

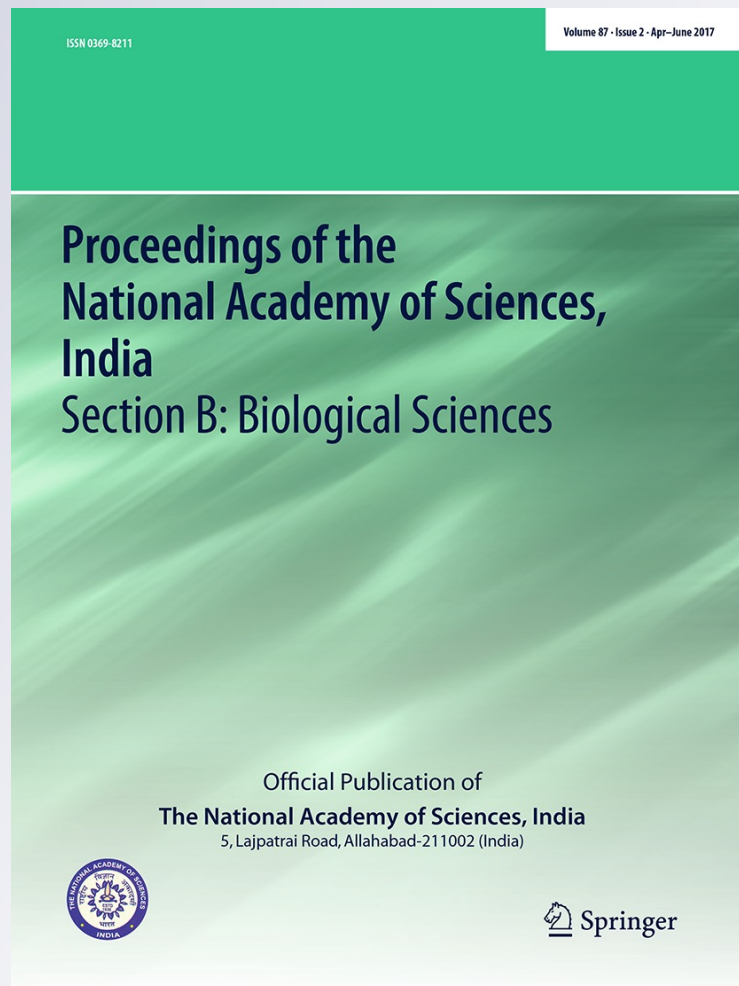
Species Composition of Ants in Cashew Plantations and their Interrelationships with Cashew

**K. Vanitha, P. S. Bhat, T. N. Raviprasad
& K. K. Srikumar**

**Proceedings of the National
Academy of Sciences, India Section B:
Biological Sciences**

ISSN 0369-8211
Volume 87
Number 2

Proc. Natl. Acad. Sci., India, Sect. B Biol.
Sci. (2017) 87:399-409
DOI 10.1007/s40011-015-0600-3



Your article is protected by copyright and all rights are held exclusively by The National Academy of Sciences, India. This e-offprint is for personal use only and shall not be self-archived in electronic repositories. If you wish to self-archive your article, please use the accepted manuscript version for posting on your own website. You may further deposit the accepted manuscript version in any repository, provided it is only made publicly available 12 months after official publication or later and provided acknowledgement is given to the original source of publication and a link is inserted to the published article on Springer's website. The link must be accompanied by the following text: "The final publication is available at link.springer.com".

Species Composition of Ants in Cashew Plantations and their Interrelationships with Cashew

K. Vanitha¹ · P. S. Bhat¹ · T. N. Raviprasad¹ · K. K. Srikumar^{1,2}

Received: 18 November 2014 / Revised: 21 February 2015 / Accepted: 20 June 2015 / Published online: 26 July 2015
© The National Academy of Sciences, India 2015

Abstract In cashew plantations of south west Karnataka, India, foraging activity of 49 ants species belonging to 24 genera and 7 subfamilies were recorded. The study found that ants visited cashew trees regularly throughout the year. Myrmicinae ants were most dominant comprising 22 species followed by Formicinae with 13 species while, among Aenictinae and Dorylinae, only single species was found. Species richness was high in old cashew plantations recording 89.8 % of total species, while medium and young plantations recorded only 46.9 and 24.5 %. Dominance of different ant species was noticed on cashew canopy, trunk and soil in different aged cashew plantations. Old cashew plantations were characterized by *Oecophylla smaragdina*, followed by *Anoplolepis gracilipes*, while, *Camponotus compressus* and *C. sericeus* were dominant in young and medium aged plantations. Pit fall trap collection consisted mostly of *Odontomachus haematodus*, *Lophomyrmex quadrispinosus*, *Technomyrmex albipes*, *Myrmecaria brunnea*, *Diacamma* sp., *C. compressus* and *C. sericeus*. During flowering and fruiting period of cashew, foraging of up to 10 ant species was seen on the same tree at a time. Activities of most ant species were predominant during winter and summer which coincides with flowering and fruiting period of cashew (December–May), while during heavy down pour of south west monsoon, activities of only 10 species were seen. A significant positive correlation was found between number of ant species and maximum air temperature (0.842) and also with afternoon soil temperature (0.925).

Keywords Cashew · Ant species · Diversity · Foraging · Monsoon · Nest

Introduction

In India, cashew (*Anacardium occidentale* L.) is a commercially important nut crop. It can be grown from sea level to an elevation up to 700 m and has been cultivated at places receiving 600–4500 mm rainfall and temperature ranging from 20 to 36 °C [1]. Cashew is grown in 9.82 lakh ha of land including coastal, ghat regions, marginal and degraded lands with poor orchard management practices [2]. Less anthropogenic activity in cashew plantations supports high abundance and species richness of many insect species. Cashew is infested by more than 150 insect species that reduce the productivity in most of the cashew growing regions [3]. Currently, cashew pest management is mainly done by the calendar based application of pesticides, coinciding with flushing, flowering and fruiting stages or during peak pest infestation. Since, cashew is an insect-pollinated crop, an alternative management strategy is essential especially to avoid chemical spray during flowering season. Though, ant-cashew relationship is known since long, their species composition, role and diversity—dynamic patterns are not fully understood, a fact that really undermines the potential usefulness of ants in pest management programmes.

Worldwide, a total of 15,000 ant species have been recorded [4], belonging to 296 genera and 16 subfamilies [5], in which 9000–10,000 species have been described. Knowledge about ants in India concerns only faunistic data in different regions of the country [6, 7]. The most recent species list of India includes approximately 660 species

✉ K. Vanitha
vanis102@gmail.com

¹ Crop Protection, Directorate of Cashew Research, Dakshina Kannada Dt., Puttur, Karnataka 574 202, India

² Present Address: Entomologist, Tea Research Foundation, UPASI, Valparai, Tamil Nadu, India

from 87 genera belonging to 12 subfamilies [8]. In cashew plantations of Kerala, India and Malaysia, surveillance made by Rickson and Rickson [9] resulted in documentation and 43 ant species involving 17 genera of 4 subfamilies. Recently, 10 species of ants were documented in cashew plantations of Kerala [10]. There are several anecdotal notations in the Indian literature of incidental ant predation of certain cashew pests [11–13]. Further, a few attempts were focused on biological management of cashew insect pests using red ants [14–16]. But many aspects like species composition of ants, their abundance, foraging activity in cashew plantations, seasonality and the interactions with cashew are not studied extensively. During the present investigation, cashew is found to be visited by many species of ants throughout the year even during non-flushing dormant period. To understand the diversity and stability of an ecosystem, it becomes important to study the species composition and changes that occur due to variations in microclimate and habitat. Ants have the potential to be used as indicators since they are sensitive and also because of the rapidity at which they adapt to changes brought about in the environment [17]. Hence, the present work was aimed at understanding the species composition of ants in cashew ecosystems in relation to plant age, season and their interrelationships with cashew.

Material and Methods

The study was conducted in 130 ha of cashew plantations in and around Puttur of Dakshina Kannada district of Karnataka, India. The region is a hilly track between the west coast and the Western Ghats of India, located at 12.77°N and 75.22°E at an average elevation of 87 m. The vegetation cover of the study site was dominated by cashew which was grown as a mono crop. The soil type was lateritic [18] and up to 9 cm of leaf litter was seen below trees. Meteorological data of the study site was obtained from the observatory of Directorate of Cashew Research, Puttur. The temperature in the area varied from 16.0 to 39.0 °C. The region received heavy rain during the southwest monsoon between June and September with an annual mean rainfall of 3970 mm. The relative humidity varied from 43 to 98 %, generally above 90 % from June–November.

Random field surveillance was undertaken for a period of 3 years (2011–2013) at monthly interval. Daily visits were made in the forenoon and afternoon in different aged cashew plantations. For convenience, cashew plantations of 1–3, 4–12, above 12 years were grouped as young, medium and old aged cashew plantations respectively. In each age group, a minimum of ten random trees were sampled fully.

Ant species richness was done using visual collection on cashew trees, weeds, dead logs, leaf litter and soil of the same aged cashew plantations by adopting all-out-reach method. To estimate ground ant diversity and abundance, at monthly intervals, bait traps consisting of a mixture of corn flakes, wheat powder, milk powder and honey, and also bait traps of dead wax moths were kept at 10/ha on a 30 min cycle until the bait were completely removed by ants. Ant's visits were recorded and the representative specimens were collected. Besides at monthly intervals, pitfall traps consisting of plastic cups of 8 cm dia. × 2 cm height having 70 % ethanol or detergent water at ten numbers each were also kept and inverted lids were used to keep out rain water. After 24 h, ants were sorted from the material collected in the cup. Ant species were grouped into very common (found in many numbers, >30 occasions), common (20–30 occasions), moderate (8–19 occasions), rare (3–7 occasions) and very rare (only one or two occasions). Representative specimens were preserved in 70 % ethanol and identified at Patiala University, Punjab. The mean of two years weather data was correlated with the species richness to find out the influence of weather factors on species composition.

Results and Discussion

Upon surveillance of cashew plantations, a total of 49 ant species representing 24 genera and 7 subfamilies were recorded in south west Karnataka (Tables 1, 2, 3; Fig. 1). The study found that cashew trees were consistently visited by ants during all the seasons of the year (Fig. 2). Though foraging activity of same ant species was seen throughout the day, activity was generally more during morning hours. Most of the ant species were attracted for the extra floral nectarines present on young leaves (Fig. 3), developing inflorescences and young fruits. Rickson and Rickson [9] reported that cashew leaves with a full complement of nectarines possess about 150–300 ant feeding locations per leaf depending on leaf size and maturity. In cashew, foraging ants were led around by both temporal and spatial functioning of extra floral nectarines and was regarded as a “movable feast” [19, 20].

Species belonging to Myrmicinae were most dominant comprising 22 species (44.9 % of total species) (Table 2; Fig. 1). Formicinae with 13 species was the immediate successor, while, Aenictinae and Dorylinae were represented by only single species. Even among the 12,629 species described in the world, subfamily Myrmicinae represents 45.89 % of the species and Formicinae represents 25.77 % of the species [4]. This indicates the dominance of Myrmicinae ants throughout the world. Myrmicinae ants have a diverse range of feeding habits

Table 1 Formicinae ant species recorded in cashew plantations and their characteristics

S. No.	Common name	Scientific name	Abundance	Active foraging site	Season of foraging activity	Nesting site	Plantation where recorded
1	Carpenter ant	<i>Camponotus compressus</i> Fabricius	VC	Leaf, flowers, fruits	Throughout year	Soil	All aged
2	Black golden ant	<i>Camponotus sericeus</i> Fabricius	VC	Leaf, soil	Throughout year	Soil	All aged
3	–	<i>Camponotus angusticollis</i> (Jerdon)	M	Trunk, leaf	Throughout year	–	Young; Medium
4	–	<i>Camponotus nirvanae</i> Forel	LC	Soil	S, M, PM	–	Medium
5	Giant honey ant	<i>Camponotus irritans</i> Smith	M	Trunk	W ^a , S	–	Old
6	–	<i>Camponotus</i> sp.2.	LC	Weeds	W ^a , S	–	Old
7	–	<i>Camponotus</i> sp. 3.	R	Soil	W, S	–	Old
8	Weaver ant	<i>Oecophylla smaragdina</i> (Fabricius)	VC	Leaf	PM ^a , W ^a , S ^a	Leaf- arboreal	Medium; old
9	Yellow crazy ant	<i>Anoplolepis gracilipes</i> Smith	VC	Leaf, soil	PM ^a , W ^a , S	Soil, crevices, tree base	Medium; Old
10	–	<i>Polyrhachis thrinax</i> Roger	LC	Leaf	PM, W ^a , S	Leaf	Young, medium
11	Common Bulldock ant	<i>Polyrhachis lacteipennis</i> Smith	LC	Leaf	PM, W ^a , S	Leaf, arboreal nest	Young, old
12	–	<i>Polyrhachis</i> sp.	R	Leaf	S	Leaf	Old
13	–	<i>Prenolepis naoroji</i> Forel	C	Leaf	Throughout year	Crevices, buildings, soil	All aged

Where, VC very common, C common, M moderate, LC less common, R rare, M monsoon, W winter, S summer, PM post monsoon

^a Represents abundance

with some being specialist predators, scavengers, seed harvesters and nectarivores [21]. Less specificity and easy availability of the required resources coupled with varied and non-specific niche requirements and dominance in both arboreal and terrestrial zones has resulted in dominance of Myrmicinae.

The present survey is in line with the earlier ant diversity study in Karnataka that recorded same seven subfamilies [22, 23]. *Camponotus* was found as the most species rich genus represented by 7 species followed by *Monomorium* by 6 species. But, 15 other genera were represented by only one species (Fig. 1). Among the ant species, *Camponotus compressus*, *Camponotus sericeus*, *Oecophylla smaragdina* and *Anoplolepis gracilipes* all belonging to Formicinae were considered as abundant and very common (Fig. 4). Upon survey, 7 species were considered as common, 15 as moderate, 12 as less common, while, 10 as rare (Fig. 4). However, the jumping ant *Harpogonathous saltator*, an endemic species to the Western Ghats [24] was not recorded in the study region. Presence of two world's worst invasive ant species namely *A. gracilipes* and *Pheidole megacephala* in cashew plantations of survey region attracts attention. *A. gracilipes* is a well known tramp species widely distributed in the Afro-Tropical region, and is most infamous for causing the

“ecological meltdown” of Christmas Island [25]. It was expected that *A. gracilipes* could cause significant damage to native biological diversity, and strong quarantine measures were encouraged to keep it from spreading to new localities. Similarly, *P. megacephala* is also a very successful invasive species [26] known to cause significant damage to native biological diversity including vertebrates, and also significant damage to agricultural systems. In the same way, *Tetramorium bicarinatum* and *Monomorium destructor* can achieve dense populations in disturbed habitats and likely to affect native biodiversity adversely.

A general increase in ant species richness was observed over increasing age and size of trees over all sampling sites. In old plantations, a total of 44 species were recorded, while in medium aged and young plantations it was only 23 and 12 species respectively. The combination of increased habitat complexity and increasing extra floral nectary numbers, due to greater tree branching might lead to increased ant diversity both within the habitat and on the cashew trees [9]. Further, dominance of different ant species was noticed on cashew canopy, trunk and soil in different aged cashew plantations (Table 4). Among the ant species, *O. smaragdina* was dominant in old plantations followed by *A. gracilipes*. In young and medium aged plantations, *C. compressus* and *C. sericeus* were dominant.

Table 2 Myrmicinae ant species recorded in cashew plantations and their characteristics

Sl. No.	Common Name	Scientific name	Abundance	Active foraging site	Season of foraging activity	Nesting site	Plantation where recorded
1	Deceptive serrated ant	<i>Catalaucus taprobanae</i> Smith	R	Trunk	PM, W ^a , S ^a	Dead logs	Old
2	Cocktail ant	<i>Crematogaster</i> sp. 1	M	Leaf	PM, W ^a , S	Weed leaf, lignicolous	Medium, old
3	–	<i>Crematogaster wroughtonii</i> Forel	M	Trunk, leaf	PM, W ^a , S	Dead log-lignicolous	Old
4	–	<i>Crematogaster</i> sp. 2	LC	Shoots	PM, W ^a , S	Trunk, Arboreal nest	Young, medium
5	Harvester ants	<i>Monomorium floricola</i> (Jerdon)	C	Leaf, flowers	PM ^a , W ^a , S ^a	Leaf, trunk-lignicolous	All
6	–	<i>Monomorium glabrum</i> Andre	C	Leaf, Soil	PM, W ^a , S ^a	Soil	All
7	The Singapore ant/destroyer ant	<i>Monomorium destructor</i> Jerdon	M	Soil, leaf, flowers	PM ^a , W ^a , S ^a	Leaf, soil	All
8	–	<i>Monomorium</i> sp.1	LC	Soil, leaf	PM, W ^a , S	Soil	Young, old
9	–	<i>Monomorium</i> sp. 2	LC	Leaf, leaf	W ^a , S	Weed shoot, arboreal	Medium
10	–	<i>Monomorium</i> sp. 3	LC	Soil, leaf	W, S ^a	–	All
11	Guinea ant/Penny ant	<i>Tetramorium bicarinatum</i> Nylander	M	Soil	PM, W ^a , S ^a	Soil	Old
12	Sluggish ant	<i>Tetramorium</i> sp.	LC	Soil	PM, W ^a , S ^a	Soil	Old
13	Silky shield ant	<i>Meranoplus bicolour</i> Guerin	M	Leaf, soil	PM ^a , W ^a , S	Soil	All
14	Harvester ants	<i>Pheidole sharpi</i> <i>hoogwerfi</i> Forel	LC	Soil	PM, W ^a , S ^a	Soil	Old
15	Big headed ants	<i>Pheidole megacephala</i> (Fabricius)	M	Soil	PM, W ^a , S ^a	Soil	Old
16	Harvester ants	<i>Pheidole</i> sp.	R	Soil	PM, W ^a , S	Soil	Old
17	Short legged hunchback ant	<i>Myrmecaria brunnea</i> Saunders	C	Soil, leaf, panicles, fruits	Throughout year	Soil, tree base	Medium, old
18	Marauder ants	<i>Pheidologeton affinis</i> Jerdon	M	Soil	PM, W ^a , S ^a	Soil	Old
19	Marauder ants	<i>Pheidologeton</i> sp. 1.	R	Soil, leaf	PM, W, S ^a	Soil	Old
20	Marauder ants	<i>Pheidologeton</i> sp. 2.	M	Soil	PM, W, S ^a	Soil	Medium, old
21	–	<i>Lophomyrmex quadrispinosus</i> Jerdon	C	Soil, leaf litter	PM ^a , W ^a , S ^a	Soil, litter	Medium, old
22	Common red fire ant	<i>Solenopsis geminata</i> Fabricius	M	Soil	PM, W, S ^a	Soil	Old

Where, VC very common, C common, M moderate, LC less common, R rare, M monsoon, W winter, S summer, PM post monsoon,

^a Represents abundance

Abundance of *A. gracillipes* is noteworthy and need for a monitoring, since this species was reported to be capable to replace *O. smaragdina* when in syntopy [27]. In the same way, monitoring of population dynamics of *Tapinoma melanocephalum* is important, since it is an excellent indicator species in determining human interference [28]. Same ant species were collected in both bait and pitfall traps, namely, *Odontomachus haematodus*, *Technomyrmex albipes*, *Lophomyrmex quadrispinosus*, *Myrmecaria brunnea*, *Diacamma* sp., *C. compressus* and *C. sericeus*. All 7

ant species were collected both in ethanol and detergent water traps. Abundant species in pitfall traps include *Diacamma* sp. (23 %), *C. compressus* (18.7 %) and *M. brunnea* (15.1 %). While, in bait traps of dead wax moths, *O. haematodus* (32.9 %) and *Diacamma* sp. (27.5 %) were abundant, and in other bait traps, *L. quadrispinosus* (42.8 %) and *C. compressus* (21.4 %) were abundant.

The study area generally receives high rainfall during south-west monsoon between June and September. During this time, activities of only 10 species were seen

Table 3 Species of ants recorded in Pseudomyrmicinae, Ponerinae, Dolichoderinae, Aenictinae and Dorylinae in cashew plantations and their characteristics

S. no.	Common name	Scientific name	Abundance	Active foraging site	Season of foraging activity	Nesting site	Plantation where recorded
Sub family: Pseudomyrmicinae							
1	Arboreal ant	<i>Tetraponera nitida</i> Smith	LC	Leaf	PM, W ^a , S	–	Old
2	Arboreal bicoloured ant	<i>Tetraponera rufonigra</i> Jerdon	M	Trunk, leaf, flowers	PM, W ^a , S ^a	Trunk- lignicolous	Old
3	Arboreal ant	<i>Tetraponera</i> sp. 2.	LC	Leaf, trunk	W, S ^a	–	Medium, old
Sub family: Ponerinae							
4	Striated bispinosus ant	<i>Diacamma</i> sp.	C	Soil, trunk	Throughout year	Soil, concealed	Old
5	Trap-jaw ant	<i>Odontomachus haematodus</i> Linnaeus	M	Soil litter	PM ^a , W, S	Soil, concealed	Old
6	Water carrying ant	<i>Pachycondyla jerdoni</i> Forel	R	Soil	PM, W, S	Soil	Old
7	Water carrying ant	<i>Pachycondyla tesseronoda</i> Emery	LC	Soil	PM, W ^a , S ^a	Soil	Old
Sub family: Dolichoderinae							
8	–	<i>Dolichoderus taprobanae</i> Smith	R	leaf	PM, W, S	Leaf, arboreal	Old
9	–	<i>Dolichoderus</i> sp.	M	Soil, trunk	W ^a , S	Trunk, Carton	Medium, old
10	Odour ant	<i>Tapinoma melanocephalum</i> Fabricius	C	Leaf, trunk, flowers	PM, W ^a , S ^a	Leaf, arboreal	Medium, old
11	Rainbow ants	<i>Iridomyrmex anceps</i> Roger	R	Soil	Throughout year	–	Old
12	White footed ghost ant	<i>Technomyrmex albipes</i> Smith	M	Leaf, flowers	Throughout year	Trunk, carton, lignicolous	Medium, old
Sub family: Aenictinae							
13	–	<i>Aenictus doryloides</i> Wilson	R	Dry leaf in soil	M, PM	Soil- litter	Old
Sub family: Dorylinae							
14	Driver ants	<i>Dorylus labiatus</i> Shuckard	R	Soil	PM	–	Old

Where, VC very common, C common, M moderate, LC less common, R rare, M monsoon, W winter, S summer, PM post monsoon

^a Represents abundance

including *M. brunnea* and *C. sericeus*. Activities of most ant species were high during winter and summer which coincides with flowering and fruiting period of cashew (December–May). During winter, 45 species were seen and during following summer 47 species were noticed (Fig. 2). Presence of maximum of ten ant species was noticed foraging on a single cashew tree at a time. A significant positive correlation was found between number of ant species and maximum air temperature (0.842) and also with afternoon soil temperature (0.925) (Table 5). A significant negative correlation was observed for rainfall and relative humidity. Similar to Punjab [29], variable number of active ant species was found during summer and winter. Negative effect of high soil moisture on the foraging behaviour of ants, especially ground-foraging ants, was reported [5].

Though activities of most ant species were noticed on cashew canopy, activities of *Diacamma* sp., *O. haematodus*, *Pachycondyla* spp., *Pheidologeton* spp., and *Pheidole* spp. were noticed mostly in soil, while *Dolichoderus* sp., *Catalaucus taprobanae*, *Tetraponera rufonigra* and *Crematogaster* sp. were seen on cashew trunk. Nesting habits of many ant species were also documented during the present study (Tables 1, 2, 3; Fig. 5). Most ant species built their nests in soil, but a few species built in leaf, trunk region or dead logs. Nesting habits of ants are important since they can alter the soil nutrients concentration and biogeochemical cycles [30, 31]. Apart from cashew, a few ants and their nests were seen in some common weed plants of cashew plantations. Such plants include, *Terminalia paniculata*, *Terminalia arjuna*, *Macaranga peltata*, *Clerodendron* sp., *Cassia alata*, *Cassia* sp., *Chromolaena*

Fig. 1 **a** Cashew shoot with foraging ants, **b** *Diacamma* sp., **c** Queen *O. smaragdina* with its eggs, **d** *M. brunnea*

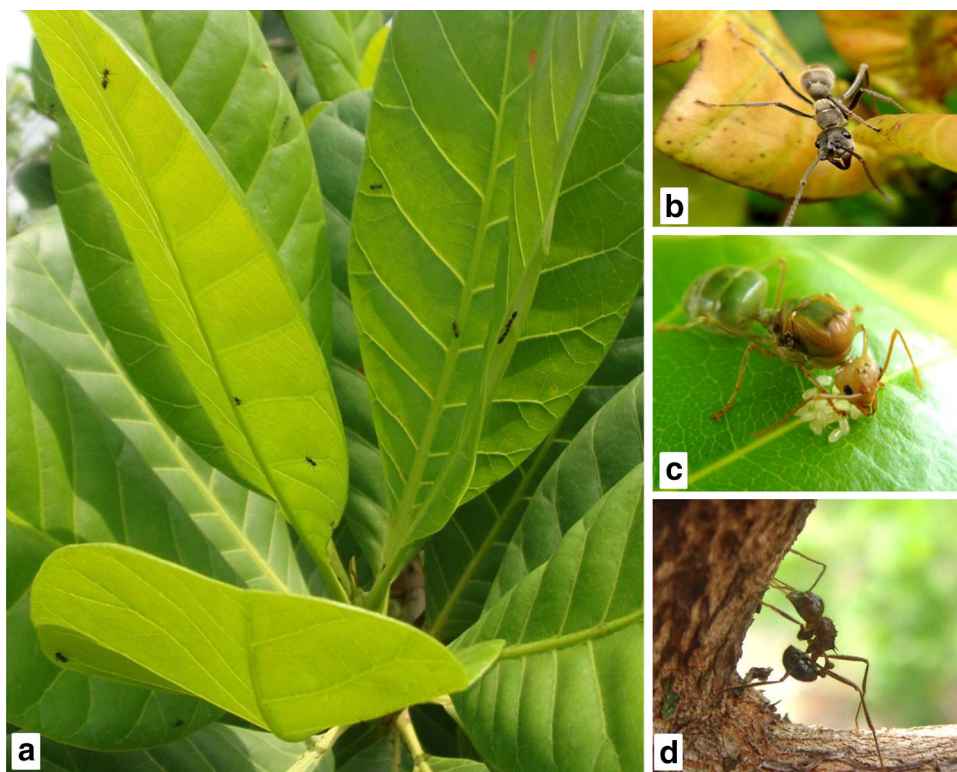
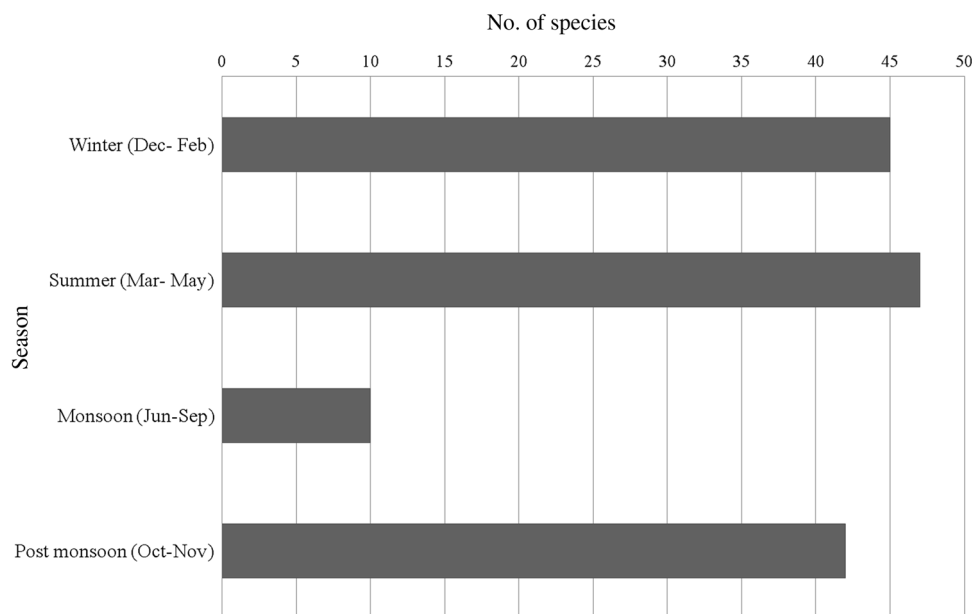


Fig. 2 Seasonal composition of ants species in cashew plantations



odotata, *Melastoma malabathricum* and *Acacia* sp. (Fig. 6). Presence of domatia, extra floral nectarines and infestation by sucking pests like aphids attracted ants to these plants. It was found that young leaves of *Macaranga* sp. possess beccarian bodies which provide lipid source [32] and the leaflet tips of some *Acacia* sp. contain beltian bodies that supply protein to ants. Many ant species were

noticed as tenders and honey dew feeders of aphids, mealy bugs and cow bugs which are minor pests of cashew (Fig. 7). In Karnataka, 11 species of ants including the genera *Camponotus*, *Crematogaster*, *Monomorium*, *Solenopsis* and *Oecophylla* were previously found associated with 24 species of aphids in other crops [33]. Ant species like *Pheidologeton* sp. were noticed mainly as seed

Fig. 3 Species richness of ants recorded under different subfamilies

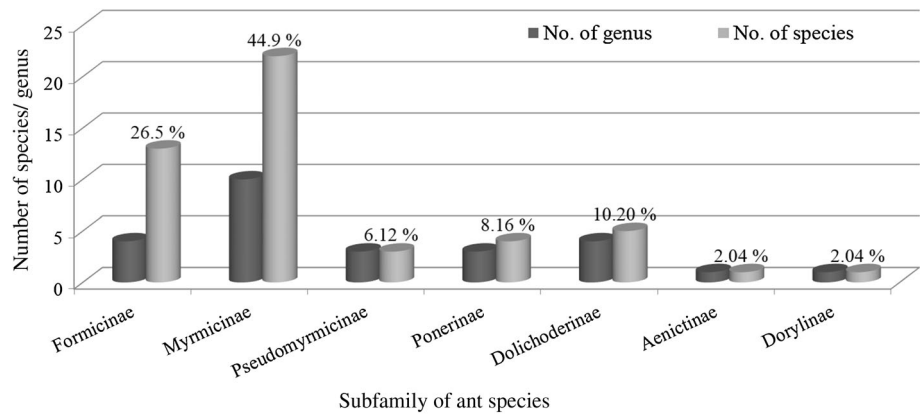


Fig. 4 Abundance of species of ants recorded under different sub families in cashew plantations

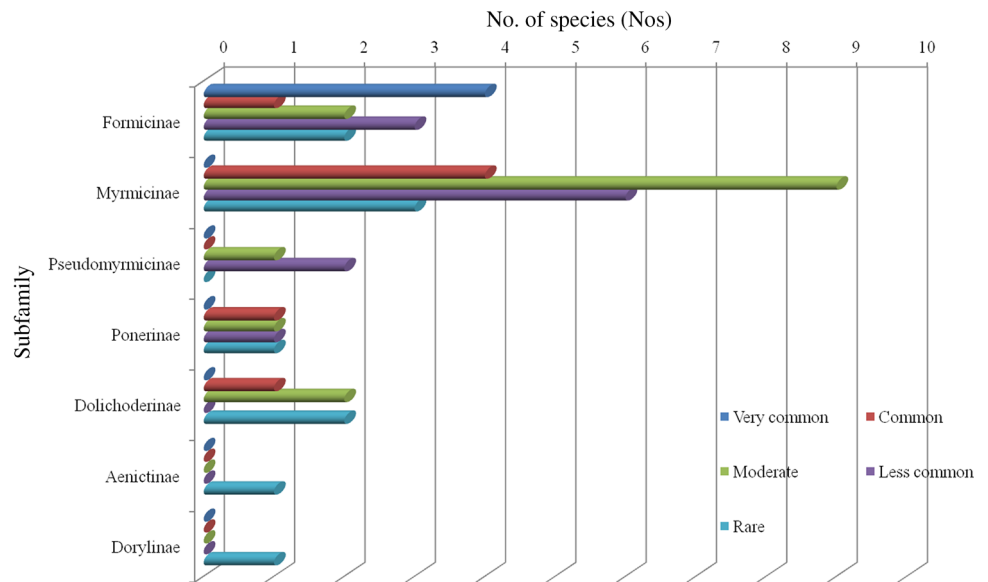


Table 4 Predominant ant species in different aged cashew plantations

Particulars	Young plantations	Medium aged plantations	Old plantations
Canopy	<i>C. compressus</i> > <i>C. sericeus</i> > <i>Monomorium</i> spp.	<i>C. compressus</i> > <i>C. sericeus</i> > <i>P. naoroji</i> > <i>Monomorium</i> spp.	<i>O. smaragdina</i> ≥ <i>A. gracillipes</i> > <i>C. compressus</i> > <i>C. sericeus</i>
Trunk	<i>Monomorium</i> spp.	<i>Monomorium</i> spp. > <i>T. melanocephalum</i>	<i>T. melanocephalum</i> > <i>T. albipes</i> > <i>M. floricola</i> > <i>T. rufonigra</i>
Soil and litter	<i>C. compressus</i> > <i>C. sericeus</i>	<i>C. compressus</i> > <i>C. sericeus</i> > <i>M. brunnea</i>	<i>L. quadrispinosus</i> > <i>O. heamatodus</i> > <i>Diacamma</i> sp. > <i>S. geminata</i> > <i>C. compressus</i> > <i>M. brunnea</i>

dispersers of annual grass weeds. Ant species of the genera *Solenopsis*, *Monomorium*, *Pheidole*, *Meranoplus*, *Myrmicaria* and *Camponotus* were found to harvest seeds [23, 34]. Interestingly, feeding activities of *Meranoplus bicolor*, *C. compressus* and *Crematogaster* spp. were witnessed on leaf, flower buds and flowers of *Cassia alata* and *Cassia* sp. which are weeds of cashew plantations (Table 6; Fig. 8). Ant herbivory has been previously documented on red gram, brinjal, tomato, cauliflower by *Solenopsis geminata*

and *Monomorium* sp. [35, 36] and on bhindi by *M. brunnea* [37].

Many ant species were noticed as predators of several cashew pests (Table 6). Predation of eggs of a cashew pest, *Euthalia* sp. (Nymphalidae: Lepidoptera) by *Tetraponera* sp. was noticed (Fig. 8). The ferocious ant, *O. smaragdina* was recorded to feed on the key pest namely, tea mosquito bug (TMB) and many other pests like hemipteran bugs, caterpillars, grasshoppers, flies etc. For two consecutive

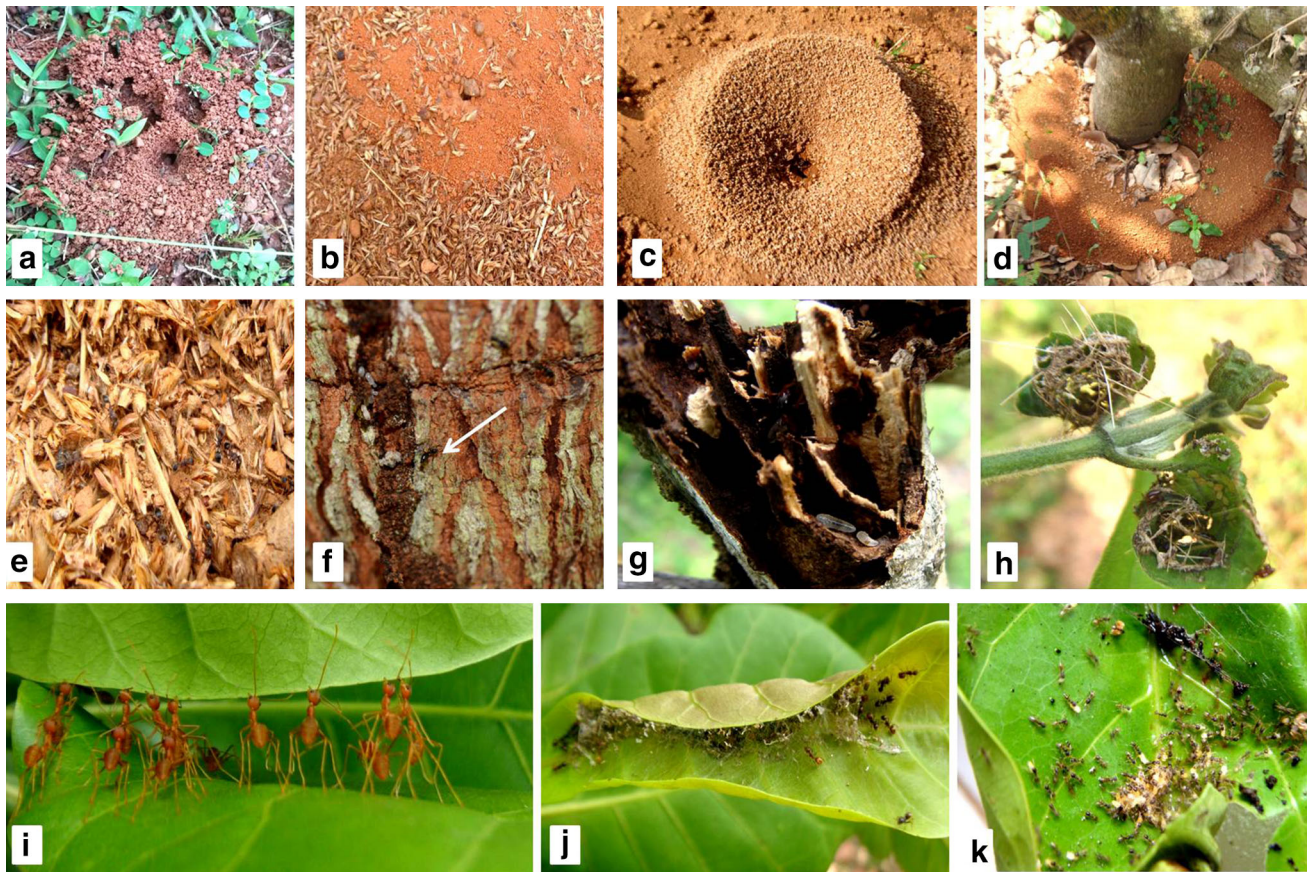


Fig. 5 Nesting habits of ants species **a** *P. tesseronoda*, **b** *C. compressus*, **c** *C. sericeus*, **d** *M. brunnea*, **e** *Pheidole* sp., **f** *T. albipes*, **g** *T. rufonigra*, **h** *Crematogaster* sp. 1, **i** *O. smaragdina*, **j** *D. taprobanae*, **k** *T. melanocephalum*

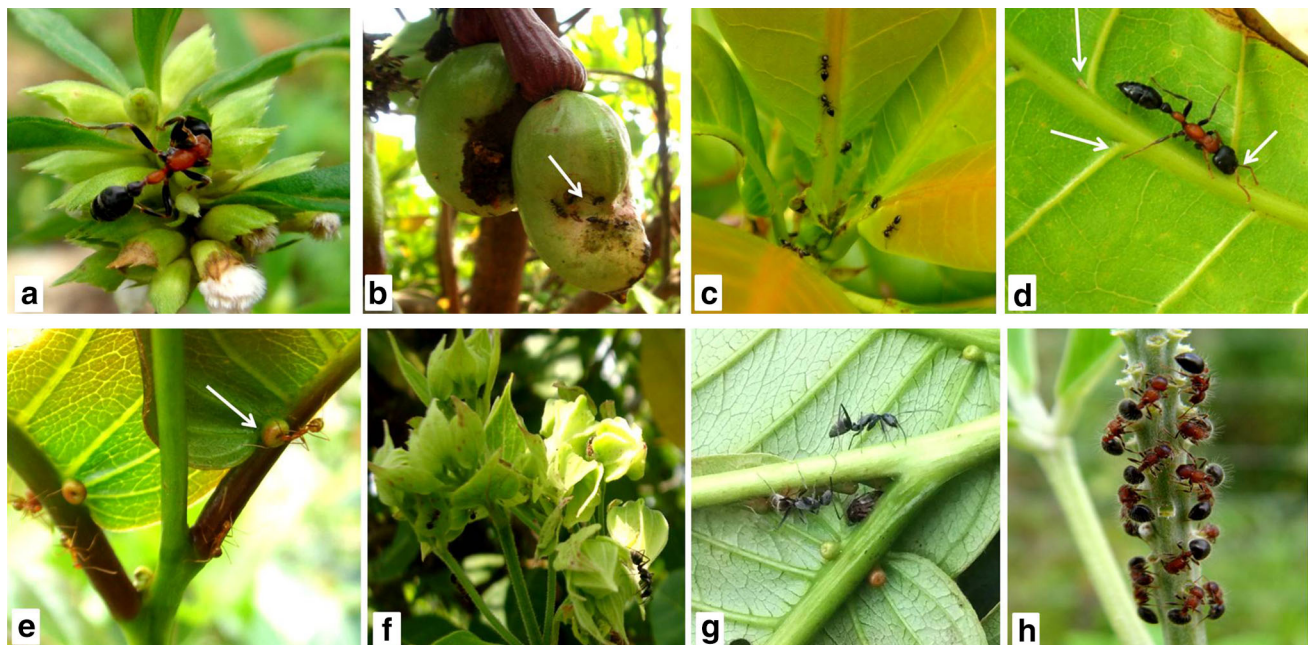


Fig. 6 Extra floral nectarines and nectar feeding by ants **a** *T. rufonigra* on *Leucas aspera*, **b** *Tetraponera* sp. on cashew nuts, **c** *Crematogaster* sp. 2 on cashew leaves, **d** *T. rufonigra* on cashew leaves, **e** *A. gracillipes* on *Terminalia paniculata*, **f** *P. naoroji* on *Macaranga peltata*, **g** *C. compressus* on *Terminalia* sp., **h** *M. bicolor* on *Cassia* sp.

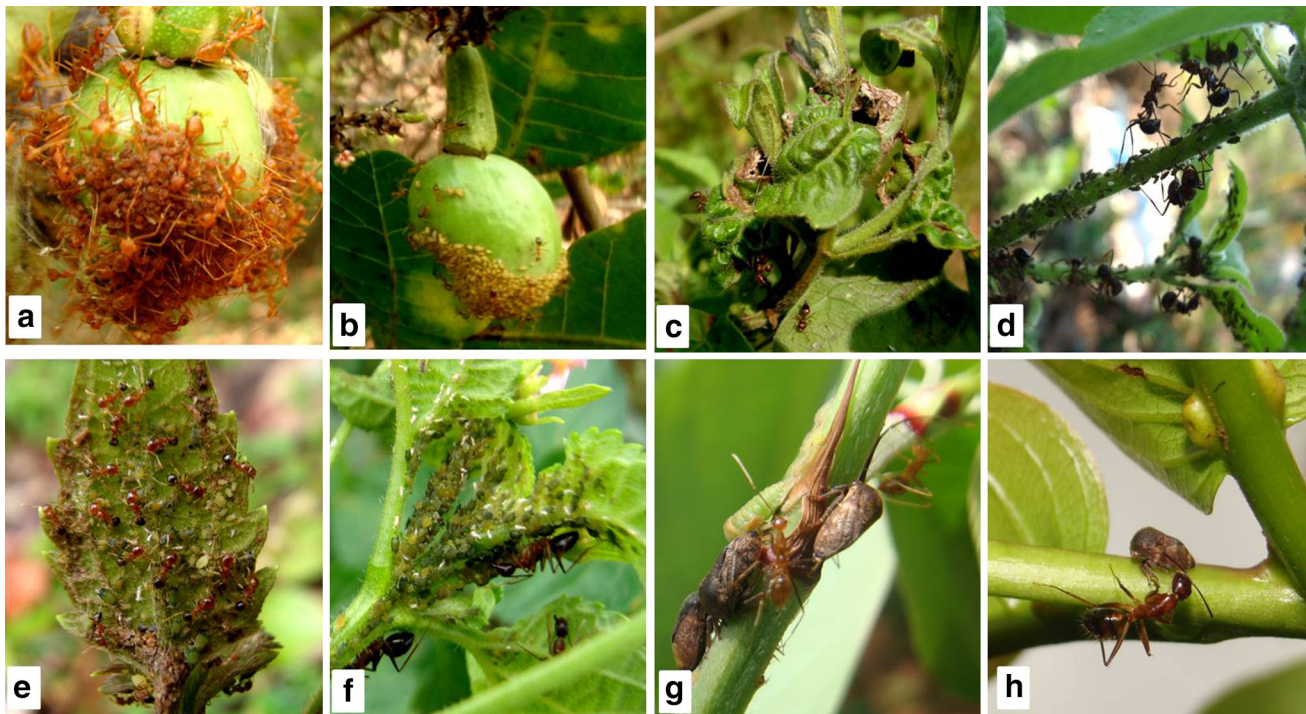


Fig. 7 Ants as honey dew feeders of sucking pests **a** *O. smaragdina* on aphids of cashew, **b** *A. gracillipes* on aphids of cashew, **c** *Crematogaster* sp. 1. on aphids of *C. odorata*, **d** *M. brunnea* on aphids of *C. odorata*, **e** *Tetramorium* sp. on aphids of *C. odorata*,

f *Camponotus* sp. 2 on aphids of *C. odorata*, **g** *A. gracillipes* on cowbug of *Terminalia* sp., **h** *Camponotus* sp. 2 on cow bug of *Terminalia* sp.

Table 5 Influence of weather parameters on the species composition of ants in cashew eco system

Weather parameters	Correlation coefficient	se
Maximum air temperature (°C) (X_1)	0.842**	1.70
Minimum air temperature (°C) (X_2)	-0.545*	3.37
Soil Temperature (°C) FN (X_3)	0.289	2.41
Soil Temperature (°C) AN (X_4)	0.925**	1.09
Relative humidity % FN (X_5)	-0.807**	0.78
Relative humidity % AN (X_6)	-0.944**	0.63
Rainfall mm (X_7)	-0.841**	0.01

Regression equation: $Y = 15.89 - 0.036 X_1 + 4.809 X_2 - 3.783 X_3 + 1.014 X_4 - 0.113 X_5 - 0.709 X_6 + 0.013 X_7$, $R^2 = 0.95$, $F = 11.36$

FN fore noon, AN after noon

* Significant at 5 %, ** Significant at 1 %

years, trees colonized by *O. smaragdina* were almost free of pests or had less TMB attack. *Diacamma* sp. fed on soil insects, small caterpillars and leaf beetles. *Crematogaster* sp. efficiently predated up on moths and caterpillars, while, *Monomorium* sp. fed on TMB, leaf hoppers, moths etc. especially when these insects encountered their nests. *T. rufonigra* carried away termites from the infested trees. These findings are in accordance with Rosy and Narendran [38], Sreekumar [16] and Peng et al. [14, 15], who reported predation by *O. smaragdina* on cashew pests including TMB, shoot tip caterpillars, blue shoot borers, fruit-nut

borers, leaf rollers and leaf miners in Kerala, Australia and Vietnam. Species like *M. bicolor*, *C. sericeus* and *A. gracillipes* were found to subdue and kill prey using formic acid secretions [25].

As observed by Offenberg et al. [39], visits to extra floral nectarines probably point to their role in additional protection of cashew from herbivores. Hence, efforts are needed to identify potential ant species and the ways to use them for pest control. Besides, as cashew is entomophilous [40], active foraging of different ant species over panicles during flowering season [41] might help in pollination to a

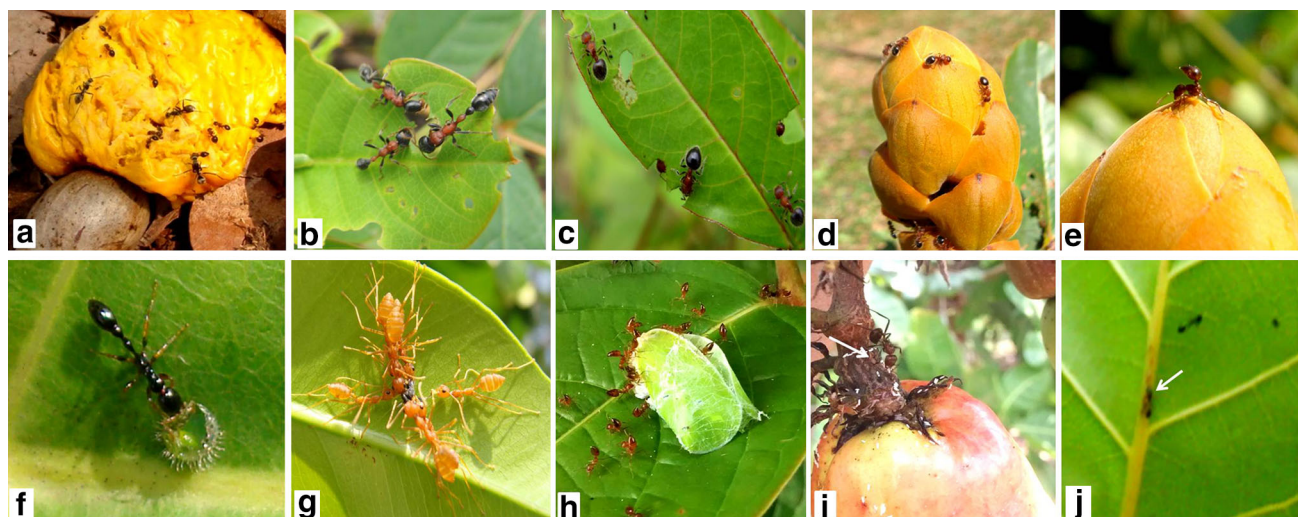


Fig. 8 a Feeding of *C. compressus* and *M. bicolor* on cashew apple, b herbivory by *T. rufonigra* on *C. alata*, c herbivory by *M. bicolor* on *Cassia* sp., d Feeding by *M. bicolor* on *C. alata* flowers, e feeding by *Crematogaster* sp.1 on *C. alata* flower, f Predation of an egg of

Euthalia sp. by *T. nitida*, g Predation by *O. smaragdina*, h Predation by *Crematogaster* sp. 1, i predation of fruit flies eggs by *M. brunnea*, j predation of respiratory process of TMB eggs by *Tetraponera* sp.

Table 6 Ant-plant interactions in cashew plantations

S no.	Interaction as	Ant species
1	Predators	<i>O. smaragdina</i> , <i>T. nitida</i> , <i>T. rufonigra</i> , <i>Diacamma</i> sp., <i>Monomorium</i> spp., <i>S. geminata</i> , <i>T. melanocephala</i> , <i>M. brunnea</i> , <i>A. gracillipes</i> , <i>Crematogaster</i> spp., <i>Tetramorium</i> spp., <i>Pheidole</i> spp., <i>P. naoroji</i> , <i>P. tesseronoda</i> , <i>P. jerdonii</i> , <i>A. doryloides</i> , <i>O. haematodus</i>
2	Extra floral nectarine/domatia feeders	<i>T. melanocephalum</i> , <i>C. compressus</i> , <i>C. irritans</i> , <i>C. sericeus</i> , <i>T. rufonigra</i> , <i>Tetraponera</i> spp., <i>P. naoroji</i> , <i>Crematogaster</i> spp., <i>T. albipes</i> , <i>M. bicolor</i> , <i>M. brunnea</i>
3	Scavengers/necrophoresis	Almost all species serve as scavengers by removing dead ants of their own groups/other ant sub-families/other plant and animal matters
4	Litter dwellers/decomposers	<i>O. haematodes</i> , <i>L. quadrispinosus</i> , <i>A. doryloides</i> , <i>A. gracillipes</i> , <i>M. brunnea</i>
5	Feeders of weed leaf/floral parts etc.	<i>M. bicolor</i> , <i>Crematogaster</i> spp., <i>C. compressus</i>
6	Seed dispersers (Myrmecochory)	<i>Pheidologeton</i> spp., <i>Pheidole</i> spp., <i>S. geminata</i> , <i>Tetramorium</i> spp., <i>P. jerdoni</i> , <i>I. anceps</i> , <i>M. bicolor</i>
7	Tenders of aphids/Honey dew feeders	<i>A. gracillipes</i> , <i>O. smaragdina</i> , <i>Crematogaster</i> spp., <i>Monomorium</i> spp., <i>C. angusticollis</i> , <i>C. compressus</i> , <i>C. irritans</i> , <i>T. albipes</i> , <i>L. quadrispinosus</i> , <i>M. brunnea</i>

certain extent at least by some species, which needs further investigation. Though, number of individuals caught is an indication of biomass, more care has to be taken in its

interpretation as collection can be influenced significantly by the procedure and site of sampling. Under field conditions, other predators and ecological factors might also influence ant activity.

Conclusion

To understand the diversity and stability of an ecosystem, it is important to study the species composition and the changes that occur due to habitat and climatic variations which would help in biodiversity conservation endeavour. Viewing the interactions of ants with cashew, it was found that ants are common in cashew plantations and are attracted to cashew trees throughout the year. It is important to conserve predatory ants in cashew ecosystems by reducing pesticide application for pest management. During field survey, it was simultaneously observed that spraying of insecticides like lambda-cyhalothrin could cause exclusion of many arboreal foraging ants including *O. smaragdina*. Hence, a pest scouting and tree-by-tree spraying program could be implemented during pest outbreak. The results also highlight the need to examine the spread and impact of invasive ant species like *A. gracillipes* and *P. megacephala* in cashew plantations.

Acknowledgments The authors express their sincere gratitude to Dr. Himender Bharti, Department of Zoology, Punjabi University, Patiala, Punjab, India for identifying the ant species. They thank the Director, Directorate of Cashew Research, Puttur for encouragement and support during the studies. They also thank the anonymous reviewers for suggestions in improving the manuscript.

References

- Moorthy VK, Yadukumar N, Raj Shankar (2007) Hand book on organic cashew cultivation. Varanasi Research Foundation, Manipal Press Ltd., Mumbai, p 65
- Cashew News (2013) The cashew: issues, challenges and strategies. Cashew news. Half yearly Newsletter of Directorate of Cashew Research, Puttur 18(1):1–2
- Sundararaju D (1993) Compilation of recently recorded and some new pests of cashew in India. Cashew 7:15–19
- Bolton B (1994) Identification guide to the ant genera of the world. Harvard University Press, London, p 222
- Agosti D, Majer JD, Alonso LE, Schultz TR (2000) Ants: standard methods for measuring and monitoring biodiversity. Smithsonian Institution Press, Washington D.C
- Gadagkar R, Nair P, Chandrasekara K, Bhatt DM (1993) Ant species richness and diversity in some selected localities in Western Ghats, India. Hexapoda 5(20):79–94
- Ali TM, Ganeshiah KN (1998) Mapping diversity of ants and root grubs. Curr Sci 75(30):201–204
- Bharti H (2012) Indian ants. www.antweb.org/india.jsp. Accessed 14 May 2013
- Rickson FR, Rickson MM (1998) The cashew nut, *Anacardium occidentale* (Anacardiaceae) and its perennial association with ants: extra floral nectary location and the potential for ant defense. Am J Bot 85(6):835–849
- Pathummal Beevi S, Mahapatro GK (2008) Species-spectrum and inter-relationship between ant and spider fauna in cashew agro-ecosystem. J Plant Crops 36(3):375–381
- Pillai GB, Dubey OP, Singh Vijaya (1976) Pests of cashew and their control in India: a review of current status. J Plant Crops 4(2):37–50
- Ambika B, Abraham CC (1984) Bio-ecology of *Helopeltis antonii* Sign. infesting cashew trees. In: Rao EVVB, Khan HH (eds) Cashew: research and development. Indian Society for Plantation Crops, Kasaragod, pp 299–300
- Sundararaju D (1984) Studies on cashew pests and their natural enemies in Goa. J Plant Crops 12:38–46
- Peng RK, Christian K, Gibb K (1999) Utilisation of green ants, *Oecophylla smaragdina* to control cashew insect pests. Rural Industries Research and Development Corporation, Canberra
- Peng RK, Lan La Pham, Keith Christian (2014) Weaver ant role in cashew orchards in Vietnam. J Econ Entomol 107(4):1330–1338
- Sreekumar KM, Vasavan N, Madhu S, Sijila J, Sreedharan MP, Sreelekha S, Cheriyan T (2011) Managing tea mosquito bug (*Helopeltis antonii* Sign.) in cashew by augmenting red ants *Oecophylla smaragdina* (F.). J Plantn Crops 39(1):110–113
- Anderson AN (1990) The use of ant communities to evaluate change in Australian terrestrial ecosystems: a review and a recipe. Proc Ecol Soc Aust 16:347–357
- Cashew News (2013) Micronutrients in cashew. Cashew News. Half Yearly newsletter of Directorate of Cashew Research, Puttur. 18 (2): 1-2
- Tilman D (1978) Cherries, ants and tent caterpillars: timing of nectar production in relation to susceptibility of caterpillars to ant predation. Ecology 59:686–692
- Fiala B, Maschwitz U (1992) Food bodies and their significance for obligate ant-association in the tree genus *Macaranga* (Euphorbiaceae). Bot J Linn Soc (London) 110:61–75
- Majer JD, Kitching RL, Heterick BE, Hurley K, Brennan KEC (2001) North south patterns within ant species assemblages from rain forests in Eastern Australia. Biotropica 33(4):643–661
- Ali TM (1991) Ant fauna of Karnataka-1. Newslett of IUSSI Indian Chapter 5:2–8
- Ali TM (1992) Ant fauna of Karnataka-1. Newslett of IUSSI Indian Chapter 6:1–9
- Ramachandra TV, Subash Chandran MD, Joshi NV, Ajay Narendra, Ali TM (2012) Ant species composition and diversity in the Sharavathi River Basin, Central Western Ghats. Sahyadri Conservation Series 3. ENVIS Technical Report: 20
- O'Dowd DJ, Green PT, Lake PS (2003) Invasional 'meltdown' on an oceanic island. Ecol Lett 6(9):812–817
- Hatada A, Ishiguro S, Hoffman B (2006) *Pheidole megacephala*. Global invasive species database. Invasive species specialist group of the IUCN Species Survival Commission, Global Invasive Species Programme. <<http://www.issg.org/database/species/ecology.asp?si=132&fr=1&sts=>>>. Accessed 2 Jan 2013
- Soans AB, Soans JS (1971) A case of intergeneric competition and replacement in the ants, *Oecophylla samragdina* Fab. and *Anoplolepis longipes* Jerdon (Hymenoptera: Formicidae). J Bombay Nat Hist Soc 68(1):289–290
- Viswanathan G, Narendra A (2000) The effect of urbanization on the biodiversity of ants in Bangalore. J Ecobiol 12(2):115–122
- Bharti H, Sharma Yash Paul, Kaur Amritdeep (2009) Seasonal patterns of ants (Hymenoptera: Formicidae) in Punjab Shivalik. Halteres 1(1):10–24
- Wanger J, Jakubczyk H and Woajcik Z (1997) Lience des fourmis sur la modification des sols et des plants dans le milieu des prairies. In: Phillipson J (ed) Methods of study in soil ecology. Proceedings of Paris symposium. UNESCO, Paris, pp 235–240
- Manmohan AA, Coddington J, Colwell RK (2000) Flying as a survival strategy for wood ants in a fragmented landscape (Hymenoptera, Formicidae). Memorab Zool 48:147–170
- Itioka T, Kawano S (2011) Myrmecosymbiosis in the Bornean Macaranga species with special reference to food bodies (Becarian bodies) and extra floral nectaries. Plant Species Biol 16(3):241–246
- Joshi S (2008) Records of aphids and aphidicolous ants (Hymenoptera: Formicidae) from Karnataka. Entomon 33(1):15–23
- Reddy DNR and Puttaswamy (1984) Pests infesting chilli (*Capsicum annum* L.) in the nursery. Mysore J Agric Sci 18:122–125
- Fletcher TB (1917) Drugs and dyes (Eds) Rep Proc Second Ent Meet Pusa, 340 pp
- Ayyar PNK (1963) Handbook of economic entomology for South India. Government of Madras, Madras
- Abraham CC, Remamony KS (1978) New records of myrmecinae ants and as pests of bhendi, *Abelmoschus esculentus* Moench. J Bombay Nat Hist Soc 75(1):242–243
- Rosy PA, Narendran TC (1985) Study on the predaceous habits of some species of ants of Malabar and their potential as biological control agents of insect pests. Proceedings of national seminar entomopathogenic institute Calicut, pp 70–71
- Offenberg J, Havanon S, Aksornkoae S, Macintosh DJ, Nielsen MG (2004) Observations on the ecology of weaver ants (*Oecophylla smaragdina* Fabricius) in a Thai mangrove ecosystem and their effect on herbivory of *Rhizophora mucronata* Lam. Biotropica 36:344–351
- Fernandes L, Mesquitea AM (1995) *Anacardium occidentale* (cashew) pollen allergy in patients with allergic bronchial asthma. J Allergy Clin Immunol 95:501–504
- Freitas BM, Paxton RJ (1998) A comparison of two pollinators: the introduced honey bee *Apis mellifera* and an indigenous bee *Centris tarsata* on cashew *Anacardium occidentale* in its native range of NE Brazil. J Appl Ecol 35:109–121