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RESEARCH ARTICLE

A STUDY ON THE FORAGING BEHAVIOUR OF HYMENOPTERANS ON VEGETABLE CROPS IN THE SOUTH-24-PARGANAS DISTRICT OF WEST BENGAL, INDIA

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ABSTRACT

The present study documented 20 species of foraging hymenopterans on seven vegetable crop species (*Solanum melongena, Solanum lycopersicum, Abelmoschus esculentus, Brassica oleracea* var. *capitata, Capsicum annuum, Raphanus sativus, Allium cepa*) across two study site (viz. Lakshmikantapur and Narendrapur) established in the South-24 Parganas district of West Bengal, India. The entire study was conducted from July 2015 to June 2017. Greater visitation rate of *Xylocopa, Bombus orientalis, Apis* and *Megachile* on flowering plant species were observed. Additionally, *Xylocopa* and *Apis* also spend longer duration of time foraging on crop species. Greater visitation rate and longer duration of visits by *Xylocopa* bees could probably be attributed to their ability to forage from a wide repertoire of food plants throughout the year. A synchrony between peak blooming period of flowers and maximum number of foraging hymenopterans as noted probably elaborate an attempt by these bees to maximize the energy intake per unit time during peak blooming period of such plants. Additionally, *Solanum melongena, S. lycopersicum, Brassica oleracea* var. *capitata, Raphanus sativus, Allium cepa* were observed attracting a large number of insect visitors. Such studies on pollinating behaviour of hymenopterans probably elaborate the pollination service as rendered by them.

INTRODUCTION

Foraging behaviour in bees is largely determined by pheromones emitted by nurse bees (Camazine, 1993) or the queen (Higo *et al.,* 1992). Such substances known to regulate the number of individuals recruited for pollen foraging is in turn associated with the pollen demands of the hive and size of pollen load carried by bees (Higo *et al.,* 1992). Importantly, the foraging range of pollinators largely reflect their inner strength and tenacity in undertaking such an act and at the same time understanding their limitations in gathering nectar and pollen (Dhaliwal and Sharma, 1974; Abrol, 1986, 1987, 1989). According to Hocking (1953) foraging range of a pollinator is species specific and increases with the size of bees which in turn reflects energy demands of different species. Such energetics employed during framing of foraging strategies provides a clue towards better understanding the principle of food procurement by animals in general (Pyke, 1984; Stephens and Krebs, 1986) and flower visiting bees in particular (Pyke, 1980; Cresswell, 1990; Dukas and Real, 1993). Being an agrarian economy, India still relies on the efforts of the small and marginal farmers. India is said to contribute towards global vegetable production with the economic value of such production reaching $726 millions (Sidhu, 2005). In the Indian subcontinent several fruit, vegetable and plantation crops are said to be dependant on the services of wild bees for pollination (Partap, 1999; Chandel *et al.,* 2004; Davidar, 2009; Krishnan *et al.,* 2012; Davidar *et al.,* 2015; Carr and Davidar, 2015; Basu *et al.,* 2011). Pollination service as rendered by several non apis species such as *Bombus*, *Nomia*, *Osmia*, *Megachile* and some stingless bees has been well documented (Westerkamp and Gottsberger, 2000; Hogendoorn *et al.,* 2000; Slaa *et al.,* 2006). Significantly, occurrence of *Nomia*, *Lassioglossum*, *Megachile*, *Xylocopa* and *Apis* has been reported from different regions of West Bengal (Sharma *et al.,* 2016). The present study was designed to identify different species of apis and non apis bees foraging on seven species of vegetable crops. Additionally, insect visitation rate and duration of such visits on each flowering plant species were also noted down. The number of flowers blooming per plant and the number of hymenopterans foraging on such plants across fixed time periods were recorded. Additionally, a synchrony between these two events, if any was also observed during the study. Importantly, some amount of information is said to be transmitted from the flowering plant species to the hymenopterans. Quantification of information content of such communication would also constitute an important aspect of this study.

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MATERIALS AND METHODS

The present study was conducted from July 2015-June 2017 across two study sites (i.e. Narendrapur-21°94'N, 88°44'E and Lakshmikantapur-22°22'N, 88°37'E) established in the South 24-Parganas district of West Bengal, India (Figure 1). Seven agricultural fields each measuring 0.2-0.25 km^2 and utilised exclusively for the cultivation of a single vegetable crop species (*Solanum melongena*, *Solanum lycopersicum, Abelmoschus esculentus, Brassica oleracea* var. *capitata*, *Capsicum annuum*, *Raphanus sativus*, *Allium cepa*) were selected at each study site. Importantly, a minimum distance of 0.1 km was maintained between each field. Each vegetable crop species were sampled for the flower visiting hymenopterans at an interval of 7 days during its flowering period. Hymenopterans observed inserting their body into the corolla followed by its withdrawal after about 1 minute was considered to be involved in the act of foraging. Each observation time was divided into several observation time units of 10 minutes each interrupted by a period of 10 minutes interval for each hour beginning at 0600 hours and continuing till 2000 hours Such observation was carried out by walking at the rate of 10 meters per minutes in both the directions across each row established in these fields. Some of these insects were identified on field while others were captured using sweep nets and preserved for subsequent identification in the laboratory. The date, time and site of collection along with their foraged plant species were recorded carefully to assist in future identification. The flower visitation rate of hymenopteran insects expressed as number of visits per hour and duration of such visit on each flowering plant species was

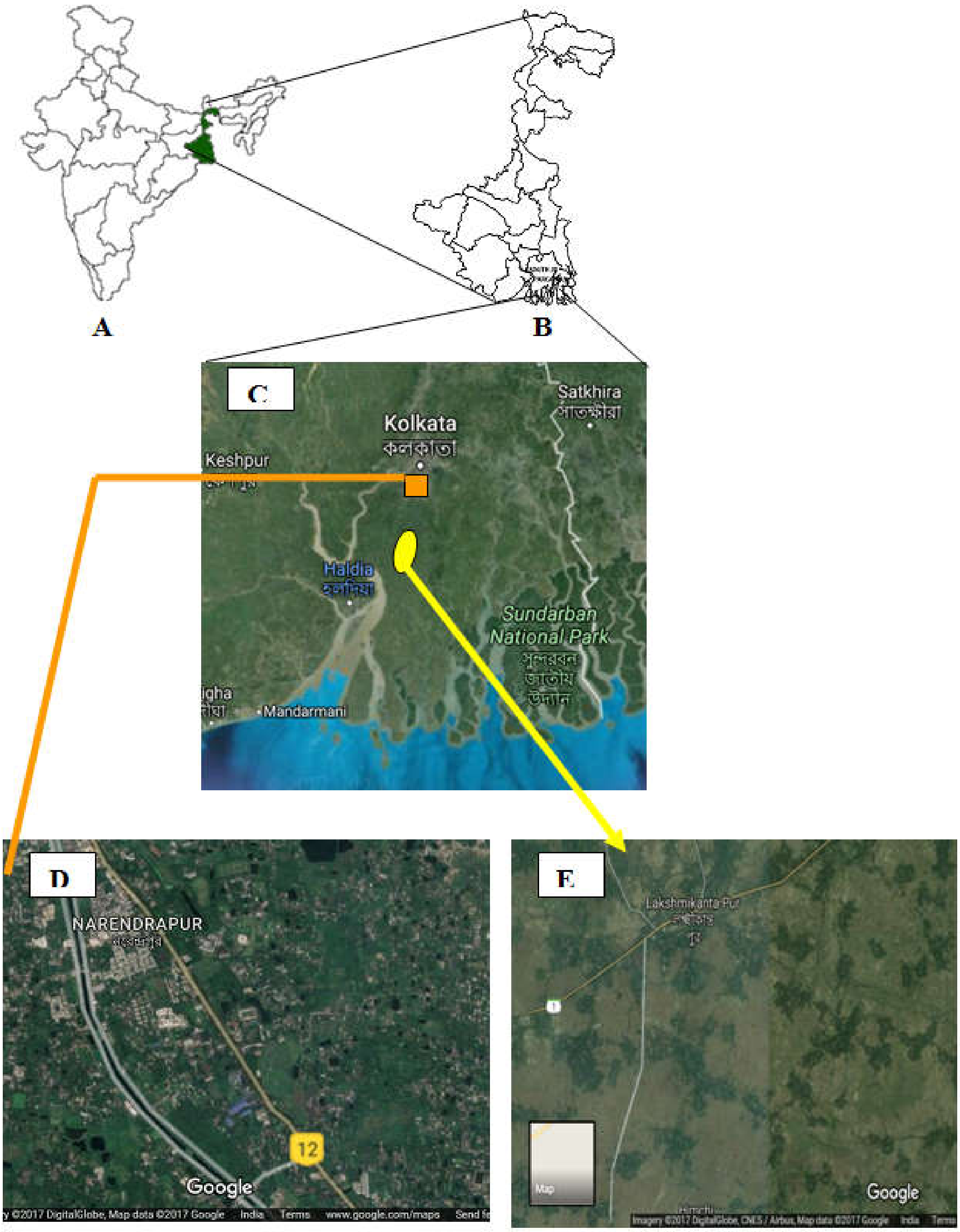

Figure 1. Map of the study area (where A- Map of India showing West Bengal; B- Map of West Bengal showing South 24-Parganas; C-Satellite imagery of South 24-Parganas: D-Satellite imagery of Narendrapur; E-Satellite imagery of Lakshmikantapur)

also noted down. Box plots were constructed to display such information during this study. The number of foraging hymenopterans was recorded across fixed time period. Additionally, the number of flowers blooming per plant across the same time interval was also noted down. Subsequently a synchrony between these two events if any was observed. Diversity indices of different vegetable crop species visited by hymenopterans were ascertained using Shannon-Wiener function (Shannon and Weaver, 1949) and Brillouin's Index (Krebs, 1999). Since, base 2 log was used; the units of information content of sample were bits per floral patch.

The formula used to determine diversity indices and their explanations are as follows:

Shannon-Wiener Function (H´):
$H' = \Sigma^{s}_{i=1}(pi)\ (\log_2 pi)$
Where H´= Information content of the sample (bits/patch) =Index of species diversity
S= Number of species
pi = Proportion of total sample belonging to the i^{th} species
Brillouin's Index ($\hat{H}$):
$\hat{H} = 1/N\log_2\ [N!\ /\ (n_1!)\ (n_2!)\ (n_3!)\ldots]$
Where $\hat{H}$= Brillouin's Index
N= Total number of individuals in entire collection
n_1= Number of individuals belonging to species 1
n_2= Number of individuals belonging to species 2

Importantly, Shannon-Wiener function value above 2.5 and Brillouin's Index values above 2.4 were considered to indicate higher species diversity and thereby attracting greater number of insects.

RESULTS AND DISCUSSION

The present study attempted to document 20 species of hymenopterans visiting seven vegetable crops probably in an attempt to pollinate them (Table 1).

Such involvement of apis and non apis species illustrates the fact that both wild and domesticated non apis bees are actively associated with honey bees in pollinating crops (Greenleaf and Kremen, 2006; Hoehn *et al.,* 2008). This has led to the increase in concern for pollinating insects of such crops (Klein *et al.,* 2007) worldwide. With insect mediated pollination contributing essentially to 70% of global agricultural production (Roubik, 1995), similar studies from the Indian perspective in recent times is worth mentioning (Davidar, 2009; Basu *et al.,* 2011; Carr and Davidar, 2015; Davidar *et al.,* 2015; Bhattacharya and Basu, 2016). The number of foraging trips (expressed as visitation rate) undertaken by hymenopterans per hour and the duration of such visits was highly variable among *apis* and non-apis species (Figure 2, 3). Interestingly, *Xylocopa, Bombus orientalis, Megachile* and *Apis* visited their foraging resource a greater number of times (Figure 2). Additionally, *Xylocopa* and *Apis* were also engaged in foraging for a longer period of time (Figure 3). Thus with greater visitation rate and longer duration of visits on flowers, *Xylocopa* appears to be the most popular non-apis forager in this study (Figure 2, 3). This could probably be attributed to their ability to forage from a wide repertoire of food plants throughout the year (Raju and Rao, 2006). Lane (1999), Moncks (2001) along with Cervancia (2003) demonstrated the pollination of several fruit, vegetable and other economically important crops by these bees. Floral morphology (shape, size and pattern of corolla) contribute significantly towards plant-forager association among *Xylocopa* bees. In this study, *Solanum melongena*, *Solanum lycopersicum* and *Capsicum annuum* with actinomorphic flowers appears to be a favourite among these bees as evident by their greater visitation rate and longer duration of visits on such flowers (Figure 2, 3). Similar preferences for actinomorphic flowers have been reported by Raju and Rao, (2006). However *Xylocopa* visited other flowers in this study probably due to their ability to switch over their preference between appropriate and inappropriate flowers for compensating any food scarcity (Raju and Rao, 2006).

Table 1. List of hymenopteran species foraging on seven different plant species in the study site

Plant species → / Hymenopteran species ↓	A	B	C	D	E	F	G
I	+	+	+	+	+	-	-
II	-	+	-	+	+	-	-
III	+	+	+	-	-	+	+
IV	+	-	-	-	+	+	+
V	+	-	-	-	+	+	-
VI	+	-	-	-	-	+	-
VII	-	-	-	-	+	-	-
VIII	-	-	-	-	+	-	-
IX	-	-	-	-	+	-	-
X	-	-	-	-	+	-	-
XI	-	+	+	-	-	-	-
XII	+	+	+	-	+	+	+
XIII	+	+	+	-	+	+	+
XIV	+	+	+	-	-	+	+
XV	+	-	-	-	-	-	-
XVI	-	-	-	-	-	+	-
XVII	-	-	-	+	+	+	+
XVIII	-	-	-	+	+	+	+
XIX	-	-	-	+	+	+	+
XX	-	-	-	+	+	+	+

where: A- *Solanum melongena* L.; B- *Solanum lycopersicum* L.; C- *Capsicum annuum* L.; D- *Abelmoschus esculentus* (L.) Moench; E- *Brassica oleracea* L.; F- *Raphanus sativus* L.; G- *Allium cepa* L.; I-*Halictus acrocephalus* Blüthgen,1926; II-*Halictus grandiceps* Cameron,1896; III-*Bombus orientalis* Smith,1854; IV-*Megachile femorata* Smith, 1853; V-*Megachile nana* Bingham,1897; VI-*Megachile rotundata* (Fabricius, 1787); VII-*Nomia iridescens* Smith, 1853; VIII-*Nomia curvipes* (Fabricius, 1793); IX-*Lasioglossum albescens* (Smith, 1853); X-*Andrena ilerda* Cameron, 1907; XI-*Trigona thoracica* Smith, 1857; XII-*Xylocopa fenestrata* (Fabricius, 1798); XIII-*Xylocopa pubescens* Spinola, 1838; XIV-*Xylocopa aestuans* (Linnaeus, 1758); XV-*Anthophora zonata* Bingham, 1897; where "+" is presence ; "-" is absence XVI-*Andrena leaena* Cameron, 1907; XVII-*Apis cerana* Fabricius, 1793; XVIII-*Apis mellifera* Linnaeus, 1758; XIX-*Apis dorsata* Fabricius, 1793; XX-*Apis florea* Fabricius, 1787

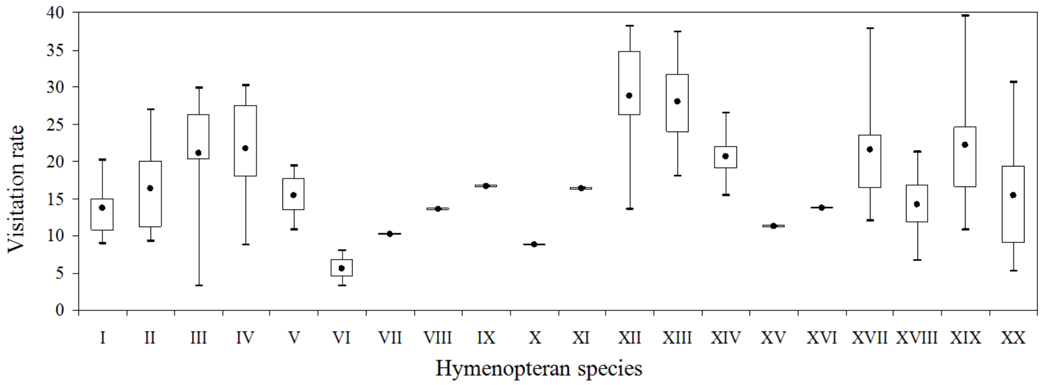

Figure 2. Box-whisker plot illustrating the visitation rate of hymenopteran species on seven floral patches (where the names of the hymenopterans are represented by roman numerals as provided in Table 1)

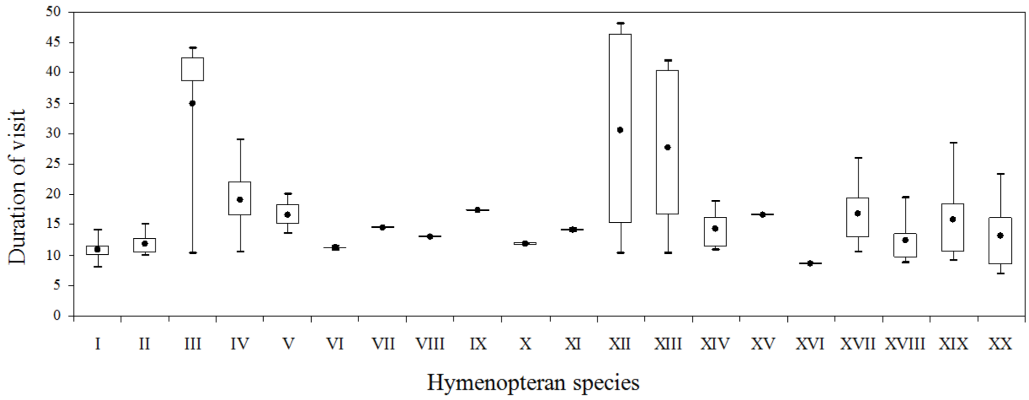

Figure 3. Box-whisker plot illustrating the duration of visits of hymenopteran species on seven floral patches (where the names of the hymenopterans are represented by roman numerals as provided in Table 1)

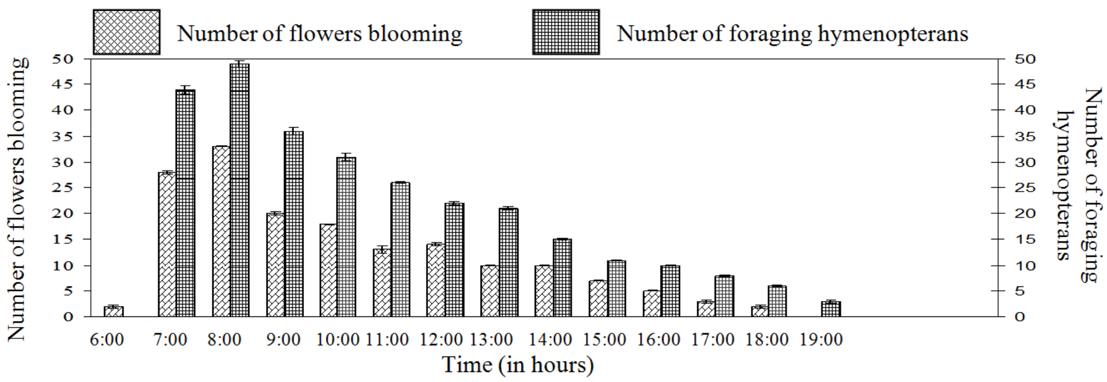

Figure 4. Graphical representation of the number of foraging hymenopterans and the number of *Solanum melaungena* flowers blooming across a fixed time period

Preference for medium (*Capsicum annuum*) and large sized flowers (both *Solanum melongena* and *Solanum lycopersicum*) by these bees also justify similar investigations by Raju and Rao, 2006. However, total absence of *Apis* foragers from *Solanum melongena*, *Solanum lycopersicum* and *Capsicum annuum* as observed in this study was interesting (Table 1). Solanaceous plants are buzz pollinated exclusively by non-apis species (Raw, 2000; Carr and Davidar, 2015; Davidar *et al.,* 2015) thereby leading to their higher visitation rate and greater duration of visits by *Xylocopa* bees. Besides *Xylocopa*, higher visitation rate and longer duration of visits to flowers of crop species as reported by *Bombus orientalis* could probably be attributed to their efficiency in adapting to and pollinating crops across varied agro ecosystems (Corbet *et al.,* 1991). Additionally, the distribution of *Bombus* throughout the northern hemisphere (Goulson, 2003) also justifies their role as an important pollinator species in this study (Table 1).

Foraging range of pollinators elaborates their intrinsic capabilities (Hocking, 1953; Abrol, 1986, 1989) or more specifically their energy requirements (Abrol, 1988). The greater foraging range of *Megachile* depends largely on greater energy requirements (Abrol, 1988) which in turn could probably be corroborated with their higher visitation rate and greater duration of visits to flowering species in this study (Table 1). Honey bees are blessed with an ability to ignore unrewarding floral patches (Zimmerman, 1981) and are thus known to be very efficient in switching between profitable and non profitable floral mosaics on a daily and seasonal basis (Visscher and Seeley, 1982; Yokoi and Fujisaki, 2007; Kevan and Menzel, 2012). Such ability to differentiate between rewarding and non rewarding floral patches based mostly on scent marks (Goulson *et al*, 1998; Williams and Poppy, 1997) probably justifies their association with specific crop species in the study (Table 1).

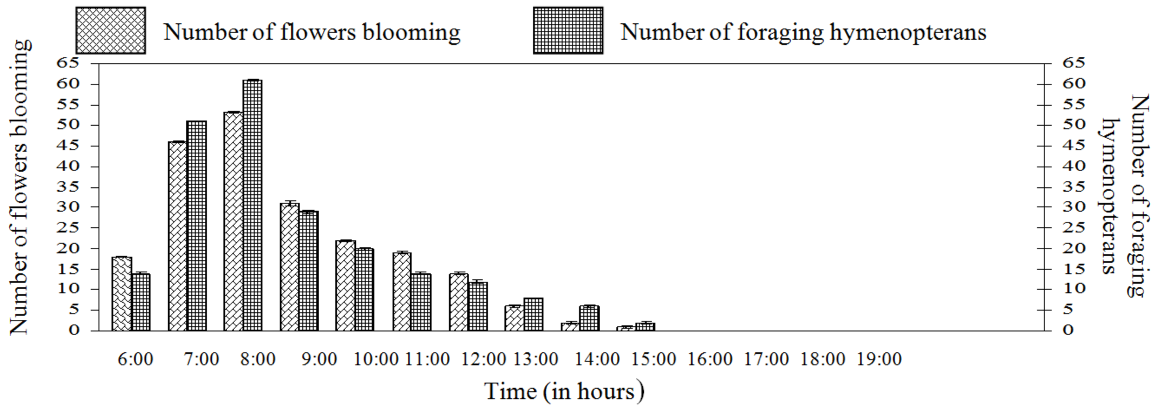

Figure 5. Graphical representation of the number of foraging hymenopterans and the number of *Abelmoschus esculentus* flowers blooming across a fixed time period

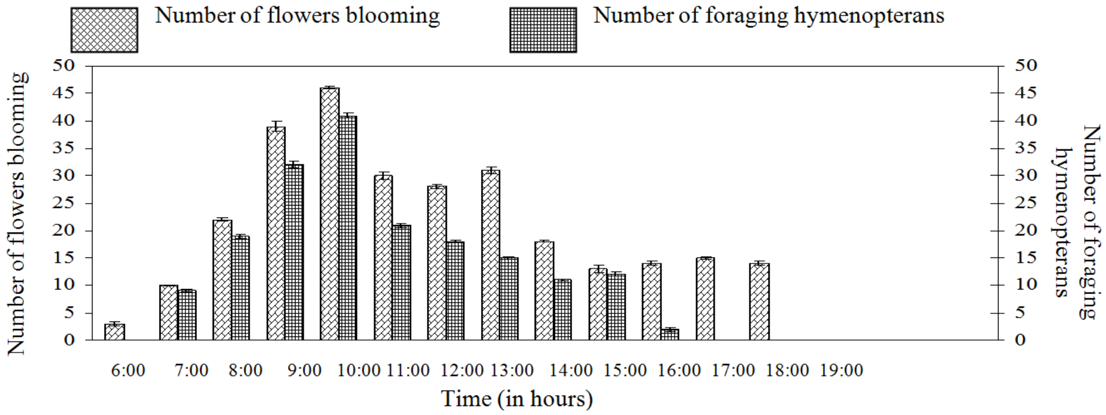

Figure 6. Graphical representation of the number of foraging hymenopterans and the number of *Brassica oleracea* flowers blooming across a fixed time period

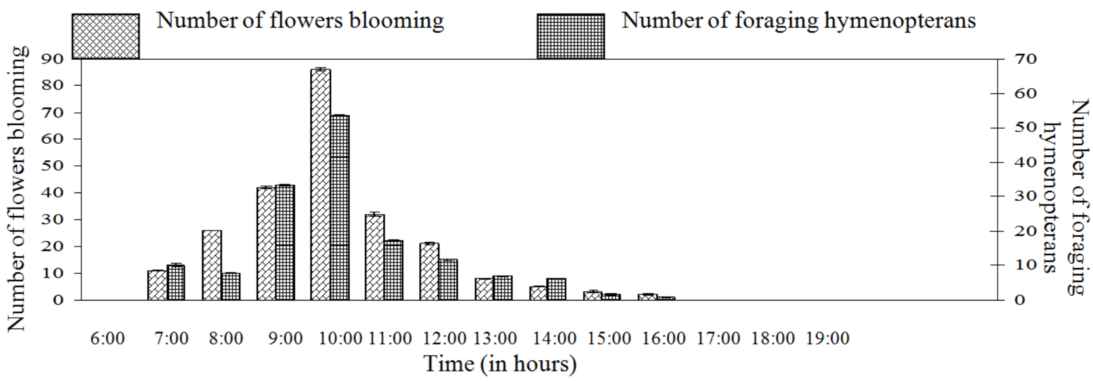

Figure 7. Graphical representation of the number of foraging hymenopterans and the number of *Raphanus sativus* flowers blooming across a fixed time period

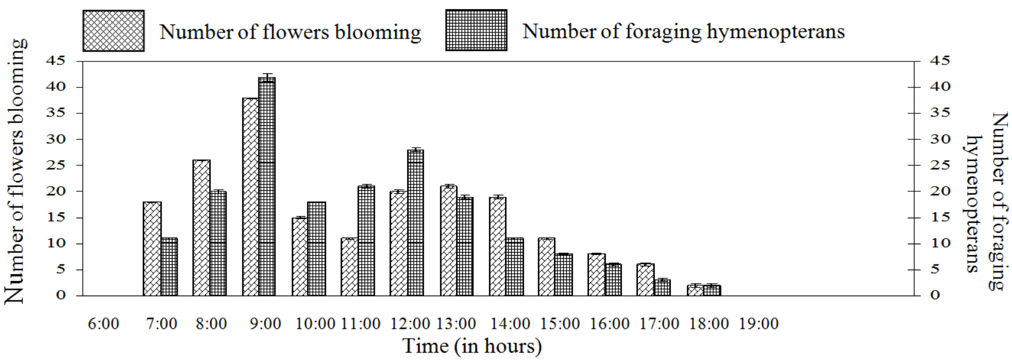

Figure 8. Graphical representation of the number of foraging hymenopterans and the number of *Solanum lycopersicum* flowers blooming across a fixed time period

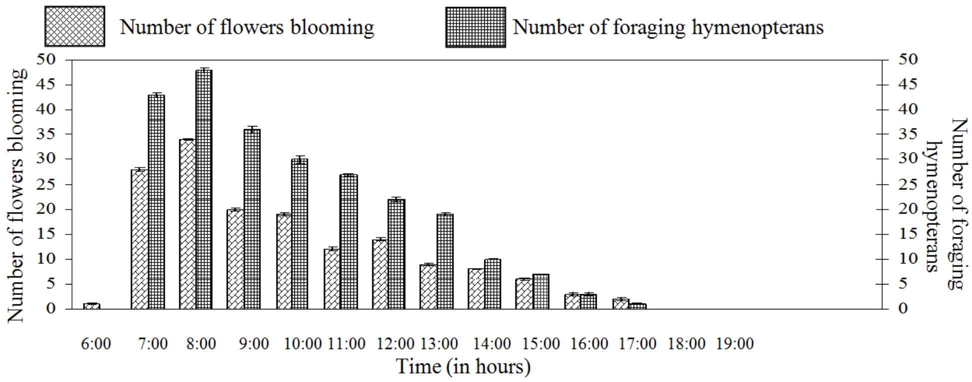

Figure 9. Graphical representation of the number of foraging hymenopterans and the number of *Allium cepa* flowers blooming across a fixed time period

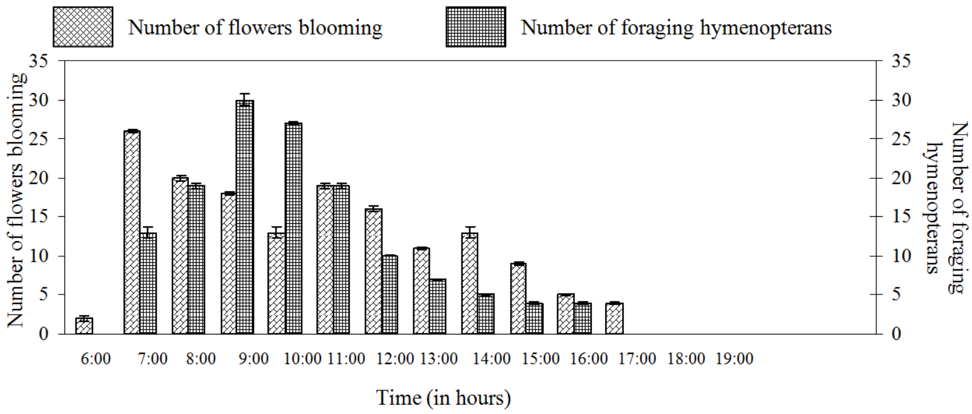

Figure 10. Graphical representation of the number of foraging hymenopterans and the number of *Capsicum annuum* flowers blooming across a fixed time period

Table 2. Summary of the species diversity indices (bits per patch) of seven vegetable crop species studied

Floral Patches	Shannon -Wiener Function (bits/patch)	Brillouin's Index (bits/patch)
Solanum melongena L.	2.947	2.795
Solanum lycopersicum L.	2.629	2.485
Capsicum annuum L.	2.41	2.284
Abelmoschus esculentus (L.) Moench	2.432	2.325
Brassica oleracea L.	3.632	3.472
Raphanus sativus L.	3.431	3.264
Allium cepa L.	2.978	2.840

Importantly, the utilization of *Apis* sp as an efficient pollinator of onion as noted in this study (Table 1) also supports previous observation (Rao and Suryanarayana, 1989; Chaudhary and Sihag, 2003; Chaudhary, 2004; Shafqat and Masood, 2008). However *Apis* are incapable of floral sonication (Higo *et al.,* 2004) an ability possessed only by the non apis bees thereby restricting their visit only to non solanaceous crops in this study (Table 1). Optimal foraging theory suggests that if a plant species offers a greater reward it will be visited by more individuals (Pleasants, 1981; Dreisig, 1995), and will in turn entertain a larger number of visitor species (Possinghan, 1992). A positive relationship probably exists between the total number of nectar visitors found in a community at a given time and floral abundance of all plant species (Heithaus, 1974; Potts *et al.*, 2003). Interestingly, the number of flowers blooming across a fixed time interval and the number of pollinating hymenopterans was found to be synchronous with most of the vegetable crop species in this study (Figure 4 - 9). Such synchrony between these two events justifies an attempt by these bees to maximize the energy intake per unit time during peak blooming period of these plants (Belavadi and Ganeshaiah, 2013).

Previous observation elaborating the benefits of high biodiversity in maintaining a proper synchrony between plants and their respective pollinators at the community level are also available (Bartomeus *et al.*, 2011). However a non-synchronous event as evident in the case of *Capsicum annuum* is also worth mentioning (Figure 10). Studies regarding transfer of information content among individuals of the same species (Haldane and Spurway, 1954; Wilson, 1962) and between plant-insect visitors (Sengupta *et al.,* 2012; Sengupta and Ghorai, 2013) have seldom been conducted. Species Diversity Indices (Shannon-Wiener function and Brillouin's Index) representing the diversity of hymenopteran insects on crop species is provided in Table 2. Vegetable crop species such as *Solanum melongena* (H′=2.947; Ĥ=2.795), *Brassica oleracea* var. *capitata* (H′=3.632; Ĥ= 3.472), *Raphanus sativus* (H′= 3.431; Ĥ= 3.264), *Allium cepa* (H′=2.978; Ĥ= 2.840) and *Solanum lycopersicum* L. (H′=2.629; Ĥ=2.485) possessed higher values of Shannon-Wiener function and Brillouin's Index respectively. Therefore such crop species are probably known to generate greater information entropy thereby attracting a large number of insect visitors. Above studies on pollinator behaviour of some hymenopterans in response to their foraging resource along with their judicious utilization could help in enhancing our knowledge about pollination service as rendered by them. Importantly, the availability of similar conditions along with designing of similar studies in other regions of West Bengal could probably contribute towards augmenting the agricultural productivity of our state.

Conclusion

The association between 20 species of hymenopterans with seven vegetable crop species was examined in the current study. Higher number of foraging trips as undertaken by *Xylocopa, Bombus orientalis, Apis* and *Megachile* to flowering crop species was significant. *Xylocopa* and *Apis* also exploited the available floral resources for a longer duration. Additionally, a synchrony between the flowering density and the number of pollinators was evident in most cases during the present study. Significantly, Shannon-Wiener Function and Brillouin's Index values used to demonstrate the amount of information generated by the flowering plants and received by the foraging hymenopterans was determined. Similar studies could prove beneficial in highlighting the role of hymenopterans as pollinators of vegetable crops in several regions.

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