INTRODUCTION

Bees form a large group of insects that are specialized for feeding at flowers and gathering nectar and pollen. Bees and plants interact in a variety of ways and very often, the relationship between them is inseparable. In bee-flower relationships, the bees provide pollination service to the flowers while the flowers provide food to the bees in return. Bees play an important role in the life of flowering plants. They participate in the sexual reproduction of plants. The bee-flower relationships are essential to a viable structure and healthy functioning of forest and agricultural ecosystems. Bees use pollen as a protein source and nectar as an energy source. Adult female bees collect pollen primarily to raise their brood. The pollen they inevitably lose in going from flower to flower is important to plants for pollination. Different bees have different pollinating abilities depending on the floral density, architecture and other characteristics. Different bees occur in different areas depending on the availability of forage. The important bees include honey bees, stingless bees, digger bees, carpenter bees, leaf-cutting bees, green bees and bumblebees. Each category of bees has a unique role in the sexual reproduction of plants, in the absence of which there would be no fruit setting. Therefore, the bee diversity is directly related to plant diversity and the relationships that exist between bees and plants are mostly mutualistic for the benefit of both. It is essential to provide nesting, resting, mating habitats and food sources for bees in order to provide
free ecological services to plants in forest as well as agricultural ecosystems which in turn benefit mankind and finally sustain diversity of life on this planet.

The Convention on Biological Diversity held in 1992 at Rio de Janeiro has realized the importance of bees and expressed concern for bees which are disappearing at alarming rates owing to the habitat losses both in forest and agricultural ecosystems. Batra (1995) stated that the services of bees in the ecosystem are not free and dependent on the quality and quantity of provisions available in different plant species. Prescott-Allen and Prescott-Allen (1986), Parker et al. (1987) and Torchio (1991) showed that wild bees are so important in the sexual life of both cultivated and wild plants and also in maintaining biodiversity. Several other workers also emphasized that bee-plant relationships are inseparable and are very vital for the reproductive success of both partners (Tan 2008; Zhang et al. 2009; Santos and Absy 2012; Hannan et al. 2012; Ramirez-Freire et al. 2012). The general awareness of the diversity of bees and public knowledge of their value to ecosystems is increasing in Europe and North America (Batra 1995). In India, the research activity on bees is in a state of neglect and also there is a total negligence to create general awareness in the public about the importance of bee-flower relationships to maintain biodiversity despite the fact that India is rich in biodiversity (Batra 1993; Savoor 1998; Solomon Raju 2011; Solomon Raju et al. 2012). This suggests that there is an urgent need to take up studies on bee-flower relationships to understand their interdependencies for
the benefit of both partners and the functions of such relationships in the ecosystem.

Among bees, honey bees have been given importance for research because of their value for honey and wax, and crop pollination. All other bees have been little studied and the information available on them is very limited. This status holds true for almost all parts of the world. However, in recent times, the North American and European countries, and also some Asian countries carried out different studies on the ecological and economic roles of wild bees and generated impressive volume of information but India is still concentrating on honey bee research mostly for economic benefits through bee-keeping and crop-pollination (Solomon Raju 1999-2000; Kiran Kumari 2002; Solomon Raju and Rao 2006). Lately, the studies on flower relationships of wild bees such as *Trigona*, *Ceratina*, *Pseudapis*, *Pithitis*, *Amegilla* and *Xylocopa* bees are beginning to appear in India (Solomon Raju and Rao 2004; 2005; Solomon Raju et al. 1999; 2002; Solomon Raju and Subba Reddi 1998; 2000; Subba Reddi et al. 1999; Solomon Raju and Rao 2006).

Carpenter bees are cosmopolitan in distribution and are the most prominent members of the Indian bee fauna (Solomon Raju and Subba Reddi 2000; Solomon Raju and Rao 2006). The genus *Xylocopa* constitutes large carpenter bees while the genus *Ceratina* small carpenter bees. They occur throughout the year, forage on a wide array of flowers during day hours; some forage even during moonlit nights (Maxwell-Lefroy and Hewlett 1971). As these
bees occur year-long and are also multivoltine, they need to track the floral resources and shift to other species that satisfy their nutritional requirements because different plant species bloom at different times although some plants species bloom synchronously offering ample amount of food for bees. When there are many plants in flowering at the same time, the bees would look for those that offer most, qualitatively and quantitatively, or that agrees to their senses in some respect (van der Pijl 1954). Based on floral forms and richness of floral rewards, these bees use different foraging behaviors for efficient harvest of the rewards (Solomon Raju and Subba Reddi 1998; Solomon Raju et al. 2012). The foraging behaviors play a key role for bees to handle and utilize the rewarding flowers efficiently. The flowers visited by these bees show certain characteristic features in terms of morphology and quantity and quality of floral rewards (Faegri and van der Pijl 1979; Solomon Raju and Subba Reddi 2000; Solomon Raju et al. 2012). This suggests that all flower types available in the habitat are not appropriate for Xylocopa bees and the flowers should have certain morphological and functional characteristics to attract them for foraging and ultimately to achieve pollination benefit. Burkill (1906) gave a long list of Xylocopa flowers without any explanation. Solomon Raju and Subba Reddi (1998; 2000) provided some information on the characteristics of some Xylocopa flowers and foraging behaviours employed by Xylocopa bees in India. They provided a small list of Xylocopa flowers and suggested further studies to list out Xylocopa flowers based on floral form and function, and foraging behaviours of Xylocopa
bees. There are no other studies made on any aspect of *Xylocopa* bees and hence further studies are very much required for understanding the relationship between flowers and *Xylocopa* bees with reference to their foraging activities and behaviours. Such studies would surely help us to understand the relationships between carpenter bees and plants and in future to prepare floral calendar for *Xylocopa* flowers and take appropriate measures for the conservation and management of habitats of carpenter bees in order to sustain biodiversity.

The present study is a humble attempt to provide information on nesting material, flowering seasons, flower morphology, floral biology and floral rewards of fifteen plant species belonging to seven plant families in relation to foraging activities and behaviours of two large carpenter bee species, *Xylocopa latipes* and *X. pubescens*. The plant species included in this study were *Calotropis gigantea*, *C. procera* (Asclepiadaceae), *Tecoma stans* (Bignoniaceae), *Cassia alata*, *C. fistula*, *C. occidentalis*, *C. siamea*, *Peltophorum pterocarpum* (Caesalpiniaceae), *Crotalaria laburnifolia*, *C. verrucosa*, *Pongamia pinnata* (Fabaceae), *Hyptis suaveolens* (Lamiaceae), *Moringa oleifera* (Moringaceae), *Solanum carolinense* and *S. surattense* (Solanaceae). The foraging activity of other insects on some of these plants was also recorded with a view to evaluate their fidelity to the floral rewards of such species. Further, the floral rewards have been examined for their chemical characteristics such as nectar volume, sugar concentration, sugar content, sugar types, sugar energy per flower, essential and non-essential amino acids and protein content; and also pollen output, pollen essential and non-essential amino
acids and protein content. Based on this information, the importance of reciprocal relationships between carpenter bees, other insects and flowers to maintain biodiversity has been discussed in the light of relevant existing literature. The work outlines summarized here has been done with the objective of contributing some important information to our knowledge of *Xylocopa* species in relation to their association with certain plants. The work presented in this thesis would form strong foundation for further studies on carpenter bee-plant associations and their importance in sustaining biodiversity.