research Institute, New Delhi, the Director, Zoological Survey of India, Kolkata for giving permission to examine the collections of stingless bees and the Professor and Head, Department of Entomology, UASB, for providing facilities for our study. We are grateful to the unknown referees for reviewing the manuscript and offering their comments. This study is partially funded by the Indian Council of Agricultural Research, New Delhi.

Conflict of interest On behalf of the co-author, the corresponding author states that there is no conflict of interest.

References

- Attasopa K, Banziger H, Disayathanoowat T, Packer L (2018) A new species of *Lepidotrigona* (Hymenoptera: Apidae) from Thailand with the description of males of *L. flavibasis* and *L. doipaensis* and comments on asymmetrical genitalia in bees. *Zootaxa* 4442:63–82. <https://doi.org/10.11646/zootaxa.4442.1.3>
- Cockerell TDA (1929) Descriptions and records of bees.—CXX. *Ann Mag Nat Hist* 10:584–594
- Cortopassi-Laurino M, Imperatriz-Fonseca VL, Roubik DW, Dollin A, Heard T, Aguilar I, Venturieri GC, Eardley C, Nogueira P (2006) Global meliponiculture: challenges and opportunities. *Apidologie* 37:275–292
- Dollin AE, Dollin LJ, Sakagami SF (1997) Australian stingless bees of the genus *Trigona* (Hymenoptera: Apidae). *Invertebr Taxon* 11:861–896
- Heard TA (1999) The role of stingless bees in crop pollination. *Annu Rev Entomol* 44:183–206. <https://doi.org/10.1146/annurev.ento.44.1.183>
- <https://www.cbd.int/countries/profile/?country=in> (2021) India – main details: Biodiversity facts: status and trends of biodiversity, including benefits from biodiversity and ecosystem services. Accessed 12 June 2021
- Kumar MS, Singh AJAR, Alagumuthu G (2012) Traditional beekeeping of stingless bees (*Trigona* sp) by Kani tribes of Western ghats, Tamil Nadu, India. *Ind J Tradition Knowl* 11:342–345
- Moure JS (1961) A preliminary supra-specific classification of the old world meliponine bees (Hymenoptera, Apoidea). *Stud Entomol* 4:181–242
- Rasmussen C (2013) Stingless bees (Hymenoptera: Apidae: Meliponini) of the Indian subcontinent: diversity, taxonomy and current status of knowledge. *Zootaxa* 3647:401–428. <https://doi.org/10.11646/zootaxa.3647.3.1>
- Rasmussen C, Thomas JC, Engel MS (2017) A new genus of eastern hemisphere stingless bees (Hymenoptera: Apidae) with a key to supraspecific groups of Indomalayan and Australasian Meliponini. *American Museum Novitates* No 3888, 33 pp
- Sakagami SF (1975) Stingless bees (excl. *Tetragonula*) from the continental Southeast Asia in the collection of Bernice P. Bishop Museum, Honolulu (Hymenoptera, Apidae). *J Fac Sci Hokkaido Univ Ser VI Zool* 20:49–76
- Sakagami SF (1978) *Tetragonula* stingless bees of the continental Asia and Sri Lanka (Hymenoptera: Apidae). *J Fac Sci Hokkaido Univ Ser VI Zool* 21:165–247
- Schwarz HF (1939) The Indo-Malayan species of *Trigona*. *Bull Am Mus Nat Hist* 76:83–141
- Shanas S, Faseeh P (2019) A new subgenus and three new species of stingless bees (Hymenoptera: Apidae: Meliponini) from India. *Entomon* 44:33–48. <https://doi.org/10.33307/entomon.v44i1.424>
- Viraktamath S, Rojeet T (2021) Two new species of *Tetragonula* (Hymenoptera: Apidae: Meliponini) from North-East India with notes on their nest structure. *Biologia* 76:1691–1704. <https://doi.org/10.2478/s11756-020-00662-0>
- Viraktamath S, Tanuja N, Nirmala P (2020) A technique to collect male stingless bees. *Curr Sci* 119:435–437
- Viraktamath S, Naik T, Shishira D (2021) Morphometry of female and associated male stingless bees of the genus *Tetragonula* (Hymenoptera: Apidae: Meliponini) from India. *The Bioscan* 16:9–26

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.