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ORIGINAL RESEARCH ARTICLE

Nesting behavior and nest site preferences of the giant honey bee (*Apis dorsata* F.) in the semi-arid environment of north west India

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In the semi-arid environment of north west India, I found that 22.3% of colonies of the giant honey bee, *Apis dorsata* nested on man-made structures (buildings), whereas 77.7% nested on trees. The latter had a higher Nesting Site Occupation Index (N_{sioi} = 0.008) than buildings (N_{sioi} = 0.002). The nesting source reoccupation index (N_{sori}) was maximal for Indian rosewood (0.772), whilst the nesting site reoccupation index (N_{siri}) was maximal for buildings (0.91) followed by Indian rosewood (0.147). On the basis of these indices, Indian rose wood was the best nesting resource whereas buildings provided the best sites. *A. dorsata* preferred smooth surfaces over unevenly grooved surfaces for nesting. More than 95% of the colonies nested on supports with an inclination from 0° to 45°. About 48.6% of colonies constructed their nests in an east/west direction, and about 70% of colonies nested at heights between 14 and 17 m. The majority of the "immigrated swarm colonies" had 100–120 cm nest length and 30–50 cm nest height. Likewise, about 56% of the "reproductive swarm colonies" had 30–40 cm nest length and about 53% had 20–25 cm nest height. The basal thickness of the comb in the non-honey region was 2.04 ± 0.6 cm whilst in the honey region it was 5.7 ± 1.2 cm. Three types of nest shapes on the horizontal as well as inclined surfaces were observed. This information will be valuable in devising strategies for the domestication and conservation of *A. dorsata*.

Comportamiento de anidamiento y preferencias de nidificación de abejas melíferas gigantes (*Apis dorsata* F.) en medio ambiente semiárido del noroeste de India

En el medio semiárido del noroeste de la India, encontré que el 22.3% de las colonias de abejas gigantes, *Apis dorsata* anidó en estructuras artificiales (edificios), mientras que el 77.7% anidó en árboles. Estos últimos tenían un índice de ocupación del sitio de anidamiento más alto (Nsioi = 0.008) que los edificios (Nsioi = 0.002). El índice de reocupación de la fuente de nidificación (Nsori) fue máximo para el sisu (Indian reosewood en inglé) (0.772), mientras que el índice de reocupación del sitio de anidamiento (Nsiri) fue máximo para los edificios (0.91) seguido del sisu (0.147). En base a estos índices, el sisu fue el mejor recurso de anidación, mientras que los edificios proporcionaron los mejores sitios. *A. dorsata* prefirió superficies lisas sobre superficies ranuradas desigualmente para anidar. Más del 95% de las colonias anidaron en soportes con una inclinación de 0 a 45°. Alrededor del 48.6% de las colonias construyeron sus nidos en dirección este/oeste, y alrededor del 70% de las colonias anidaron en alturas entre 14 y 17m. La mayoría de las "colonias de enjambres inmigrados" tenían una longitud de nido de 100–120 cm y una altura de nido de 30-50 cm. Del mismo modo, aproximadamente el 56% de las "colonias de enjambres reproductivos" tenían 30–40 cm de longitud de nido y aproximadamente 53% tenían 20–25 cm de altura de nido. El grosor basal del panal en la zona no mielera fue de 2.04 ± 0.6 cm mientras que en la zona con miel fue de 5.7 ± 1.2 cm. Se observaron tres tipos de formas de nido en las superficies horizontal e inclinada. Esta información será valiosa en la elaboración de estrategias para la domesticación y conservación de *A. dorsata*.

Keywords: *Apis dorsata*; giant honey bee; nesting behavior; nesting preference; pollination; conservation

Introduction

The giant honey bee (*Apis dorsata* F.) is a wild, natural and important pollinator of several crops in south Asia, south east Asia and Pakistan, and is an excellent bioresource of honey too (Oldroyd, 2006; Sihag, 2014). As with declines in the populations of some other wild pollinators (Biesmeijer et al., 2006; Potts et al., 2010), *A. dorsata* populations too have declined during recent years (Sihag, 2014), which has necessitated conservation of this bee. For the latter purpose, knowledge about its nesting behavior and nest site preferences is essential. Some earlier researchers have studied the nesting behavior of *A. dorsata* in tropical climates of south and south east Asia (Basavarajappa and Raghunandan, 2013; Liu et al., 2007; Neupane et al., 2013; Roy et al., 2011; Ruttner, 1987; Woyke et al., 2012a, 2012b, 2016a, 2016b). In those studies, the bee was found to make a single comb on inaccessible sites on tall trees and buildings.

In the Nilgiri Biosphere Reserve of India, *A. dorsata* was found to prefer cliffs to man-made structures and tall trees for nesting (Roy et al., 2011). There was significant variation in nest densities between sites; the Sathyamangalam area, which had more cliffs than man-made struc-

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tures and tall trees, witnessed the highest nest densities. Conservation of nesting structures such as cliffs and tall trees was considered to be important for maintaining viable populations of this important bee species. Results of studies carried out by Basavarajappa and Raghunandan (2013) from the same Karnataka state of South India were, however, entirely different. Here, *A. dorsata* colonies were found to select 20 tree species to nest with 1646 colonies (68.38%) at an elevation ranging from 5 to 80 feet; 580 colonies (24.10%) nested on human built structures at heights between 8 and 75 feet, and 181 colonies (7.5%) nested on rock cliffs at heights between 10 and 30 m. In Chitwan (Nepal), the annual mean number of *A. dorsata* nests was highest on water towers followed by residential buildings; the lowest number were in trees, and rarely on rocks (Neupane et al., 2013). The colonies stayed for longer at residential buildings (6.2 months per year) followed by water towers (5.8 months per year) and trees (3.3 months per year). Previous year's sites were given the highest preference. However, the bees never built nests on the remnants of a previous colony if it had been burnt, treated with chemicals or painted with enamels. Several swarms settled adjacent to each other without causing disturbance to the neighbors (Neupane et al., 2013). In southern China, *A. dorsata* often conducted seasonal, long-distance migrations between a preferred tree (with more than one nest) and alternate sites (Liu et al., 2007). Although individual worker bees could not make a round-trip journey, colonies re-utilized preferred trees after an absence of several months. These researchers performed comb experiments in which bases and all abandoned combs were entirely scraped off and their sites covered with plastic, or comb was moved to trees of the same species. Swarms investigated trees where combs were removed and continued to nest on the same trees. However, placing combs in nets on previously used trees, or on nearby trees of the same species, did not attract more swarms. The same number of colonies that left returned to previously occupied trees (Liu et al., 2007).

Nest size of *A. dorsata* varies in length as well as height. According to Sattigi et al. (1995–96), average comb length varied from 38.75 to 82.5 cm, height from 34.5 to 92.5 cm and thickness from 3.2 to 7.3 cm. Honey and brood cells were 4.0 and 1.7 cm in depth, respectively. However, Basavarajappa and Raghunandan (2013) reported different statistics of these parameters from the same region of India. They found that nest length was 54 cm, nest height 35 cm and nest thickness for brood and honey comb cells was 1.74 and 2.03 cm, respectively. Neupane et al. (2013) reported nest height from 2 to 30 cm and nest length from 5 to 150 cm with a shape variation from round to elliptical. The thickness of the comb at the attachment point and bottom end was 7 and 3 cm respectively. In a later study, Woyke et al. (2016a) gave methods of derivation of nest shape indices, and described different kinds of *A. dorsata* nest built under diverse conditions (Woyke et al., 2016b).

The floristic and the human habitation conditions in the tropics, sub-tropics, arid and mountainous regions are different, and generalization of one region cannot be applied in another region. Therefore, with this background of diverse reports about the nesting behavior and nest site preferences, declining colony numbers and with the aim of conservation of this honey bee in the semi-arid environment of the north western region of India, study on its nesting behavior was considered to be of immense importance. This prompted me to undertake the present investigation.

Materials and methods

Study area

A. dorsata immigrates in the north western region of India during October/November, stays and reproduces there during winter and spring, and emigrates in summer. During its stay, *A. dorsata* acts as an excellent pollinator of many crops (Figures 1 and 2). This study was

Figure 1. *A. dorsata* pollinating onion (*Allium cepa* L.) flowers.

Figure 2. *A. dorsata* pollinating fennel (*Foeniculum vulgare* L.) flowers.

carried out at the main campus (in an area of about 5 km^2) of CCS Haryana Agricultural University, Hisar between 1983 and 2012, where *A. dorsata* makes many nests every year (Sihag, 2014). This site is adjacent to the Thar Desert (longitude 75° 46′ East and latitude 29° 10′ North). Here, the period from May to early July witnesses a very high temperature in the range of 43–48 °C and from June to mid-September is a period of floral dearth (Sihag, 1990, 2014). This place is an ideal representative of the semi-arid environment.

Nesting sources and nesting sites

Live and deserted *A. dorsata* nests of the giant honey bee were observed for studying its nesting behavior from 1984–1985 to 2011–2012. Annual observations were recorded for the nesting source selection and reoccupation of nesting sites (n = 5604 colonies) and triennial for other parameters (n = 1604 colonies). The structures on which nests were made were referred to as "nesting sources" and the places on the nesting sources where the nests were made or fixed were referred to as "nesting sites". Thus buildings and trees are nesting sources and branches of trees and the eaves/projections of buildings are nesting sites. Both "immigrated swarm colonies" and "reproductive swarm colonies" were observed that made nests on trees and man-made structures (Sihag, 2014). A record of the number of nesting sources, actual nesting sites and potential nesting sites (places where nests could be made) and presence or absence of the colonies on those sites was made. The number of live and deserted nests on those sources and sites made the basis of nesting preferences. The following indices were derived from the recorded data to determine or confirm the nesting preferences of this honey bee.

Nesting site occupation index

$$N_{sioi} = n_{sio}/N_{sio} \quad (1)$$

where N_{sioi} = nesting site occupation index; n_{sio} = number of nesting sites on a source actually occupied by the bees by making nest; N_{sio} = total number of potential nesting sites on the given nesting source.

Reoccupation indices of nesting sources and sites

To confirm whether *A. dorsata* repeatedly makes nests on the same source (same building or same tree) or site (the place where a nest was made in the previous year), 13 nesting sites on buildings and 36 on trees were monitored annually from 1984 to 2012. Thus a total of 28 observations were recorded on each source as well as site (reoccupation started after one year). A record of the number of times a source and a site were reoccupied was maintained. The reoccupation indices of the nesting sources as well as sites were derived using following formulae:

Nesting source reoccupation index

$$N_{sori} = \left[\frac{\sum n_{sor} \times V_{sor}}{\sum N_{sor} \times V_{sor}}\right] \quad (2)$$

where N_{sori} = nesting source reoccupation index; n_{sor} = number of times the source was reoccupied; N_{sor} = number of times observations were recorded on each source; V_{sor} = number of sources monitored.

Nesting site reoccupation index

$$N_{siri} = \left[\frac{\sum n_{sir} \times V_{sir}}{\sum N_{sir} \times V_{sir}}\right] \quad (3)$$

where N_{siri} = nesting site reoccupation index; n_{sir} = number of times the site was reoccupied by the bees by making nest; N_{sir} = number of times observations were recorded on each site; V_{sir} = number of sites monitored.

To know the probable parameters guiding reoccupation of the old nesting sites, the thickness of the nesting supports and the textures of the nesting surfaces were determined. The thickness of the nesting support was measured in the middle of the nest with the help of a measuring tape. The texture of the nesting surface was classified as smooth or unevenly grooved, based on the nature of the surface. For example the bark of an old branch of a ber fruit tree (*Zizyphus mauritiana*) has an unevenly grooved surface, but a young branch of a shisham (*Dalbergia*) tree has a smoother surface. The presence or absence of the old relics of a previous year's nest on a site was also recorded.

Angle, direction and height of the nesting support

I approximated the angle of a nesting support by drawing an imaginary horizontal line with the line of nesting support. Likewise, I determined the directional orientations of the nests by frequent visual observations using a compass and binoculars (10 × 50).

I recorded the height of the nesting site from the ground with the help of a 0.5 cm thick string. In the beginning of this study, I measured the height of a five storey building and an example of the tallest tree (*Dalbergia sissoo*) where *A. dorsata* made nests. This, I did by hanging the string from the site of the nest up to the ground (on the dropping end, a small piece of stone was tied to keep the string straight) and measuring the length of the string. I considered these heights as the maximum and standard for making subsequent comparisons. In all the later measurements, I approximated the heights by the visual observations and made comparisons with the standard string lengths.

Nests dimensions, shapes and shape indices

The colonies of *A. dorsata* emigrate from this region in May every year (Sihag, 2014) leaving behind empty combs. The sizes (length, height and thickness at the base) of the deserted nests were measured with the help of a centimeter tape and Vernier calipers. For the nests fixed on horizontal surfaces, nest length was measured as the horizontal dimension at the base of the nest, nest height as the vertical dimension of the nest. For the nests fixed on inclined support, base length was taken as nest length, perpendicular dimension from the center point of base length was considered as height, from the center point of base length and up to the lowest vertical point made the vertical dimension (Woyke et al., 2016a). I measured the thickness of the nest in the middle part of the brood area and in the upper swollen part of the honey area of the nest. I could measure the actual dimensions of all the nests constructed on the building of College of Basic Sciences & Humanities and only of the selected nests from the trees. For all others, rough estimates were made keeping in view the one standard nest that was fixed at an approachable horizontal site on this building and another nest that was fixed on an inclined site on a tree.

The nest shapes were determined with the help of drawn sketches of such nests as described above. From the data recorded on the horizontal, vertical and perpendicular dimensions of these nests, I determined the shape indices of the nests fixed on horizontal and slopped supports following Woyke et al. (2016a). These included: i. nest fixed on horizontal support: a. vertical semi-ellipse, b. semi-circle, and c. horizontal semi-ellipse; and ii. nest fixed on slopped support and the nesting support making an angle: a. between 0 to 15°, b. between > 15 to 30°, c. between > 30 to 45°, d. between > 45 to 60°, and e. > 60°.

The results on thickness of the nests were compared statistically using *t*-test following Snedecor and Cochran (1967). For data on nest height, direction and angle, and nest measurements, the total number of colonies in each case was 1604 whereas on reoccupation this number was 5604.

Results

Preferences for nesting sources and sites

At the study location, probable nesting sources of *A. dorsata* included man-made structures such as water towers and multi-story office/residential buildings, and big trees such as Indian rosewood (*D. sissoo*), eucalyptus (*Eucalyptus hybrida*), Indian banyan (*Ficus benghalensis*) and religious peepal (*Ficus religeosa*). Besides these, horticultural trees such as guava (*Psidium guajava*) or plum (*Prunus domestica*) were also present. The list of buildings and trees (not exhaustive), and their approximate numbers are presented in Table 1. Eucalyptus was the most abundant (~1000) followed by ber (~800) and Indian rosewood (~500); buildings were fewer in numbers than the trees.

Table 1. Nesting site occupation indices (N_{sioi}) of different sources nested by *A. dorsata* at Hisar, India.

Nesting source	No. of nesting sources	No. of potential nesting sites	No. of sites occupied	N_{sioi} of a nesting source	N_{sioi} of a group
Buildings/man-made structures					
Residences/offices[a]	30	15,000	31	0.002	36/15,022 = 0.002
Water tank towers[b]	2	22	5	0.227	
Trees[c]					
Dalbergia sissoo	200	1000	92	0.092	126/15,700 = 0.008
Eucalyptus hybrida	1000	5000	13	0.002	
Ficus benghalensis/Ficus religiosa	20	100	6	0.06	
Acacia nilotica	500	2500	5	0.002	
Zizyphus mauritiana	800	4000	4	0.001	
Kigelia africana	200	1000	4	0.004	
Mangifera indica	50	250	2	0.008	
Psidium guajava	50	250	0	0.0	
Citrus sinensis	50	250	0	0.0	
Syzigium cumini	30	150	0	0.0	
Phyllanthus emblica	20	100	0	0.0	
Prunus domestica	20	100	0	0.0	
Millettia pinnata	50	250	0	0.0	
Pongamia glabra	50	250	0	0.0	
Azadirecta indica	50	250	0	0.0	
Albizia lebbeck	50	250	0	0.0	

[a]Total potential nesting length = 30,000 m, 2 m length for one site.
[b]Actual nesting sites.
[c]Each tree was considered to provide on an average 5 potential nesting sites.

A. dorsata) made nests both on man-made structures as well as trees (Figures 3–7). Of the total of 1604 colonies studied on a triennial basis, only 357 (22.26%) constructed nests on man-made structures; 308 (19.20%) on the eaves/projections of multi-story residential/office buildings and 49 (3.05%) on water towers. The remaining 1247 colonies (77.74%) constructed nests on trees (Figure 8). Indian rosewood attracted maximal number of bee colonies (57.29% of the total colonies) followed by eucalyptus (8.29%), *F. benghalensis/Ficus religiosa* (3.86%), *Acacia nilotica* (2.81%), *Z. mauritiana* (2.37%), *Kigelia africana* (2.12%) and *Mangifera indica* (1.00%). Out of 796 immigrated swarm colonies, 440 constructed nests on trees with the remaining 356 on the buildings. Likewise, out of the 808 reproductive swarm colonies, 807 made nests on the trees and only one on a building. Except for one water tower (WT-1, Figure 4), no nest congregation on any other site was observed in this region, but sometimes 2–3 swarm colonies made on some Indian rosewood trees. If the number of nests present on the nesting sources is taken as a measure of nesting preference, at Hisar, *A. dorsata* seemed to show distinct preference for trees over man-made structures (Figure 8).

I tried to confirm whether or not the differential availability of nesting sources was influencing the nesting preferences of this honey bee. To rule out this possibility, I derived "nesting site occupation index" (N_{sioi}) of different nesting sources. At the place of this study, residential and office buildings ($n = 30$) provided

Figure 3. *A. dorsata* nesting on the projection of an office/laboratory building (height of nesting support was about 15 m from the ground; these buildings provided around 30,000 m length of nesting support for about 15,000 potential nesting site at the place of this study, however, only 8 sites were occupied). In these cases, angle of support was invariably 0°, hence nest shapes were: (1) vertical semi-ellipse; (2) semi-circle; and (3) horizontal semi-ellipse (near to latter shape in this figure). Upper left swollen part represented honey cells which were larger than the brood cells. This site was found to be occupied in all the 29 annual observations (with 28 reoccupations).

Figure 4. *A. dorsata* nesting on the water tower building, WT-1 (height of the nesting sites was about 15 m from the ground). Only 5 nesting sites were occupied with different annual occupations whereas remaining 9 sites of this tower and all the 8 sites of another similar tower WT-2 were not occupied even for once during the entire period of this study. The tree adjoining to the tower is siris (*A. lebbeck*), an excellent nectar source where this bee was first reported foraging during night time (Sihag, 1984). The angle of all the nesting sites was around 30°.

Figure 5. *A. dorsata* nesting on a ficus (*F. religiosa*) tree; height of the nesting support was around 5 m above the ground. Angle of the nesting support is between 30° and 45°; nest inclination index was <2. The surface of nesting support was smooth.

around 30,000 m available length in the form of building eaves/projections (Figure 9). If 2 m length is taken as a safe place for one nest of *A. dorsata*, these buildings therefore served as potential sites for about 15,000 nests. The water towers had 22 such potential sites, thus the total available sites on man-made structures came out to be 15,022. On the other hand, if on an average, a single tree has five nesting sites (viewing the structure of different trees of this study and nesting behavior of *A. dorsata* at Hisar, this seemed to be the logical maximal number), 3140 trees of this study provided 15,700 potential nesting sites (Figures 10–16). Like the results of % nest on the nesting sources (Figure 8), the results on "nesting site occupation index" (N_{sioi}) too revealed that as a group, trees were more preferred than the man-made structures (group N_{sioi} for buildings = 0.002 and for trees = 0.008; Table 1). The results suggest that nesting sites availability was not a factor in influencing the nesting site preferences of this honey bee. However, there were minor variations between the results on percent nesting (Figure 8) and those on "nesting site occupation index" (N_{sioi}) (Table 1). Results on individual sources revealed that the "nesting site occupation index" (N_{sioi}) showed maximal value for water tower WT-1 (0.227) followed by Indian rosewood (0.092) (Table 1). On the basis of these indices, water tank towers seemed to provide the most suitable nesting sites to this honey bee as 22.7% of its available nesting sites were occupied. However, in the light of congregation nesting behavior of *A. dorsata*, non-occupation of 77.3% of available nesting sites of TW-1, 100% of the TW-2 and many thousand available nesting sites of other buildings, it is evident that nesting sites availability is not a constraint in influencing the nest sites preferences of this honey bee. Results on "nesting site occupation index" (N_{sioi}) (Table 1) further reveal that water tower WT-1 was the best nesting source (in this case there was 35.7% nesting site occupancy, as out of 14 nesting sites 5 were occupied); Indian rosewood was second in the preference for nesting (9.2% occupancy). Although other buildings provided huge surface for potential nesting, values of their "nesting site occupation index" (N_{sioi}) were low and equal to *Acacia* and eucalyptus (0.2% occupancy) which was lower than *Ficus* (6% occupancy), *Mangifera* (0.8% occupancy) and *Kigelia* (0.4% occupancy); *Z. mauritiana* (0.1% occupancy) had the least N_{sioi} and seemed to be the lowest in preference (Table 1). Some other trees like *P. guajava*, *Citrus sinensis*, *Syzigium cumini*, *Phyllanthus emblica*, *P. domestica*, *Millettia pinnata*, *Pongamia glabra*, *Azadirecta indica* and *Albizia lebbeck* though having plenty of potential nesting sites, did not attract even a single colony (Table 1). The same seemed to be true in case of a second water tank tower WT-2 that had 8 potential nesting sites but did not attract even a single colony during the entire period of this study.

To further validate this latter point, data on annual observations recorded on the number of colonies making nests on different sources were subjected to derivation of "nesting source reoccupation index" (N_{sori}) (Table 2). The latter was maximal for the Indian rosewood followed by the water towers; other buildings and *K. africana* had lower values of N_{sori}. On this basis too, Indian rosewood was the most preferred nesting source; water tank towers seemed to be the second in preference. All other sources had very low "nesting source reoccupation index" (N_{sori}). Due to the extremely low individual values of N_{sori} of trees other than Indian rosewood, the trees as a group seemed to be less preferred in comparison to the buildings.

A very high percentage of nesting site reoccupation was observed on the buildings (91%) in comparison to the trees (11.2%). Individually too, while buildings had very high nesting site reoccupation, low to very low nesting site reoccupation was observed on trees (Table 3): 14.7% on *D. sissoo*; 11.9% on eucalyptus; 11.4% on *Ficus*; 8.6% on *Kigelia*; 5.9% on *Acacia* and 3.5% each on *Mangifera* and *Z. mauritiana*. To explore the reasons for the nesting sites reoccupation, I studied the presence/absence of relics of old nests and the textures of the nesting surfaces. Both of these factors seemed to be influencing nesting site reoccupation.

The majority of the colonies nesting on buildings made nests on sites having relics of old nests. Buildings provided 13 such sites where 332 colonies showed nesting site reoccupation during the period of this study (Table 3). However, trees did not provide such a clue for nesting site reoccupation by this honey bee. Smoothness of the surface may be the reason for nesting site reoccupation in majority of the latter cases, as the surface of the occupied sites was smooth; the unevenly grooved or highly rough surfaces were seldom occupied. That was the reason that only those tree branches having smooth surfaces were selected for fresh nesting. The transformation of smooth to unevenly grooved tree bark seemed to dissuade the bees for fresh nesting as well as reoccupation of the old sites. Eucalyptus is unique in keeping the smoothness of its trunk as well as branches by peeling off its old bark every year. That is why, some sites of this tree were occupied for multiple times (two sites for 4 times and one site for 2 times) (Table 3). *Z. mauritiana* was exception; its nesting surface was highly wrinkled and unevenly grooved, but still some colonies nested on this tree (Figure 6).

The diameter (thickness) of the tree branch seemed to influence the nesting behavior of *A. dorsata*. For the immigrated swarm colonies (settled here after immigration to this region in October/November (Sihag 2014)), tree branches with about 20 cm diameter seemed to be the most preferred nesting support. Of the total 440 such colonies, 210 nested on branches with 20 cm diameter (47.73%) followed by 115 colonies (26.14%) that nested on 25 cm diameter branches, 85 colonies (19.32%) nested on 15 cm diameter branches and 30 colonies (6.81%) nested on 10 cm diameter branches, the latter seemed to be the least preferred (Figure 17).

Table 2. Nesting source reoccupation indices (N_{sori}) of different sources nested by *A. dorsata* at Hisar, India.

Nesting source	No. of sources monitored	No. of times observations were recorded on each source	No. of times the source was reoccupied	N_{sori} of a nesting source	N_{sori} of a group
Buildings					
Residences/ offices	4	28	28	190/840 = 0.226	218/896 = 0.243
	5	28	15		
	1	28	3		
	20	28	0		
Water tank towers	1	28	28	28/56 = 0.5	
	1	28	0		
Trees					
Dalbergia sissoo	3	28	5	4045/5600 = 0.722	5449/42,476 = 0.128
	8	28	15		
	5	28	7		
	155	28	25		
	29	28	0		
Eucalyptus hybrida	3	28	2	1356/28,000 = 0.048	
	50	28	3		
	80	28	15		
	867	28	0		
Ficus benghalensis/ Ficus religiosa	1	28	1	15/280 = 0.054	
	2	28	3		
	2	28	4		
	5	28	0		
Acacia nilotica	2	28	3	8/8400 = 0.001	
	1	28	2		
	297	28	0		
Zizyphus mauritiana	2	28	2	4/56 = 0.071	
Kigelia africana	3	28	4	17/84 = 0.202	
	1	28	3		
	1	28	2		
Mangifera indica	2	28	2	4/56 = 0.071	

However, for the reproductive swarm colonies, 15 cm diameter thick branches seemed to be the most preferred, as out of 800 colonies 461 (57.62%) nested on such branches. This was followed by 216 colonies (27%) that nested on branches with 20 cm diameter, 73 colonies (9.13%) nested on branches with 10 cm diameter and 50 colonies (6.25%) nested on branches with 25 cm diameter (Figure 18). Thus, immigrated swarm colonies preferred thicker tree branches as compared to the reproductive swarm colonies that preferred relatively thinner branches for nesting. This differential preference seemed to be associated with the growth of the colonies. The immigrated swarm colonies grew about 1 m in length and 0.5 m in vertical height (Figures 22–25) with honey cells on the base requiring thick branches to bear the loads of the nests. Broadly, the reproductive swarm colonies remained about half in growth that of the migrated swarms colonies and did not build honey cells too primarily due to the small post swarming season.

Degrees of incident nesting angles and directions of the nests

A. dorsata made nests in different directions and on various inclined supports giving an initial impression of their role in the nesting site preferences. More than 95% of nests were found to be attached on supports making an angle from 0° to 45°; there were small differences among the groups (Figure 19). Nevertheless, inclination of nesting support with 15–30° seemed to be maximally preferred (25.25%) than others. This was followed by 0–15° (20.38%), 0° (19.20%), 30–45° (17.78%) and 45–60° (14.96%). Nest support with >60° inclination was least preferred and had only 39 nests (2.43%) (Figure 19). Thus, the angle of nesting support too seemed to guide the nesting preference of *A. dorsata*.

Of the 1604 colonies studied, 780 (48.6%) constructed their nests in an east-west direction, followed by 472 (29.4%) in a north east-south west direction and 215 (13.4%) in north west-south east direction (Figure 20). Only a small proportion of the nests were constructed in

Table 3. Nesting site reoccupation indices (N_{siri}) of *A. dorsata* at Hisar, India.

Nesting site	No. of sites monitored	No. of times observations were recorded on each site	No. of times the site was reoccupied	N_{siri} of a source	N_{siri} of a group
Buildings/man-made structures					
Residences/offices	4	28	28a	204/224 = 0.91	332/364 = 0.91
	3	28	26a		
	1	28	24a		
Water tank towers	2	28	28a	128/140 = 0.91	
	2	28	25a		
	1	28	22a		
Trees					
Dalbergia sissoo	8	28	5b	66/448 = 0.147	113/1008 = 0.112
	5	28	4b		
	3	28	2b		
Eucalyptus hybrida	2	28	4c	10/84 = 0.119	
	1	28	2c		
Ficus benghalensis/ Ficus religiosa	2	28	4b	16/140 = 0.114	
	2	28	3b		
	1	28	2b		
Acacia nilotica	2	28	2b	5/84 = 0.059	
	1	28	1b		
Zizyphus mauritiana	2	28	1b	2/56 = 0.035	
Kigelia africana	3	28	3b	12/140 = 0.086	
	1	28	2b		
	1	28	1b		
Mangifera indica	2	28	1b	2/56 = 0.035	

Notes: a: Relics of old nests present; b: Presence of relics of old nests not confirmed due to inaccessible height in *D. sissoo* and absence of clues in other cases; c: Relics of old nests were absent due to the peeling off of the bark.

other directions; for example, 30 (1.8%) nests were in north-south direction, 58 (3.7%) in east-south west direction and 49 (3.1%) in west-south east direction, respectively (Figure 20). Therefore, in the semi-arid environments of north west India, *A. dorsata* seemed to prefer those nesting sites where it could construct its nests in east-west and north east-south west directions.

Heights of the nesting sites

The nests of *A. dorsata* were distributed over different heights. At the study location, about 99% of colonies chose to nest at a height > 5 m; 95% at > 8 m; 80% nested at a height > 11 m; 60% at a height > 14 m, and about 70% at a height between 14 and 17 m. However, about 95% made nests at a height < 20 m (Figure 21). This indicated that majority of colonies (78.55%) preferred nesting at heights between 11 and 17 m.

Sizes and shapes of the nests

Of the total immigrated swarm colonies (N = 796), the majority (50.76%) in this region attained nest length (horizontal or base dimension) of 100–120 cm, followed by those having nest length 80–100 cm (26%), 120–140 cm (21.36%) and 60–80 cm (1.88%) (Figure 22). Minimum nest length recorded was 63 cm and maximum was 139 cm. On the other hand, nests of reproductive swarm colonies (N = 808) had relatively smaller lengths; a majority of these had length 30–40 cm (56.31%) followed by those with 40–50 cm (24.88%), 20–30 cm (10.02%) and 50–60 cm (5.08%); only a small proportion had 10–20 cm nest length (3.71%) (Figure 23).

Likewise, there was a difference in the height (vertical dimension) of the nest of two types of colonies; the majority of the immigrated swarm colonies had nest height 40–50 cm (51.76%) followed by those having nest height 50–60 cm (25.25%), 30–40 cm (15.58%) and least were those with 20–30 cm (7.41%) (Figure 24). The majority of the reproductive swarm colonies had nest height 20–25 cm (53.34%) followed by those 25–30 cm (20.67%), 15–20 cm (19.43%) and 10–15 cm (6.56%) (Figure 25).

The basal nest thickness (just below the attachment) of *A. dorsata* varied greatly; in the non-honey region there was narrower nest thickness (mean ± SD = 2.04 ± 0.6 cm, range = 1.7–3.1 cm, n = 150) where as in the honey region, the nests had broader basal thickness (mean ± SD = 5.7 ± 1.2 cm; n = 150); the difference between the two was significant ($p < 0.05$, df = 148, Independent Sample t-test).

The nest shape of *A. dorsata* varied greatly depending upon the angle of the nesting support. There were usually three types of shapes of the nests attached to the horizontal supports: (1) vertical semi-ellipse; (2) semi-circle; and (3) horizontal semi-ellipse. Of the 308 colonies

Figure 6. *A. dorsata* nesting on a ber (*Ziziphus mauritiana*) tree; height of nesting support was around 2 m above the ground. Angle of the nesting support was around 15°; the nest shape index was >2. The surface of nesting site was unevenly grooved.

that nested on the horizontal surfaces of buildings (offices and residences), 262 (85.1%) had horizontal semi-ellipse shape with 2.37 ± 0.19 (mean ± SD) nest shape index (Table 4). Colonies with other shapes were low in numbers; 29 (9.4%) had semi-circle shape with 2.04 ± 0.05 (mean ± SD) nest shape index and 17 (5.5%) had vertical semi-ellipse shape with 1.73 ± 0.03 (mean ± SD) nest shape index; among these, one colony had curved (concave) nest. This was due to the non-availability of enough nesting space on the nesting site (Woyke et al., 2016b).

Observations recorded on nest supports making angle between: (1) 0° to 15°; (2) >15° to 30°; (3) >30° to 45°; (4) >45° to 60°; and (5) >60° revealed that nests attached to such slanted supports also showed usual three types of shapes as described by (Woyke et al., 2016a). These included nests having inclination index: (1) <2; (2) 2.0; and (3) >2 (Table 4). In the first group, there was a sub-group of 327 colonies (Table 4, Sr. No. 4). These colonies had inclination index (II) <1. These colonies had perpendicular dimensions more than the vertical dimensions. These 327 colonies were small in size (Figures 22–25), made nests on supports with inclination angle 0° to 15° and all were reproductive swarm colonies. In the second sub-group (Table 4, Sr. No. 5), there were 405 colonies. These colonies had inclination index > 1 < 2. These colonies had perpendicular dimensions less than the vertical dimensions. These 405 colonies were also small in size, made nests on supports with inclination angle 15°–30° and these too were reproductive swarm colonies. The second group of 285 colonies was from those attached to the supports making angle 30°–45° (Table 4, Sr. No. 6). Both immigrated swarm colonies and reproductive swarm colonies comprised this group and nested on water tank towers (all these were immigrated swarm colonies) and trees (49 such immigrated swarm colonies nested on water tank tower WT-1, and 161 such colonies nested on trees; the remaining 75 reproductive swarm colonies also nested on trees (Table 4)). These were large colonies but not the largest ones. Like first group, in the third group too there were two sub-groups. The colonies of first sub-group were attached to the supports

Table 4. Nest shapes and nest shape indices of *A. dorsata* at Hisar, India.

Sr. No.	Nest shape	Nesting source	No. of nests	NSI = B/V	II = V/P
Nests fixed on the horizontal surface					
1.	Vertical semi- ellipse	Residential/Office Building	16a + 1b	1.53 + 0.13	NA
2.	Semi-circle	Residential/Office Building	29a	2.04 + 0.03	NA
3.	Horizontal Semi-ellipse	Residential/Office Buildings	262a	2.77 + 0.39	NA
Nests fixed on the slopped surface					
4.	Sloped with 0°–15°	Trees	327b	NA	0.64 ± 0.09
5.	Sloped with 15°–30°	Trees	405b	NA	1.23 ± 0.17
6.	Sloped with 30°–45°	Water tank towers and Trees	49a* + 161a + 75b	NA	2.03 ± 0.14
7.	Sloped with 45°–60°	Trees	240a	NA	2.37 ± 0.31
8.	Sloped with >60°	Trees	39a	NA	3.22 ± 0.38

Notes: NSI = Nest shape index, II = Inclination index, B = Base dimension, V = Vertical dimension, P = Perpendicular dimension; a = immigrated swarm colonies, b = reproductive swarm colonies.
*Colonies nesting on water tank tower WT-1.

making angle 45°–60°. Their vertical dimensions were about twice larger than the perpendicular dimension (Table 4, Sr. No. 7). These 240 colonies were exclusively immigrated swarm colonies and were among the colonies with the largest sizes. The second sub-group was represented by a very small number of 39 colonies attached to the supports making angle >60°. The vertical dimensions of these colonies were more than three times greater than the perpendicular dimensions (Table 4, Sr. No. 7). All these colonies were immigrated swarm colonies and they too grew to the largest sizes.

Discussion

Two species of Asiatic wild honey bees, the dwarf honey bee (*Apis florea*) and the giant honey bee (*A. dorsata*) have proved to be very promising natural wild pollinators of many plants in the north western region of India (Mann & Singh, 1983; Sihag, 1986, 1988, 2000a, 2000b, 2014) and are the bioresource of honey too. *A. dorsata* gathers 8–10 times more honey (5–8 kg) in its large nest than *A. florea* (0.5–1 kg) which builds a small nest (comb) (Oldroyd, 2006; Sihag, 2000a, 2000b). Furthermore, these two honey bees have their own distinct pollination importance (Sihag, 1986, 1988, 2000a, 2000b, 2014); due to the high energetic demand of *A. dorsata* (Sihag & Kapil, 1983) the latter should visit more flowers per foraging flight making it more efficient pollinator than *A. florea*. Therefore, conservation of this honey bee has become very important. For this purpose, study of its major nesting sources and nesting behavior was important.

The majority of the immigrated swarm colonies had the value of their nest size index as well as inclination index > 2. On the other hand, reproductive swarm colonies had the value of their nest size index and the inclination index < 2 (Table 4). These results are in agreement with those of Woyke et al. (2016a); low inclination index means the colonies are nesting on a support making angle < 30°. Reproductive swarm colonies preferred inclination angle < 30°. Here colonies with inclination index < 1 were those small colonies having vertical dimension smaller than the perpendicular dimension (colony fixed on the slopped nesting site). The young colonies nesting on sloped sites had such nests. Here base dimension was longer than the vertical dimension. This perhaps happens in the early settlement of the colony when majority of the bees tend to remain near the comb attachment. However, Woyke et al. (2016a) did not report such types of colonies. Likewise, the colonies with as high inclination index as > 2 means that the colonies are fixed on a support having angle > 45° (Table 4). The presence of maximal number of nests of immigrated swarm colonies nesting on horizontal supports of buildings with nest size index > 2 indicates that in these colonies nest growth was more in the horizontal dimension than the vertical dimension and the nest sites had sufficient space for expansion of the nests (Figure 3). Likewise, presence of maximal number of nests of immigrated swarm colonies nesting on slopped supports of buildings and trees with nest inclination index > 2 indicates that in these colonies nest growth was more in the vertical dimension than the perpendicular dimension (Woyke et al., 2016a).

The nesting preferences of *A. dorsata* seemed to vary from region to region. In the semi-arid environment of north west India, it mainly relies on trees for nesting (Figure 8). In Bangaloru too, this honey bee showed same kind of preference (Basavarajappa & Raghunandan, 2013). However, the findings of Neupane et al. (2013) were different. In Nepal, this honey bee was found to prefer buildings over the trees for nesting (Neupane et al., 2013). There, the availability of the nesting sites seemed to be the major reason in determining the preference for nesting sources and sites of the giant honey bee. At the place of this study, however, availability of nesting sites did not seem to be a constraint in determining the preference for nesting sources and sites of the giant honey bee, as both these were in plenty in diversity as well as suitability. There were only two water towers. However, complete rejection of WT-2, 9 sites of WT-1 and many thousand potential nesting sites of other buildings (Figure 9) strongly support this view point. The Indian rosewood seemed to be the most preferred nesting source of this honey bee followed by the water tank tower TW-1 (Table 2, Figures 4 and 8). This gives credence to the other speculations too that there are other factors that too play decisive roles in the selection of nesting sources and sites by this honey bee.

The majority of the nests of *A. dorsata* were located at unapproachable heights (Figure 21). This preference

Figure 7. *A. dorsata* nesting on a mango (*M. indica*) tree; nest located around 2 m above the ground. The shape of the nest was unusual curved having usual uncovered swollen honey area. Due to the gradual change in the angle of support from about 60° at the origin to 30° at the distal end, the nest has taken an unusual shape. Curved (concave towards east) nest was observed on one of the nesting sites of the buildings also where nesting site provided inordinately broad attaching surface. Here too, surface of the nesting site was smooth.

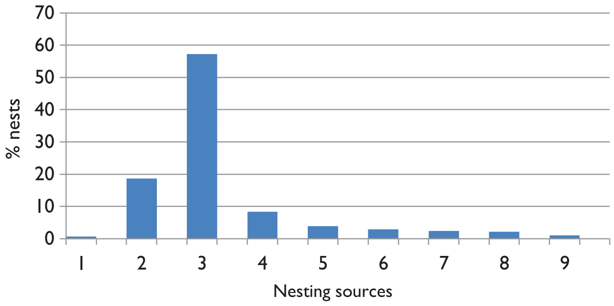

Figure 8. Nests of *A. dorsata* on different sources.
Notes: (1) water tank towers; (2) multi story buildings; (3) *Dalbergia sissoo*; (4) *Eucalyptus hybrida*; (5) *Ficus benghalensis/Ficus religiosa*; (6) *Acacia nilotica*; (7) *Zizyphus mauritiana*; (8) *Kigelia africana*; (9) *Mangifera indica.*

Figure 9. Building of the College of Basic Sciences & Humanities having sun shade projections where *A. dorsata* made nests. The colony in Figure 3 was present on the projection of this building. On four floors, this building alone carries about 5000 m surface length for about 2500 potential nesting sites.

has been reported by the earlier researchers too, and the behavior seemed to be guided by the anthropological disturbance factor (Basavarajappa and Raghunandan, 2013; Neupane et al., 2013). This is because, in this study, some colonies located in the horticultural area were on the lower heights e.g., on *M. indica* and *Z. mauritiana* where there is relatively less anthropological disturbance (Figures 6 and 7).

In the north western region of India, immigrated swarm colonies of *A. dorsata* make large nests with more than 1 m in length and 0.5 m in breadth (Figures 22–25). The same kind of behavior was reported by the earlier researchers too (Basavarajappa & Raghunandan, 2013; Neupane et al., 2013). However, in this region

Figure 10. *Ficus benghalensis.*

Figure 11. *Ficus religiosa.*

availability of several trees for potential nesting notwithstanding (Table 1, Figures 10–16), this honey bee predominantly preferred Indian rosewood trees for nesting (Figure 8). Moreover, number of nests on trees was never in the ratio of their actual numbers. Many of these trees possessing potential nesting sites were not at all nested by this honey bee in this region (Table 1, Figures 10–16). The Indian rosewood tree perhaps provided the better conditions for a combination of nesting parameters for this honey bee viz. height, smoothness

Figure 12. *Acacia nilotica.*

Figure 13. *Kigelia africana.*

and thickness of the nesting support and the inclination of the support (Figures 17–22). The nesting site with larger thickness seemed to provide better support to the very large colony. Similarly a nesting support with a smooth surface having inclination from 0° to 45° coupled with 14 to 17 m height of the support seemed to provide additional physical support against the gravity and protection against the enemies. Deviations from these parameters were less preferred. Immigrated swarm colonies nested on tree branches and eaves of water tank tower having inclination even > 45°. This is because these colonies immigrate and settle in this region during the period of still air current in October-November. At this time, air disturbance does not seem to be a factor, but probably does play a role in the winter and post winter seasons when reproductive swarm colonies are released (Sihag, 2014). The latter colonies,

Figure 14. *Eucalyptus* spp.

Figure 15. Neem (*Azadirecta indica*).

Figure 16. Jamun (*Syzigium cumini*).

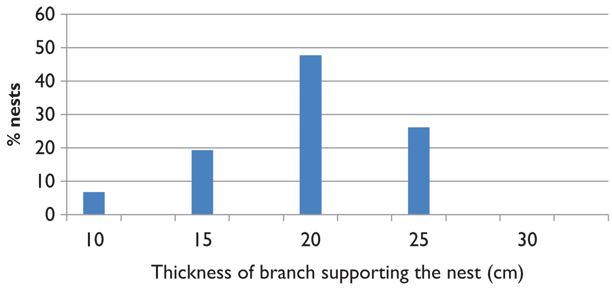

Figure 17. Nests of migratory (parent) swarm colonies located on different thickness of supporting branches.

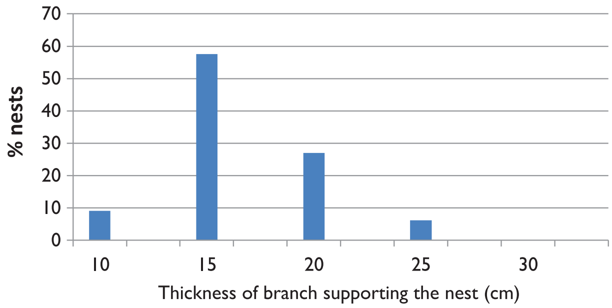

Figure 18. Nests of reproductive swarm colonies located on different thickness of supporting branches.

however, distinctly prefer nesting supports with inclinations from 0° to 45°. All the eaves/projections of office and residential buildings occupied by *A. dorsata* had approximately 0° angle of inclination and the majority of the nesting sites/supports were at a height > 14 and < 17 m (Figure 21). *A. dorsata* showed a preference

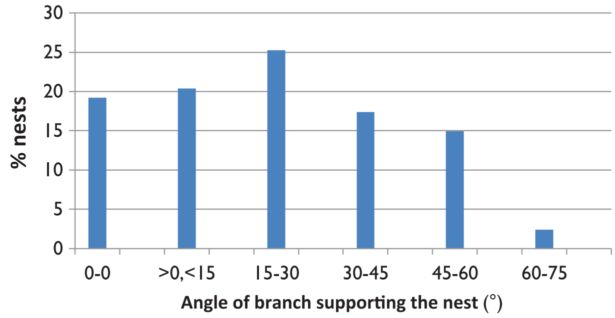

Figure 19. Nests located on tree branches showing different angles with the horizontal.

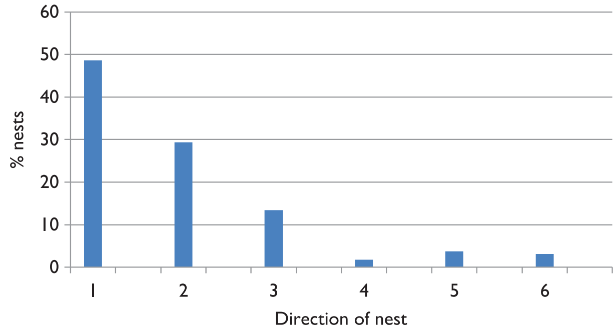

Figure 20. Nests located in different directions on the nesting sites.
Notes: (1) east-west; (2) north east-south west; (3) north west-south east; (4) north-south; (5) east-west-south; (6) west-east-south.

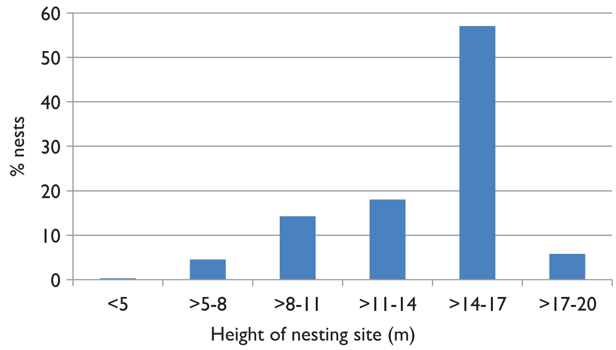

Figure 21. Nests at different heights.

for the direction of the nest also. The majority of the nests (about 78%) were fixed in east-west and north east-south west directions (Figure 20). This preference seems to be related to the local wind currents. In this region mainly western or northern winds flow and the majority of the built nests were parallel to these currents. This behavior seemed to ensure protection of the colonies against wind currents.

Nest site reoccupation seemed to be a very important trait of *A. dorsata*. This preference seemed to be more for the buildings and water towers than the trees.

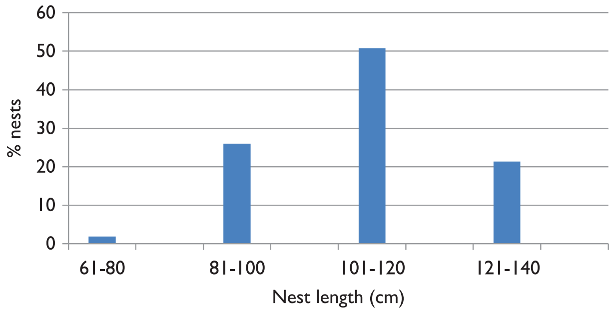

Figure 22. Nests of migratory (parent) swarm colonies showing different nest lengths.

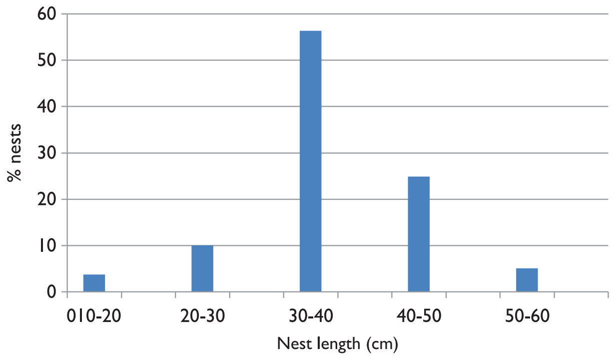

Figure 23. Nests of reproductive swarm colonies showing different nest lengths.

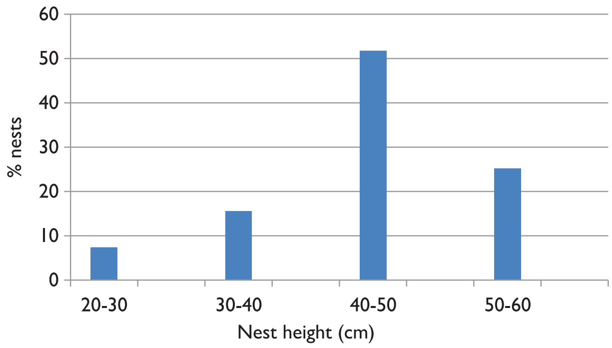

Figure 24. Nests of migratory (parent) swarm colonies showing different nest heights.

The presence of relics of the old nests seemed to be the sole factor guiding this behavior. Paar et al. (2000) too reported that *A. dorsata* forms massive single-comb colonies which usually hang from a tree branch or the eaves of buildings. Although colonies regularly migrate over many kilometers, they found that they often returned to their original nest site, even after an absence of up to two years. How the bees do this was however, unknown, as workers live for only a few weeks (Paar et al., 2000). Thapa and Wongsiri (2015) too reported that *A. dorsata* used wax specks to recognize old nest sites.

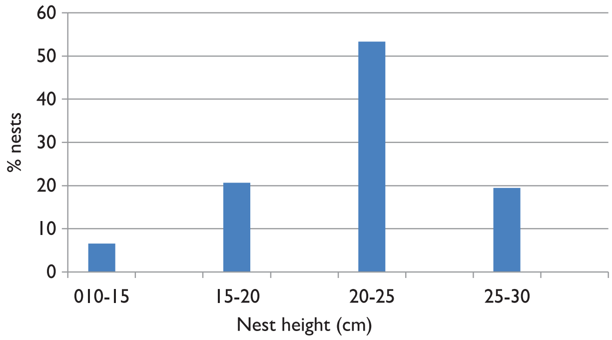

Figure 25. Nests of reproductive swarm colonies showing different nest heights.

In north west India, nest site architecture and its thickness seemed to be some of the important factors governing the nest preferences of *A. dorsata*; these factors remained fixed in case of buildings but varied greatly in case of trees. Among the trees, larger frequency of reoccupation on Indian rosewood trees seemed to be due to larger availability of this nest site combination coupled with height, inclination and direction of supports on the latter tree than the other trees of this region.

In my earlier study (Sihag, 2014), I reported that the maternal (immigrated swarm) colonies and reproductive swarm colonies all emigrate together from this place to the alternative seasonal migration places when floral condition in this region deteriorates. Woyke et al. (2012a) too suggested that the reproductive swarms stay at a place and when the floral condition deteriorates at the end of the season, they emigrate together with the old maternal swarms. I also reported the declining numbers of *A. dorsata* colonies in north western region of India and I speculated that declining numbers of Indian rosewood tree was the probable cause for this decline. That speculation is fully validated by the results of this study. Since Indian rosewood is the major nesting source of *A. dorsata* in this region, and in the recent past, number of this tree has declined markedly due to human interventions as well as rising saline water in this region (Khan et al., 2004); thus there has been a persistent habitat loss for this honey bee causing a decline in its colony numbers. One alternative for halting this decline in colony number could be through the conservation and vigorous propagation of Indian rosewood. However, other efforts like domestication of *A. dorsata* on the artificial nesting devices for "Dorsata Rafter Beekeeping" may impart additional fruitful results. To accomplish the latter task, information generated through this study will be very useful and timely in guiding the latter venture.

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