DISCUSSION
Honeybees are social beneficial insects especially known for their economically valuable products such as honey, wax, royal jelly and propolis. Though the use of honey is well known for a long time, the similar use of wax is yet to be realised despite its application in several industries.

The wax is produced by all worker bees of 14 - 18 days of age (Barrington, 1967), by their three pairs of wax glands present on the ventral side of the abdomen. The wax thus produced is utilized for the construction of the nest. Needless to mention that bees build their nest entirely by their own secretion without using other materials. Further the comb so constructed consists of hexagonal cells of different types on both sides with a common septum. Usually the cells are of three types in which bees rear the larvae of worker, drone and queen. In addition the comb contains cells for storing pollen and honey. The cells near or over the nest support are referred as supporting cells.

The comb is designed and constructed for a variety of functions, such as shelter, rearing of larval population, storage of food substances, protection against ecological factors, and natural
enemies. Thus the comb plays crucial role in the growth and development of honeybee.

Honeybees and their myriad ways of life have been well studied by biologists, ecologists, ethologists and entomologists. Much information exists and at the same time much remains to be investigated, particularly comb building activity in different species of honeybees. The present study though primarily intended to provide comprehensive information on the comb building activity of the domesticated honeybee *A. cerana* and two wild species of honeybees *A. dorsata* and *A. florea*, also provides substantial vital information on nesting behaviour, including the distribution of honeybee species.

Results of the present study provided valuable information on nature and distribution of nest sites, including their height, shape, symmetry, orientation, and density. Honeybees known to build their nests (comb) on a variety of supports that includes trees, shrubs, rocks, and other man made structures such as buildings, bridges, water tanks, temples, etc. (Rau, 1946; Singh, 1962; Morse and Laigo, 1969; Chakrabarti and Chaudhari, 1972; Deodikar et al., 1977; Reddy, 1983; Ahmed and Abbas, 1985). Nest found on trees and shrubs are classified as arboreal nests and those found on other than trees and shrubs are referred as terrestrial nests. The results of the study reveal the occurrence of 10 arboreal and 35
terrestrial nest sites of *Apis dorsata*, 61 arboreal and 5 terrestrial
nest sites of *Apis florea*, and 2 arboreal and 8 terrestrial nest sites
of *Apis cerana* in the study area. Considering the geography of the
study area which consists of greater part of urban area, the number
of nest sites of all the three species of honeybees are relatively
greater in number.

The successful identification of large number of nest sites in
the study area was made possible as a result of intensive survey.
Often the location of the nest sites of *A. florea* and *A. cerana* is
extremely strenuous and time consuming task. Sometimes the
nests of *A. florea* and *A. cerana* are found in inaccessible places
and quite often deep inside the supporting structure. Such of those
nest sites which reveals the presence of a nest but could not be
visible for observations partially or totally were excluded. Further, *A.
cerana* even though it is fully domesticated and beekeeping with
this species is being widely practised throughout Karnataka, still
exists as a wild species. Lavrekhin (1958) reported that in the east
*A. cerana* was found in feral conditions. Results show the
occurrence of as many as 10 natural nest sites of *A. cerana* in the
study area.

The results obtained on the nature of nest sites indicate the
presence of greater number of terrestrial nest sites of *A. dorsata*
and *A. cerana*, and greater number of arboreal nest sites in case of
A. florea. The occurrence of large number of terrestrial nest sites of
A. dorsata shows that the terrestrial support were preferred over
arboreal supports for nesting. It also suggests the greater
availability of terrestrial supports in the study area. Results also
indicate that A. dorsata selects only the most suitable nest sites
among the the available nest supports for establishing colonies.
A. dorsata prefers those nest sites that offer maximum space for
building large number of nests at selected directions and protection
against sun, wind and rain. In the present study area A. dorsata
built more nests on terrestrial supports (35) and only 10 on arboreal
supports. The occurrence as well as the type of nest sites vary from
place to place.

The A. dorsata occurs as a single colony and in aggregation
of colonies ranging from a few to a couple of hundreds. The results
indicate the presence of single, double, and multiple colonies in the
study area. As many as 16 single, 13 double and 16 multiple colony
nest sites were identified in the study area. Results confirm the
occurrence of A. dorsata as single, double and multiple colonies
(Butani, 1950; Lindauer, 1957; Singh, 1962; Morse and Laigo,
1969). The occurrence of A. dorsata as single, double and multiple
colony nest site on both arboreal and terrestrial supports in different
parts of India is well reported. Several factors are known to
influence the nesting behaviour and nest site selection. Distribution
of different types of nest sites, type of nest sites, nature of nest
support and suitability of nest support are the important factors that determines nest site selection. Generally A. *dorsata* starts nesting with a single colony and depending upon the nature of nest site it builds a few to several nests in course of time. Usually the arboreal nests are more in rural and agricultural areas when compared to more terrestrial nests in urban areas.

As many as 66 nest sites of *A. florea* which includes 5 terrestrial and 61 arboreal nest sites were observed in the study area. The nest sites of *A. florea* includes 16 trees, 45 shrubs and 5 terrestrial supports. The presence of large number of nests on shrubs indicate that *A. florea* preferes shrubs over trees and terrestrial supports. Further, selection of nest sites largely depends on the availability and suitablility of nest site area. Nest sites that provide greater shade and safety were preferred (Kshirsagar et al., 1983). Results also suggest that *A. florea* preferes relatively small nest sites with numerous branches and sub branches. The presence of colonies behind the dense foliage is not uncommon. The dense foliage coupled with net like branching and sub branching provides total protection to the colonies against sun, wind and rain. Partial hidden nature of nest also helps to escape from predators and pests. *A. florea* occurs naturally only as a single colony. In the present study the presence of more than one colony in a single nest site was not observed. The distribution of *A. florea* in different agro-climatic regions has been well studied.
Comparatively the nest sites of A. florea are smaller than that of A. dorsata. Unlike A. dorsata it prefers small trees and shrubs for nesting. It also prefers terrestrial supports for nesting. No particular plant species or man made structure preferred exclusively for nesting.

A. cerana preferred 8 terrestrial and 2 arboreal supports for nesting. Greater number of terrestrial support and lesser number of arboreal supports clearly suggests the preferential selection of the former over the latter. Generally A. cerana nests deep inside the nesting support. As a result enough space is not available inside the arboreal supports unless it is a dry and old log. Obviously terrestrial supports particularly the buildings provides space for closed nesting inside their structures. The occurrence of nests of A. cerana in a variety of structures is not uncommon. Generally A. cerana also occurs as a single colony and its occurrence in more than one colony in a nest site was not observed. The presence of multiple colonies of A. cerana on a single nest site has not been reported so far.

The two wild honeybee species A. dorsata and A. florea construct their nests either on terrestrial or on arboreal supports at a considerable height from the ground level. Comparatively the nests of A. dorsata usually found at a height greater than the height at which A. florea builds. The height of the single colony of
A. dorsata varies between 6.1 and 27.48 m from the ground level. No single colony was observed below 6 m and above 27.5 m. The height of nest is related to the height of nest support. Obviously nest support greater than 27.5 m and below 6 m was not available in the study area. Similarly, the height of double colonies found at a nest site was determined, and the height varies from 8 to 30 m. Earlier reports indicated that the height range of nests varied from a few centimeters from the ground to 20 m (Morse and Laigo, 1969; Chakrabarti and Chaudhari, 1972; Deodikar et al., 1977). The occurrence of single or double nest depends on the availability of the area of the support. Greater the area of nest support larger is the colony population. The occurrence of more double colonies on terrestrial support and less on arboreal support clearly indicates that terrestrial nest sites had more supporting area for nesting.

The height of colonies found on a multiple colony nest site varies between 3 m and 95 m range. A maximum of 35.25% colonies were observed at a height between 7 and 27 m. Only 1.78% colonies were noticed at a height between 22 and 95 m. The number of colonies found on a nest site is highly variable, and varies from as low as 4 to as high as 237. The occurrence of large number of colonies (237) on a single nest site, Ficus bengalensis at GKVK, is due to availability of nesting support at different heights and at different directions. Higher nest density on arboreal nest sites is in agreement with the earlier report (Singh, 1962). The
presence of 237 colonies in a single nest site is a world record as such large number of colonies has not been reported so far. Results suggests that the colony population of *A. dorsata* can be increased substantially if suitable supporting area is available.

Results of the study indicated the occurrence of maximum number of colonies of *A. dorsata* at a height between 16 and 20 m, followed by at 11 and 15 m. A few colonies were noticed at a height greater than 40 m, but their number was negligible. Comparatively the height at which colonies of *A. florea* found varies from 2 to 10 m only. Maximum colonies were observed between 2 and 4 m from the ground level. The colonies of *A. dorsata* were seen at a height far greater than *A. florea* which usually occurs at a height upto 10 m from the ground level. The present observations agree with Deodikar et al., (1977) who reported that height preference may be related to incidence of sun rays on combs and also may provide protection from pests and predators. Comparatively all the three species of honeybee prefer different heights from the ground level for nesting. Though nests of all the three species are noticed at different heights, each species has it's own height preference. The height preference where maximum nests observed for *A. dorsata* and *A. florea*, was between 10 and 20 m and 2 and 4 m respectively. The occurrence of maximum nests of *A. dorsata* at greater heights may be related to the height of bee forage. Recent information on nesting behaviour on foraging ecology suggests that
*A. dorsata* forages preferably on tall trees and plants. Nesting considerably at a greater height and foraging on tall trees is an ecological adaptation to maximise rewards and minimise energy loss.

The shape of a comb of *A. dorsata* and *A. florea* is generally U-shaped or semicircular or cuneiform. A maximum of 38.41% of *A. dorsata* and 38.27% of *A. florea* combs were U-shaped. However, eight different shapes of *A. dorsata* and five different shapes of *A. florea* were observed. The presence of different shapes of combs suggest that the comb shape is not fixed and differs from place to place and also from nest site to nest site. Further, combs of different shapes within the same nest site were noticed.

On the basis of shape, the combs of *A. dorsata* and *A. florea* were classified into symmetrical and asymmetrical. Of the 638 combs of *A. dorsata* observed, 540 were symmetrical as against 98 asymmetrical. Comparatively, the number of asymmetrical combs of *A. florea* is greater. Results of the study suggest that the comb shape is variable in nature and as such the symmetry differs with the shape of the comb. Though the comb of *A. dorsata* and *A. florea* is built with different shapes, the most common shape found to be more or less U-shaped. In addition to U shape, the plane of the comb at the point of attachment with the support is not always straight. The curved nature of the base and U shaped comb
is technically described as cateneous shape, which is known to bear maximum tension and greatly responsible for the long life of the comb. The cateneous shape also facilitates heavy load bearing for longer duration.

The nests of *A. dorsata* and *A. florea* show remarkable orientation in relation to North - South bearing. Maximum nests were oriented towards North - South, North - West and North - East. Relatively less or no colonies were observed orienting towards South - West or South - East. Results indicate that the nests were selectively oriented towards North - West and North - East. The present result support the findings of Deodikar et al., (1977) who reported the preference of North - South axis for building the nests. Nandi and Mahabal (1974) observed the relationship between the direction of the combs and direction of the wind. This preferential orientation may result in better navigation from hive to food source and back. It also helps in better incidence of sunlight on the colonies. The selective orientation of nests is also related to the direction of wind and may also be related to the direction of the earth gravitation.

Unlike *A. florea* and *A. cerana*, *A. dorsata* occurs in aggregation of colonies. The aggregation of colonies varies from nest site to nest site. The result obtained on nest density show the presence of greater number on arboreal support than terrestrial.
The nest density of arboreal nest sites varies from 3 to 237 during the study period. Comparatively arboreal nest sites supports greater nest density in view of greater availability of nest support at different height and directions. The terrestrial nest sites cannot support greater nest density as a result of limited supporting area at a fixed height and particular direction. Further arboreal nest sites provide better protection to the colonies against sun, wind and rain. The monthly nest density in five perennial multiple nest sites for three years clearly proves the nest population of *A. dorsata* is not constant but showed definite rhythmic oscillation in different months of the year. The results clearly indicate that the nest population in all the five nest sites increased during April and decreased from June to September of each year. The nest population increased gradually during spring and reached peak during summer. The nest population cycle increasing during summer and decreasing in rainy season may be due to the availability of abundant pollen and nectar during spring & summer and the dearth of these food substances during rainy seasons.

The comb of honeybee shows variation with regard to width, height and thickness. The width of a comb of all the species of honeybee is greater than height. The thickness of comb of *A. dorsata* is greater than that of *A. florea* and *A. cerana*. The greater width (Morse and Laigo, 1969) of the comb could be due to availability of greater or more horizontal support. Further, increase in
the distance from the attachment results in breakage of the comb, as load carrying capacity of the comb decreases. Comparatively the size of *A. dorsata* is bigger than that of *A. cerana* and *A. florea*. The comb width, height, thickness and size of *A. dorsata* was far greater than that of *A. florea* and *A. cerana*. It confirms the earlier findings by Deodikar, et al., (1977). The greater width, height, thickness and size of a comb of *A. dorsata* may be due to bigger body size and greater population and more food storing capacity. The variations observed in the dimension of comb of *A. dorsata*, *A. florea* and *A. cerana* are partially due to differences in the height and support of nest site. It may be due to different body size which is species specific and are genetically controlled.

Cell diameter of a comb with regard to supporting cells, worker cells and drone cells shows variation from species to species. Comparatively the cell diameter of supporting, worker and drone cells of *A. dorsata* is greater than that of *A. florea* and *A. cerana*. The variation in the diameter of a cell is directly related to body size of the particular species. Morphologically the size of *A. dorsata* is bigger than other two species. The size of *A. florea* is smallest and that of *A. cerana* is intermediate. The size variation is genetically controlled and is species specific. Difference in the cell diameter of supporting, worker and drone cells of *A. florea* is significant and in case of *A. dorsata* and *A. cerana* except worker and drone cells, difference in the cell diameter is significant. The
results of the present study is in confirmation of the previous studies by Muttoo (1956), Thakar & Tonapi (1961), Deodikar et al., (1958), Zander and Weiss (1964), Ruttner et al., (1985 a).

Similarly the thickness in the cell wall of support, worker and drone cells of A. florea shows significant difference. In case of A. dorsata significant difference was observed only in case of support and drone cells. The significant difference observed in the wall thickness of worker and drone cells of A. cerana is in agreement with Muttoo (1956) and Thakar and Tonapi (1961).

Significant differences were observed in the depth of support, worker and drone cells of A. dorsata and A. florea. In case of A. cerana drone and supporting cells showed significant difference.

The mean length of ten linear cells shows variation from species to species. The mean length of supporting, worker and drone cells of A. dorsata was greater than A. florea and A. cerana. The mean length of ten cells of support and worker cells of A. florea is smaller than A. cerana. The difference in the length of ten linear cells of support, worker, and drone cells of the three species is significant.

Similarly the number of cells per square decimeter area shows variation from species to species. The number of supporting and worker cells of A. dorsata is less than A. florea and A. cerana.
Both supporting and worker cells of *A. florea* are greater in number per square decimeter. The difference in the number of cells per unit area is due to difference in the size of the cells which in turn related to the body size. The present results are in confirmation of the findings of Dadant (1975).

The comb growth of 5 arboreal as well as 5 terrestrial colonies of *A. dorsata* were observed continuously for a period of 90 days. There is a difference in the rate of comb growth from one arboreal nest site to another and also from one terrestrial nest site to another. The maximum comb growth in arboreal colonies varied between 6985.80 sq. cm. and 9385.00 sq. cm. and it was between 5564.00 sq.cm to 7187.60 sq. cm. in case of terrestrial colonies. Maximum growth of arboreal colonies was observed at Yelahanka and minimum comb growth was observed at Mavally. In case of terrestrial colonies the maximum and minimum comb growth was observed at Bangalore and Malathally respectively. The comb growth was observed continuously in all arboreal and terrestrial nest sites throughout the study period. There is significant difference in the growth rate in arboreal and terrestrial colonies. Arboreal colonies grows faster than terrestrial colonies.

Difference in the rate of comb growth either in case of arboreal or terrestrial colonies is due to difference in the population size, as the size of the population of each colony from one site to
other nest site is highly variable. Greater the population more is the comb growth. Further comb growth increases with increase in the wax secreting population (Szabo, 1977) but the amount of comb constructed per bee decreases (Freudenstein, 1961). Comb growth also increases in relation to brood rearing activity. Increase in the brood rearing activity increases comb growth. There is an inverse relationship between comb growth and honey production, increase in honey production results in decrease in comb growth. Greater growth in arboreal colonies may be due to greater availability of pollen than nectar. Pollen is known to stimulate brood rearing activity and in turn increases comb growth substantially. Greater flow of nectar results in increase in nectar foragers and in turn increases honey production.

The comb width of arboreal colonies of *A. dorsata* at different heights from the ground level was recorded. The growth of the comb width decreases with increase in height. The growth rate was comparatively less at 28 m height from the ground level than at 10 m. The difference was more pronounced between 60 and 90 days. Similarly the comb width shows differential growth rates in all terrestrial colonies at different nest height, being greater at lesser nest height and slower at greater nest height. The difference in the width was greater after 45 days of initiation of comb building, and reached peak at 90 days.
The growth rate in the height of the comb shows variation with height of nest site and also from one place to another. The comb growth in height of terrestrial colonies show much greater differences than arboreal colonies. The difference in the growth of comb height was more pronounced after 45 days of initiation of comb building. Ramesh (1990) reported that size of a comb of a colony decreased with the increase in the height of a colony from the ground level. The colonies of A. dorsata built at a height greater than 30 m showed smaller size compared to the colonies found below 30 m height and colonies built at greater height ceased to grow and never attained maximum size. Result of the study suggests that the size of the comb is related to the height at which it is built. Generally the combs built at considerable height from ground level are smaller in size than those found on near to the ground level. The comb size is inversely related to the height of the nest site, greater the nest site smaller is the comb size. Several factors including ecological factors may be responsible for the difference in the comb size at different heights.

Similarly the size of the comb shows variation with respect of height of the nest site and the place of nesting site. The difference in the size of comb was more pronounced in both arboreal and terrestrial colonies after 45 days of initiation of comb building. There is a significant difference in comb building until 30 days. The differential rate of comb growth observed in the study at different
nest sites and places may be due to differences in the size of adult bee population in general, wax secreting population in particular.

There is a direct relationship between population size and comb building activity (Darchen, 1957; Taranov, 1959). Comb building activity is also influenced by the brood rearing activity and the rate of nectar and pollen flow (Hepburn, 1986). It is also influenced by nature of nest site and nest height from the ground level.

The rate of growth of a comb is correlated with the presence and absence of comb remnant on the nest support. There is a significant difference in the comb growth on a remnant support and non-remnant support, being greater at remnant support than at non-remnant support. Difference in the comb growth on remnant and non-remnant support were observed throughout 90 days. The use of the old nest site with the support having remnants of old deserted combs is confirmed in the present study. This observation strongly supports the earlier information that old combs or comb remnants may influence the reuse of old support for comb building (Deodikar et al., 1977). Similarly differential comb growth on remnant and non-remnant nest support of arboreal colonies were observed. Like terrestrial colonies the comb growth of arboreal colonies on remnant nest support is greater than in non-remnant
nest support. Differential comb growth on remnant and non-remnant support was observed throughout 90 days.

The comb growth of *A. florea* with respect of comb width, comb height and comb size was observed at 5 arboreal nest sites located in different places of study area, and one terrestrial nest site for a period of 105 days. Comparatively the rate of comb growth of arboreal colonies is greater than that of terrestrial colonies. The comb growth rate of arboreal colonies at five nesting sites shows variation and the maximum growth rate was observed at Cubbon park and the minimum was at Jnanabharathi. Variation in the rate of comb growth at different places was due to variation in the size of adult bee population and availability of food substances. Greater flow of pollen stimulates brood rearing activity which in turn increases comb building activity. The pattern of comb growth of *A. florea* and *A. dorsata* shows similarity. The factors that influence the comb growth in *A. florea* also influence *A. dorsata*.

Similarly comb growth of domesticated honeybee *A. cerana* with respect of comb width, comb height and comb size was recorded continuously for a period of 45 days. Comb growth was observed continuously and attain a maximum size of 223.59 sq.cm. in a period of 45 days. The growth rate was greater during the earlier period.
The comb building activity of *A. cerana* is faster than *A. dorsata* and *A. florea* and attained optimum size in 36 days as against 105 days by *A. dorsata* and 110 days by *A. florea*.

The comb growth with respect to width and height was observed continuously. The daily rate of comb growth of *A. dorsata*, *A. florea* and *A. cerana* was compared. It was 0.87 cm, 0.20 cm and 0.45 cm in comb width respectively. Similarly the comb height of *A. dorsata* was greater than *A. florea* and *A. cerana* and it was 0.77 cm, 0.15 cm and 0.36 cm respectively. Comparatively the comb building activity of *A. dorsata* is faster than *A. florea* and *A. cerana*. *A. dorsata* builds bigger and faster combs than *A. florea* and *A. cerana*.

In general the comb showed continuous growth in all three species of honeybee. However the rate of growth is not similar in all the three species and in all nest sites. There is a inverse relationship between comb building and honey gathering activity. Comb building activity was relatively slow during honey flow seasons than non honey flow seasons. Majority of foragers switch to nectar collection during honey flow seasons. Increase in nectar foragers reflects in decrease in the pollen collectors, which in turn reduces significantly pollen flow. Reduction in the supply of pollen substantially decrease brood rearing activity. The brood rearing activity is directly related to the comb building activity.