Honey and honeybees are known to man since time immemorial. The use of honey especially for religious and medicinal purposes is known for long time (Singh, 1962; Joshi & Godbole, 1970). Although beekeeping and agriculture have been practiced together since ancient times, scientific beekeeping on modern lines was established in India only after the invention of movable frame hives in 1882. It was only in the later part of this century that some steps were taken to modernize beekeeping in India.

The success of beekeeping industry depends on the degree of exploitation of the nectar and pollen resources of the flowering plants by the bees (Suryanarayana et al., 1983). Continuous flow of food substances throughout the year is essential for the success of beekeeping. The availability of nectar and pollen to foraging bees fluctuates with time of the year and also flowering of different plant species at different seasons (Loper et al., 1976; Schafferi & Schaffir, 1977; Nunez, 1977; Corbet, 1978a,b; Reddi et al., 1980; Hadisoesilo & Furgala, 1986). Honeybees are known to adjust its foraging schedule to the abundance and the time of availability of food sources (Kevan, 1976; Corbet, 1978a). Many factors including the quality and quantity of pollen and
nectar, nectar sugar concentration, density of flowers and the number of competing insects determine the rate of attractiveness of foraging bees to a particular plant (Faulkner, 1976; Free, 1977; Boetler & Wilson, 1984; Barth, 1985; Akratankul, 1987; Johansen & Mayer, 1987). In addition to bee-flower attraction, foraging bees show distinctive preference for those plants yielding greater quantity of pollen and nectar (Deodikar & Suryanarayana, 1972; Butler, 1974; Gary et al., 1977a,b; Chaudhary, 1978; Kevan, 1978; Kevan & Baker, 1983; Iakovleoa, 1985; Lobreaw et al. 1987).

Honey yielding capacity of colonies varies from place to place and also within the apiary (Hassanein & El-Bandy, 1960, Moeller, 1961; Rinderer et al., 1985; Pesante et al. 1987). Honey production and races of honeybees were related (Bar-Cohen et al., 1978; Szabo & Lefkovich, 1987). Also honey production is correlated with foraging activity (Sugden & Furgala, 1982). Milne (1985) obtained correlation between longevity and honey production. Phenotypic and genotypic variability have greatly influenced honey gathering ability (Free & Williams, 1973; Rinderer et al., 1984, 85; Danka et al., 1986, 87; Pesante et al., 1987; Calderone & Page, 1988; Calderone et al., 1989; Nova, 1989; Robinson & Page, 1989). Many factors like the frequency of nectar trip, pollen collection frequency, foraging time, length of foraging life and size of foraging load are highly variable from colony to colony and also from place to place (Nova, 1989).
The quality and quantity of nectar as well as its source greatly influence the foraging behaviour of honeybees. Nectar is primarily a sugar solution with minute quantities of various other substances, which contribute to the characteristic aroma of the honey produced (Brown, 1961; Mostowska, 1965; Von-Handel et al., 1972; Seogin, 1979). The composition of floral and extrafloral nectars show variation from one plant species to another (Baker et al., 1978). Floral nectar with rich hexose sugar are less attractive to most lepidopteran insects (Baker & Baker, 1983). The ratio of sucrose, glucose and fructose vary from one flower species to another (Percival, 1965).

Honeybees preferred solutions of single sugars in the following descending order, sucrose, glucose, maltose and fructose (Wykes, 1952). Furgala et al. (1958) worked on Mililotus alba found that the proportions of sucrose, glucose and fructose in the proportion of 36%, 27% & 24% of the total solids than in Medicago sativa, Trifolium hybridum and Trifolium pratense. Kartashova and Novikova (1964) revealed that in 12 dicotyledonous species sucrose and glucose occurred in greater quantities than fructose.

Southwick et al. (1981) correlated sucrose/hexose ratio with flower morphology and found that tubular flowers had more sucrose than open flowers which had more hexose. Baker and Baker (1983) observed that nectars of flowers visited by
long tongued bees are usually sucrose rich, while those pollinated by short tongued bees are generally hexose rich. El-Banby et al. (1985) reported that in *Gossypium barbadense* levulose (8.4%) comprised the highest percentage followed by dextrose (7.8%), sucrose (1.6%) and raffinose (0.78%).

Nectar production by a flower depends not only on the secretory machinery in the nectary but also the rate of photosynthesis, respiration and sugar transport (Southwick, 1983, 1984).

Nectar secretion is also affected by internal and external factors such as weather, soil and hereditary. Effect of weather has received more attention than any other factors (Shuel, 1967; Kropacova & Haslabchova, 1970; Waller et al., 1981; Southwick, 1984; Pinzauti, 1985). Various soil factors like soil temperature, soil fertility and soil water also affect the nectar production (Southwick, 1984). Effect of various hereditary and internal factors like differences among varieties, flower age, flowering habits and flower sex may also influence the nectar production (Girnik et al., 1971; Moffett et al., 1976; Degrandi-Haffman & Collison, 1982; Southwick, 1984; Szabo, 1984; Southwick & Southwick 1986).

There may be significant differences in the average sugar concentration and volume of nectars of different species (Percival, 1965). Different species and varieties
may have nectar with different average sugar concentration. Even within a single flower, the sugar concentration is subjected to considerable fluctuation by temperature and relative humidity (Southwick & Southwick, 1983; Szabo, 1984). The attractiveness of a species may differ at different times of the day and at different stages of flowering (Brewer & Dobson, 1969; Moffett et al. 1976).

The characteristic daily secretory rhythm of a flower species is closely followed by the abundance of nectar foraging bees visiting it. This rhythm may be influenced by the aging of the flower (Southwick & Southwick, 1983; Pinzauti, 1985) by the amount of reabsorption that occurs and by the degree of concentration which depends upon changes in relative humidity (Nye & Pedersen, 1962).

Nectar secretion may also be increased by bees and nectar gathering insects. Corbet (1978a) observed that the sugar concentration of nectar in flowers visited by bees was less than those flowers which bees had not visited. However, Moffett et al. (1976) could not establish any correlation between the quantity of nectar secretion and number of bee visits. Balzekas (1978) found that flowers of Mililotus alba visited by bees secreted more nectar. Wykes (1953) discovered that periodic removal of nectar from flowers increased the total amount of nectar and sugar secreted, although the sugar concentration was lower. Removal of
nectar from flowers three times a day produced more sugar than flowers from which nectar was removed once a day (Bogoyaulenskii & Kovarkaya, 1956). Pedersen (1961) implied that sampling the nectar concentration of flowers indicates that they have been visited and likely that they have been pollinated. Kurina (1974) found that increased secretion of nectar is directly related to repeated extraction of nectar in Brassica species and Asdepiar syriaca. Total amount of sugar produced was not effected by the frequency of nectar removal.

Echigo (1970) determined the sugar contents of Pumpkins and Milkvetch by gas-liquid chromatography and the results were glucose (27.29%), fructose (35.47%) and sucrose (30.61%), and (29.25%) glucose and (35.61%) fructose respectively. Studies on nectar sugar concentration of Heavea brasiliensis revealed 30% in the early morning 80% at 10.00 h with an average sugar concentration of 75% (Wongsiri et al., 1985).

Fahn (1948) investigated the daily secretion of 66 indigenous and cultivated plants of Israel. Sugar contents of these species varied from 0.13 mg to 2.68 mg per flower. He found that the quantity of nectar secretion was related to the size of the nectary and similar relationship was not established with nectar concentration. He also found variations in the ratios of sucrose, glucose, and fructose in
different plant species. Temperature, humidity, soil moisture, time of the day, flower age, and root pressure were important factors influencing nectar secretion (Fahn, 1949). Divan and Vartak (1980) suggested that moist soil, fine sunshine, cool breeze, humid weather and wider variations in daily temperature are beneficial for good nectar secretion. Rowley (1976) who studied sugars of 40 common Philippines nectar showed that sucrose, glucose and fructose constituted 2 to 95% of total sugars. Maltose was also detected in 2 species. Murell et al. (1982) studied the nectar secretion in 8 varieties of Lotus corniculatus. The volume produced per umbel ranged from 2.33 to 5.07 µl. It was concluded that aroma and nectar production was not always closely related. However, nectar yield was directly related to the cross sectional area of functional phloem in the peduncle.

In India, Montgomery (1958) evaluated 38 plant species for their nectar-sugar concentration. Polygonum, Lonicera, Aster, Helianthus annuus and Bideus had 50% or more concentration of sugar. Working on similar lines Sharma (1958) determined the sugar concentration of some Punjab honey plants. Sugar concentration of major honey sources were Brassica sp. (42-52%), Citrus sp. (40-44%), Cedrella sp. (36%), Berberis (48%), Peach and Pear (70%), and Tecoma grandiflora (14%). Raya (Brassica juncea) had the highest average of sugar concentration of 52%. Satyanarayana (1975)

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observed that the sugar concentration of nectar of Syzygium cumini varied from 15 to 72%, whereas in Allium cepa, it ranged from 67 to 75% (Rao & Lazar, 1980). Twenty three different plant species were studied by Sharma (1980) on nectar concentration and revealed that sugar concentration varied from 14 to 70%. Highest percentage of sugar concentration (79%) was found in Silver oak (Grevillea robusta). A variation of 35-52% was found in major honey plants.

Generally, honeybees preferred sugar concentration of 20 to 40%. Dhaliwal and Bhalla (1980) correlated bee visitation with nectar sugar concentration. Robinia pseudo-acacia showed a nectar sugar concentration of 53 to 75% and its honey potential has been estimated to 500 kg/hectare (Gupta & Dogra, 1987). Wild cherry (Prunus puddam) was evaluated for its nectar properties and honey potentials by Reddy and Gupta (1987). In this species the nectar sugar concentration varied from 12.60 to 18.10%. Honey potential of Prunus puddam is calculated to 34 kg/100 trees.

Hourly fluctuations in the sugar concentrations of different crops have been studied. In Carvia callosa the sugar concentration increased from morning until 14.00 h and then remained constant. Similarly, in Thelepaepale ixiocephala, sugar concentration in the nectar increased from 35 to 40% at 08.00 h to 64% at 15.00 h and then decreased.
slightly after 16.00 h (Phadke, 1964, 65). Tanda and Goyal (1979a) noted the fluctuations in the nectar sugar concentration of Cotton (*Gossypium arboreum*) where the concentration increased from 24% at 09.00 h to 33% at 15.00 h. Studies on Cardamom revealed an increase in sugar concentration with increase in atmospheric temperature and decrease in relative humidity (Chandran *et al.*, 1980). Reddi and Reddi (1982) investigated pollination biology of *Ipomoea kentrokaulos* and found an increase in sugar concentration from 52% at 09.00 to 71% at 17.00 h. Extra floral nectar is produced at the junction of the pedicel with the flower at the rate of 8 ul per day.

In rubber tree (*Hevea brasiliensis*) sugar concentration increased from 39.50% at 08.00 h to 73% at 10.30 h and this increase was followed by the increase in temperature and decrease in relative humidity (Shakuntala Nair & Wakhle, 1983). The nectar sugar concentration of (*Brassica compestris*) increased from 09.00 h (15.2%), reached peak at 14.00 h (40.4%) and then decreased (Tanda, 1984b). The floral reward and honeybee visitation rates on the Soapnut tree was studied by Reddi *et al.* (1980). Pistillate flowers produced nectar nearly 3 times more than that of staminate flowers. Nectar was sucrose predominant type with sucrose 85.5% and glucose and fructose 7.25% each. Sihag and Kapil (1983) analysed the nectars of 44 plants visited by *Apis florea* and *Apis dorsata*. 
Pollen is the principal source of non-liquid food and is rich in protein and lipid. It is directly responsible for the growth and development of the honeybee. Pollen is available in the anther of the flower after dehiscence. The colour of the pollen varied from plant to plant (Saraf, 1987).

Honeybees are known to exhibit preferences in pollen selection, but the basis for preference is not yet clearly understood. Honeybees have a strong tendency to collect certain species of pollen (Nye & Mackensen, 1965, 68; Cale, 1971). Pollen odour (Levin & Bohart, 1955), and colour (Lepage & Boch, 1968; Boch, 1982) are important factors in pollen attractiveness.

Studies on factors influencing pollen foragers are reported. The presence of larvae within the colony increased the number of foragers gathering pollen (Free, 1967). The proportion of bees collecting pollen showed greater seasonal variation than the proportion of bees collecting nectar (Reddy, 1980a). Lack of pollen in winter affected brood rearing (Kapil, 1957; Doull, 1973; Williams & Kauffeld, 1974). Stanger and Laidlaw (1974), found supplementary feeding of honeybees with synthesized pollen as a pollen substitute during winter and autumn induced high rate of brood rearing. Honeybees collecting fungal rust spores as substitute for pollen has been reported (Chaudhary, 1977).
The time of pollen foraging varied with the seasons of the year (Singh, 1981). Mattu and Verma (1985) have reported that bee collected pollen and nectar throughout the year in Simla. Maximum pollen collection from January to March in Delhi was reported (Bisht & Pant, 1986). Verma (1983) found that peak pollen collection by A. cerana in Jeolikot was between 08.00 and 11.00 h in February-March. A. cerana and A. dorsata collected pollen from paddy between 08.00 and 12.00 h (Singh, 1978), whereas in Karnataka peak pollen foraging time was 11.00 to 13.00 h on Paddy (Rao & Seethalakshmi, 1978). Thakur et al., (1982) reported the comparative foraging behaviour of A. cerana and A. mellifera on Mustard. Chaudhary (1978) analysed 5,200 pollen loads of A. cerana and found that only 56 loads contained pollen from more than one plant species. Similar observations were also reported (Sharma, 1970a, b; Chaturvedi, 1977; Jhajj & Goyal, 1979). In caged pollination experiments, bees did not pollinate Sunhemp flower and collected pollen without touching the stigma (Mohan, 1973).

The weight of the pollen load depended upon the species from which the pollen had been gathered (Naim & Bisht, 1979). A. cerana collected an average pollen load of 0.008 g from Mustard, 0.019 g from Brassica juncea, Pyrus malus and Zea mays (Punjabi et al., 1969). Dhaliwal (1970) compared the pollen collection by A. mellifera reared in A. cerana combs,
and found that the comb cell size affected the pollen carrying capacities of the foragers.


Honeybees select the most profitable crop by the interplay of choice and memory (Ribbands, 1949). Flower constancy of individual honeybees during a single foraging trip, successive foraging trips and days (Betts, 1935; Maurizio, 1953; Frisch, 1967; Free, 1970) has been known for
The duration of flower constancy varied from a few trips to a life time (Ribbands, 1949). As a result of flower constancy, individual foragers tend to collect only one type of pollen (Free, 1963, Sekiguchi & Sakagami, 1966) and return to the same small area over a series of foraging trips (Free, 1966; Levin, 1966).

Despite this strong tendency, occurrences of more than one colour of pollen in individual pellets collected by honeybees have been detected (Hodges, 1954; Free, 1963; Jay & Jay 1984; Davis, 1991). The frequency of mixed loading of pollen varied from 0.1 to 6.75% (Davis, 1991). Against this background of a general tendency for flower constancy, wide variation in the foraging conditions, particularly the time of pollen availability, nectar volume, nectar-sugar concentration and accessibility occur (Percival, 1955; Corbet, 1978b). Recently, evidences for behavioural flexibility of bees foraging on different floral resources are emerging. Foragers will shift from one type of flower to another due to a variety of reasons. A colony of honeybees adjusts its process of selection of plant species in relation to its colony's food requirements, a rate of resources acquisition and unloading time (Seeley, 1987; Seeley & Levin, 1987). Unloading time is a function of the rate of nectar arrival, the concentration of nectar required, and the amount of unfilled comb in the colony (Seeley, 1989). A colony of
honeybees also shows a preference for different portions of a foraging area at different times and adjusts its rates of recruitment and abandonment in accordance with the profitability of specific flower species (Gould, 1976; Weaver, 1979; Rossel & Wehner, 1982; Winston, 1987; Seeley et al., 1991).

Under these changing circumstances of bees and their food, the process of selection and collection of food by honeybees is far from simple (Schmid-Hempel, 1987). In view of the existence of flexibility in foraging behaviour, it is of great economic importance to know whether or not the switching tendency of individual honeybees vary with plant species.

It is well known that honeybees play an important role in pollination of many cultivated and wild plants, which require cross pollination. Insect pollinators especially honeybees increase the quality and quantity of agricultural produce (Free, 1970; Bohart, 1972; Wafa et al., 1972; Forster et al., 1973; Mc Gregor, 1976; Free, 1977, Freund & Furgala, 1982; Mahmood & Furgala, 1983; Tanda, 1984a; Sihag, 1986).

Bees and flowering plants evolved simultaneously and established inseparable relationship. Establishment of this relationship is also one of the most significant events of organic evolution (Deodikar, 1962; Martin, 1979).

The bee-flower association is perhaps the most fascinating example of co-evolution. Man, who has been constantly trying to understand this seemingly simple association has instead formulated a plethora of hypotheses. On the basis of intensive study, it has been predicted that the foraging behaviour of the honeybee is flexible and individual foragers modify their behaviour selectively according to variation in colony's food requirements (Ribbands, 1949; Free, 1967; Nunez, 1970; Seeley, 1986; Kolmes & Winston, 1988; Wolf & Schmid-Hempel, 1990). Also,
honeybees exhibit a remarkably high degree of fidelity to one flower species, time and location. Most foragers are known to selectively shift from one forage source to another and from pollen collection to nectar in response to qualitative and quantitative variations of environmental resources (Boch, 1956; Free, 1966; Frisch, 1967; Free, 1970; Orians & Pearson, 1979; Weaver, 1979; Nunez, 1966, 1982; Schmid-Hempel et al., 1985; Winston & Fergusson, 1985; Seeley, 1986, 87; Seeley et al., 1991).

Quantitative studies of foraging behaviour revealed the existence of several inherent relationships. Attempts have been made to relate the size of the foraging load with nectar sugar concentration (Frisch, 1923, 34, 65, 71; Seeley, 1985, 86; Schmid-Hempel, 1987); rate of flow of nectar (Nunez, 1982); longevity of foraging bee (Neukirch, 1982; Schmid-Hempel & Wolf, 1988; Wolf & Schmid-Hempel, 1989); size of the foraging bee (Nye & Pedersen, 1962); rate of flight metabolism (Heran, 1962; Heinrich, 1975); probability of stinging (Kolmes & Fergusson-Kolmes, 1989); size of the colony (Houston et al., 1988); and within the hive factors, such as the amount of brood, pollen and honey and the rate of unloading by the receiver bees and the information received from receiver bees (Vansell, 1942; Butler, 1945; Brown, 1951; Genrikh, 1958; Free, 1956, 67; Schmid-Hempel et al., 1985; Seeley, 1989).
Generally, each foraging trip is subjected to fluctuations and correlations between and within the factors vary from day to day (Nunez, 1970). Further, most correlative studies have been conducted with automatic artificial feeders containing sugar solutions. Also, the results obtained with artificial flowers were contradictory to those from natural flowers (Ribbands, 1953; Istimina, 1960; Wells & Giacchino, 1968; Frisch, 1971; Nunez, 1982; Schmid-Hempel et al., 1985; Seeley, 1986; Houston et al. 1988; Kolmes & Fergusson-Kolmes, 1989).

Most quantitative studies are confined to nectar collection and its carriage by nectar foragers. Similar information on pollen collection is meagre. This paucity of information was mainly because of considerable inherent difficulty in quantifying simultaneously the values of pollen loads and nectar loads, as pollen foragers often carry loads of both nectar and pollen and also loads of pollen from more than one species (Free, 1963, 1970; Davis, 1991). Also, pollen collection perhaps is more important for the growth and ultimate survival of honeybee colonies as it provides the chief source of protein, fat and minerals (Oster & Wilson, 1978; Brian, 1983; Hellmich et al., 1985).

Success in beekeeping depends not only upon the better strains of bees, but also on the abundance and richness of
nectar and pollen sources around an apiary (Free, 1980; Akratankul, 1987). Detailed information on the place of the availability of forage, time of presentation of forage, and the benefits and costs of foraging from various flower species are not available. Therefore, food resources must be searched for, before economically and prudent foraging decisions are made. Many methods and models have been devised for studying distribution of foraging bees on various crops and also to evaluate the foraging behaviour of bees visiting different crops. Similar information on quantification of foraging loads is not available. Generally, the availability of pollen and nectar sources, as well as the time of presentation of these substances vary not only from place to place but also from one flower species to another.

Much of the information available on distribution and behaviour of foraging bees is confined to Western honeybee, *Apis mellifera*. Information on the foraging behaviour of Asiatic honeybee *Apis cerana*, particularly the time of visitation to various crops and the time of availability of food sources is meagre.

The present studies are aimed to investigate the following aspects on bee-flower relationship, primarily to quantify the foraging behaviour of indigenous species of
honeybee *Apis cerana indica* F., visiting seven selected bee plants.

Nectar-sugar levels in selected bee plants and their fluctuations in relation to time.

Time-dependent variations in bee visitation.

Quantification of foraging activity and of pollen and nectar foragers.

Comparative analysis of foraging loads.

Investigation of volume-load relationship of foragers.

Determination of relationship between the size of foraging population and the size of foraging load.

Determination of the sources of food for pollen foragers.

Rate of switching, non-switching and re-switching behaviour of foragers.

Comparative foraging behaviour of *Apis cerana*, *Apis dorsata* and *Apis florea*.