

Flower visitors and fruitset of *Anacardium occidentale*

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Received 19 Apr. 2004, revised version received 12 July 2004, accepted 27 Aug. 2004

Bhattacharya, A. 2004: Flower visitors and fruitset of *Anacardium occidentale*. — *Ann. Bot. Fennici* 41: 385–392.

The flower visitors, pollination and fruitset of cashew (*Anacardium occidentale*) were studied. The investigation involved monitoring of flower visitors, assessment of floral rewards for pollinators and breeding experiments to establish the role of flower visitors on fruitset. Yield of fruits has been low due to the lack of appropriate pollinators and the possible role of ants in pollen damage. Bees, flies, butterflies, beetles and ants visited the flowers. Relative abundance of visitors coincided with nectar availability. Breeding manipulation by bagging experiments indicated that bees are efficient pollinators increasing fruitset, while ants decreased fruitset by damaging the viable pollen. Effective fruit production requires more activities of bees and management to reduce ant damages in *A. occidentale*.

Key words: ants, breeding manipulation, cashew, pollen damage, pollination

Introduction

Cashew, *Anacardium occidentale* (Anacardiaceae) is a hardy drought-resistant tropical and subtropical tree. It is distributed in tropical America, from Mexico and West Indies to Brazil and Peru (Johnson 1973). Ranging from warm temperate moist to tropical very dry to wet forest life zones, cashew is reported to tolerate an annual precipitation of 7–42 dm, annual temperature of 21 °C–28 °C, and pH of 4.3–8.7 (Nambiar & Haridasan 1979). Globally, India is the leading producer of cashew; other producing countries include Mozambique and Tanzania (Mutter & Bigger 1961). The demand of cashew is increasing, but the availability of seed is often a limiting factor for several reasons (Reddi 1993, Freitas 1995, Holanda-Neto *et al.* 2002). Poor

pollination, inadequate flower visitors and probably pollen damage by ants may be the reasons for low production. Consequently an understanding of the factors affecting cashew seed production has important practical applications for both genetic improvement and operational seed production.

Several researchers have provided information on the floral biology and pollination of cashew (Rao & Hassan 1957, Bigger 1960, Mutter & Bigger 1961, Northwood 1966, Free & Williams 1976, Thimmaraju *et al.* 1980, Mohan *et al.* 1981, Hanamshetti *et al.* 1986, Moncur & Wait 1986, Reddi 1993, Freitas 1995, Freitas & Paxton 1996, 1998). Rao and Hassan (1957) suggested wind as the pollinating agent, but Bigger (1960) postulated thrips to be pollinators of cashew, while Free and Williams (1976) reported

bees and wasps to be the pollinators; Mohan *et al.* (1981) and Reddi (1993) speculated the involvement of various wild flies.

Freitas and Paxton (1996, 1998) presented a comparative account of cashew pollination using introduced and indigenous bees in the native range in NE Brazil. In Tanganyika, Bigger (1960) found as many as 767 panicles on a single tree, with 63–67 hermaphrodites and 250–400 male flowers per panicle. In Mangalore, Madhava Rao and Vazir Hassan (1957) counted 329 florets on a panicle, 316 of which were staminate and 13 hermaphroditic. Usually from one to less than half a dozen fruits mature per cluster (Northwood 1966). The five reflexed petals (of the 0.85 to 1.27 cm flower) are pale green with red stripes, later turning to solid red (Morton 1961). In the male flower, about nine stamens are 4 mm long and one stamen 12 mm, not all of which may be functional. The hermaphrodite flower also has nine short stamens and one about 8 mm long. The style extends above the anthers to the same height as the long anther of the male flowers. About 20–30 flowers open per day on a panicle. The flowers open almost any time of the day, but the peak period of opening is 9:00–11:00 hrs. The stigma is receptive as soon as the flower opens, but the anthers do not dehisce until five hours later, providing an opportunity for crossing (Madhava Rao & Vazir Hassan 1957). The flower produces a low amount of nectar, which is attractive to bees, flies, wasps, ants, and other insects (Morton 1961, Free & Williams 1976). *Anacardium occidentale* is believed to be pollinated by bees, wasps and flies (Free & Williams 1976, Reddi 1993). I assume that the absence of potential pollinators (bees) often appears to limit seed set. My hypothesis for this study was that ants may damage viable pollen and lower the quality and quantity of cashew seeds.

In this paper I present investigations of the flower visitors and fruitset of *A. occidentale* with an aim to determine the role and behaviour of bees vs. ants and also to determine the negative impact of ants on fruitset. This implies recommendations to growers for using more bees in cashew pollination following proper management practices to reduce the quantity of ants and thus to get a higher production.

Material and methods

Study area

The study was conducted in a plantation of *A. occidentale* at Santiniketan, India (23°55'N, 87°40'E, 60 m a.s.l.). The adjacent vegetation was natural deciduous forest. During the study period the rainfall was 95–105 mm, the mean temperature was 30.8 °C (26 °C–36.5 °C) and RH was 81.8% (80%–86%) at 7:00 hrs.

Flowering phenology and floral traits

Flowering phenology of *A. occidentale* was recorded at weekly intervals on ten randomly selected, marked trees along a 300-m cashew plantation. Flower anthesis was observed by tagging at random ten different mature floral buds in each panicle of each tree. Pollen availability was determined by placing a smooth small piece of tissue paper over anthers after flower opening on the same panicles. The pollen adhered to tissue paper indicates anther dehiscence. The floral traits were assessed for nine traits measured from each plant: Flower size, number of hermaphrodite flowers per panicle, number of male flowers per panicle, nectar availability at different times of day, number of pollen grains per flower, pollen/ovule (P/O) ratio, number of viable pollen, pollen longevity and number of grains deposited over stigma were measured. Flower size was measured using a vernier scale. For this and other measurements, ten different flowers were selected at random from each of the ten trees at each site and a mean value was estimated. Nectar was extracted by a microcapillary tube, its volume at different times after flower opening was measured with a 10 µl micropipette, and sugar concentration was measured with a hand refractometer (Kearns & Inouye 1993). Pollen and ovule number per flower were assessed following Dafni (1992). All mature anthers from a single immediate open flower were taken, crushed in known volume of 70% ethanol with a drop of safranin within a vial; pollen remnant in the anther wall was checked under a light microscope. A small volume (50 µl) was taken on a haemocytometer and pollen

grains were counted under a light microscope, multiplied by total volume of pollen suspension, and a mean pollen number per flower was estimated. Splitting the ovary, the ovules were counted, which was reassessed after fruit maturation by counting the seeds/nuts. The number of pollen grains per flower was divided by the number of ovule to obtain pollen/ovule ratio. The pollen viability test was performed using Alexander's stain (Alexander 1969), taking the grains from long stamens of open as well as treated flowers at anther dehiscence time, where the red-stained grains were considered non-aborted/viable and the green-stained were considered aborted.

Identification and behavior of flower visitors

Observations were made on the number of visitors to flowers, the visitor species, duration of visit, and behaviour. Observations were conducted for 18 days. The observation dates were picked up randomly during the flowering period of *A. occidentale* (Reddi 1993). On each day there were six observation periods. In addition, observations were made at night, using a flashlight, to check any nocturnal flower visitors. Relative abundance (mean %) of visitors was calculated by dividing the total number of visits (by all visitors separately during the observation period) by the number of available flowers in panicle during this period. The abundance was averaged over the ten observed trees. Four types of behaviour were noticed: (I) insects fly away from trees, (II) fly to another panicle of same tree, (III) fly to another panicle of nearby tree, and (IV) move along vegetative parts of same tree (mostly ants). Insect foraging behaviour was noticed by 540 censuses on the ten trees. The flower visitors were identified to species in Zoological Survey of India, Kolkata.

Effect of insect visitation on fruitset

To investigate whether the flower visitors influenced fruitset, panicles at anthesis were enclosed in butter-paper bags to exclude insect visitors.

The bags would have also excluded ants. Seven panicles (one per treatment) on each flowering tree of the ten trees were tagged and subjected to seven treatments. Each treatment was performed once per tree, giving ten replicates per treatment. The seven treatments applied were: (I) control, no treatment; (II) unbagged 7:00–13:00 hrs and bagged 13:00–7:00 hrs; (III) unbagged 13:00–17:00 hrs and bagged 17:00–13:00 hrs; (IV) unbagged 17:00–7:00 hrs and bagged 7:00–17:00 hrs; (V) bagged continuously (spontaneous autogamy); (VI) caged with introducing bees from colony for 9:00–13:00 hrs and bagged 13:00–9:00 hrs (to exclude ants, only bees were allowed to visit); and (VII) bagged continuously using nylon net to exclude bees and other large insects, but allowing ants. The bags were removed when the petals dried and got detached, and ovary became considerably swollen, which indicated initial fruit development. The number of fruitset was counted after 14 days. The percentage of fruitset was calculated from the total number of fruits at day 14 (fruits mature but small at this time) per the total number of flowers per panicle at anthesis.

Statistical analyses

Differences in the mean number of pollen grains, viability of grains, nectar volume, sugar concentration, and fruitset percentages at different times and conditions were statistically tested calculating standard deviation (S.D.), standard error (SE) and with Student's *t*-test (Zar 1984).

Results

Flowering phenology and floral traits

A. occidentale flowered from mid-February to mid-May with a peak in March to April. After flower initiation, all the observed trees were full of bloom within 7–21 days. The flowering synchrony among and between the trees was recorded. The floral characters are presented in Table 1. The staminate and hermaphrodite flowers possess one stamen much longer (and with bigger anthers) than the remaining ones.

As a consequence of this adaptive feature pollen from long anther could easily be transferred to the stigma. The flowers attract different visitors belonging to Hymenoptera, Lepidoptera, Diptera and Coleoptera (Table 2). The nectar volume and sugar concentration changed over the course of the day. Generally the nectar volume and sugar concentration were at their minimum in the morning and at their maximum at 13:00 hrs (Table 3). Depending upon the nectar volume and sugar concentration the lowest reward was in the morning and the highest in the afternoon.

Type and number of insect visits

The insects that visited the cashew flower were predominantly bees and ants. Other insects' visits were less frequent. Bees of various species visit and forage on the flowers during daytime when pollen and stigma remain receptive. During this period other insects of Diptera, Lepidoptera and

Coleoptera also pay their visits, but less frequently, not regularly and without touching the stigma. They collect nectar only and thereby do not participate in pollen transfer. Three species of *Apis* (*A. cerana indica*, *A. florea*, *A. dorsata*), *Trigona* spp. and *Bombus* spp., two species of flies (*Chrysomya megacephala*, *Musca* spp.), were identified and recorded to visit cashew flowers (Fig. 1 and Table 2). Ants were recorded to reside in the flowers throughout the day and night (Fig. 1). The maximum abundance (46.8%) of ants was found at 7:00 hrs followed by 43.7% at 17:00 hrs, 31% at 9:00 hrs, 17.4% at 11:00 hrs, 14.3% at 15:00 hrs and 7.9% at 13:00 hrs. Intergroup aggressive behaviour among the bees, flies, butterflies, and beetles was not noticed, but aggressiveness between intragroup, bees-ants-thrips, bees-flies, flies-beetles, bees-beetles was observed. When bees, flies, butterflies, and beetles dominated and visited flowers the ants left the flowers and stayed on the vegetative parts. Among insect visitors bees were responsible for the highest number of visits.

Table 1. Floral characters of *A. occidentale*.

Flower characters (means of ten observations on each tree of ten different trees)

Flower anthesis time	7:00–11:00 hrs
Pollen anthesis time	10:30–17:00 hrs
Pollen size	17.1 ± 1.2 µm to 19.5 ± 1.4 µm
Pollen shape	Oblate spheroid
Aperture	3-colporate
Pollen per anther (± SE)	123 ± 0.77
Pollen per flower (± SE)	1230 ± 61.25
Pollen per ovule (± SE)	1230 ± 61.25
Viable pollen (%) (± SE)	76.2 ± 2.10
Mean pollen per stigma (± SE)	7.4 ± 1.83
Stigma receptive period	8:00–20:00 hrs

Table 2. Flower visitors of *A. occidentale*. Observed six times (three minutes duration, at two-hour intervals) over nine days on each tree of ten different trees, total number of observations were 540.

Name of visitors
<i>Apis cerana indica</i>
<i>A. florea</i>
<i>A. dorsata</i>
<i>Trigona</i> spp.
<i>Bombus</i> spp.
<i>Chrysomya megacephala</i>
<i>Musca</i> spp.
Formicidae (ants)
Lepidoptera
Coleoptera

Table 3. Nectar availability at different times of the day (*means of ten flowers from each of the ten trees for three days).

	Times of day (hrs)					
	7:00	9:00	11:00	13:00	15:00	17:00
Amount (µl) ± S.D.	0.04 ± 0.01	0.09 ± 0.04	0.85 ± 0.06	1.16 ± 0.12	1.05 ± 0.03	0.07 ± 0.02
Sugar conc. (%) ± S.D.	0.4 ± 0.09	0.9 ± 0.13	4.5 ± 0.51	5.1 ± 0.59	4.9 ± 0.62	0.7 ± 0.07

Feeding behaviour

Regular feeding behaviour of bees was observed. Most of the bees visited fewer than six flowers per panicle. The other large visitors of Diptera were seen bending sideways for nectar collection without touching stigmas, but rarely through fresh open flowers. The Lepidoptera members were seen to pierce a small part of proboscis at the flower base to search for nectar, without touching the stigma. The Coleoptera members forage on flowers along panicle length, they chew the anthers and move slowly towards flower base. At times, ants were observed feeding simultaneously on the flowers of the same panicles of the same tree. They feed on floral nectar, before or after the bees' visits. The approach of flies, butterflies and beetles to the flowers commenced from flower pedicel and they moved for nectar robbing, making no contact with stigmas. The ants continuously crawl on the flowers to make it unattractive to bees and are assumed to feed on pollen fluids, resulting in pollen damage.

Effect of insect visitation on fruitset

Bagging experiments revealed significant differences in fruitset and pollen viability of treated vs. natural open flowers (Table 4). The percentages of fruitset increased following pollination only by bees. The fruitset percentage for open pollinated flowers, although not so high, is greater than for treatments B and C (Table

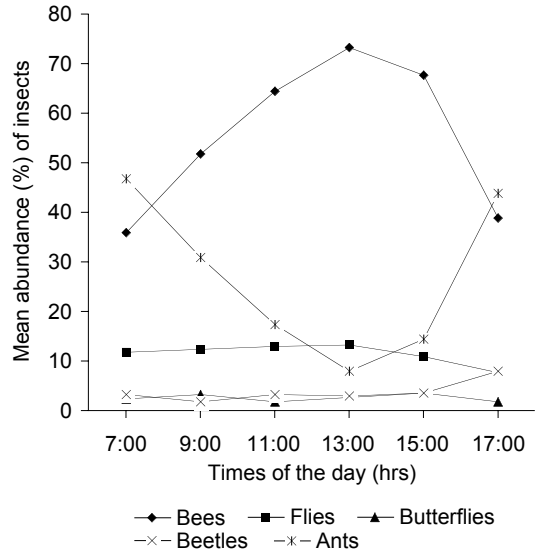


Fig. 1. Relative abundance (%) of flower visitors at different times of the day.

4), where insects were partially excluded, suggesting that the presence of insects increased fruit production. No fruitset were obtained in the treatment with continuous bagging during daytime and exposing the flowers to the visitors only at night. The percentages of fruitset and pollen viability were negligible in inflorescences where ants were allowed to forage. The viability of pollen grains was significantly different among the treated flowers. It was very low in the flowers that were accessible to ants as compared with those naturally open and accessible to bees (Table 4).

Table 4. Effect of bagging and pollination treatments on fruitset of *Anacardium occidentale*.

	Treatments						
	A	B	C	D	E	F	G
Total flowers	3485	3592	3254	3936	2960	3235	3160
Total fruitset	272	258	181	0	0	334	4
Percentage of fruitset	7.8 ^a	7.2 ^b	5.5 ^c	0	0	10.3 ^d	0.12 ^e
Percentage of viable pollen	75 ^m	77 ^m	63 ⁿ	48 ^p	76 ^m	75 ^m	26 ^q

Seven panicles, i.e. one panicle per treatment per tree (ten trees) were used. Total number of flowers per panicle varied from 295–432. Treatment codes: A = left unbagged (natural open pollination); B = exposed to visitors from 7:00–13:00 hrs; C = exposed to visitors from 13:00–17:00 hrs; D = exposed to visitors from 17:00–7:00 hrs; E = bagged continuously (autogamous self pollination); F = exposed to bees only from 9:00–13:00 hrs; G = bagged using nylon net, continuously to exclude bees and other large body insects, but to allow ants. Means followed by the same letters in columns do not differ and different letters indicate significant differences at $p \leq 0.05$, d.f. = 18.

Discussion

Floral traits, resource availability and insect visits

The flowering of *A. occidentale* gets synchronized in March–May, when it attracts abundant insect visitors (Reddi 1993). Anthesis is dependent on climatic factors and the plants' adaptability, so the flower anthesis is consistent with the results of Dafni (1992). Other floral traits of pollen productivity, P/O ratio and pollen viability may depend upon climatic factors, age, size, vigor, maturation and dispersal phase, forage behavior and possibly on physiological and biochemical characteristics corroborating the views of Allison (1990), Campbell and Halama (1993), Kearns and Inouye (1993), Marcelo and Adriana (1995), Dafni and Maues (1998), Bhattacharya and Mandal (2000), Dafni and Firmage (2000), Baez *et al.* (2002), and Montaner *et al.* (2003). Cashew flowers are not showy but they are aromatic. They offer pollen and nectar as forage to the visitors but the quantities are negligible. In spite of having a chance for self-pollen transfer due to stamen dimorphism it is believed that self-pollination does not take place as the plant is self-incompatible (Holanda-Neto *et al.* 2002). Stamen dimorphism, commonly associated with buzz-pollination, has not been recorded in this plant.

The cashew flowers are not considered to be pollen flowers with showy anthers that contain copious pollen for dispersal, which might be the characters for heteroantherous flowers. In spite of the meager floral rewards, different kinds of insects, belonging to Hymenoptera, Lepidoptera, Diptera and Coleoptera, were seen visiting the cashew flowers. Under insect enclosures, cashew flowers failed to produce fruits, but they formed fruits when the insects were allowed to forage. The bees were found to brush against the stigmas of flowers, so they clearly transfer pollen. Pollinator behaviour is markedly influenced by availability of floral rewards, especially nectar. All the insect groups that were associated with cashew flowers may not be equally effective in transferring pollen. Nectar volume and sugar concentration are most abundant in cashew flowers between 11:00 and 15:00 hrs. Nectar volumes dropped substantially by late afternoon, presuma-

bly as a result of evaporation and/or harvesting by insects. Active regulation of nectar sugar content and maintenance of constant nectar volume by the flowers was not observed in the present investigation. A steady occurrence of nectar volume and concentration between 11:00 and 15:00 hrs may increase the chance of multiple visits to a panicle by bees, leading to pollen removal from anthers and subsequent deposition on stigmas.

This investigation suggested that nectar volumes and sugar concentration may be important in relation to the variation in visiting abundance of insects, which varies from tree to tree in the orchards. The cashew orchards and wild trees which come from seedlings show great variability in floral traits among plants within the same orchard which affect cashew flower attractiveness to bees and levels of pollination received by the tree (Freitas 1995). The number of available flowers to forage; changes in habitat patch and different population dynamics may also be the factors for variability in visitation. Ants feed on nectar and other floral parts like petals, stigmas, styles, anthers and pollen. Thereby, flowers become unattractive to bees for visitation, the fed pollen grains are aborted, pollination is decreased, and finally the fruitset is reduced.

In the present study, the bagging experiment indicated that the pollen of *A. occidentale* might be damaged and its viability thus be lost due to ants, the continuous foragers of cashew flowers, consequently decreasing fruitset. It is assumed that in order to fulfill the demand of nourishment, during a nectar crisis period, the ants feed on pollen from a wide range of cashew trees. Dantas de Araujo (1994) stated that the ants are important protecting organisms against phytophagous insects in cashew inflorescences, but most pollen grains that have been fed by ants or have lost their entire liquid contents are no longer viable. Freitas (1995) and Freitas and Paxton (1998) showed that 95%–100% of pollen grains were non-viable. Thus the problem of attracting bees is accentuated by the flower-inhibiting ants, which devour the meager amounts of nectar and render the flowers less attractive and uneconomical to the bees. Ants are probably of no use as pollinators because they also look for either extra-floral secretions or honeydew secreted by aphids. Moncur and Wait (1986) doubted the

role of ants in cashew pollination and stressed the need for further investigations. Although ants were reported foraging on honeydew of aphids on cashew inflorescences (Veena & Ganeshiah 1991), yet it is believed that ants have no role in cashew pollination, rather they just damage the pollen grains. Beattie *et al.* (1985) quantified the loss of pollen viability due to ants stating that ants have metapleural glands that secrete volatile substances onto the integument that may render pollen unviable. The results suggest that association with ants could cause a reproductive trade-off for *A. occidentale*, so ant visitation to cashew flowers should be selectively discouraged.

Bees, flies, butterflies and beetles forage over short time spans with more visits in late morning to afternoon, which might be due to the higher nectar volume and sugar concentration at this time. Insect visitors may concentrate their visits during a period of high availability of floral rewards. Faegri and van der Pijl (1980) reported the same feeding behavior for insects. Raw (2000) reported that the amount of food the animal collects plays a crucial role in foraging and cross-pollination. From the bagging experiment it is clear that bees are the effective pollinating agents of cashew, this finding being in accordance with Freitas (1995) and Freitas and Paxton (1996, 1998), who reported the comparative value of introduced and native bees in cashew pollination in NE Brazil.

Effect of insect visits on fruitset

After feeding, most of the bees move to a nearby cashew tree, an ideal behavior for effective cross-pollination. A few move to other panicles of the same tree, potentially facilitating geitonogamous pollination (Lloyd & Schoen 1992, Harder & Barrett 1996). In general, the foraging behavior of bees provided opportunities for the xenogamous pollen flow, thus promoting outcrossing with a subsequent potential fruitset. The open pollinated flowers, exposed and undisturbed, set more fruits than the flowers restricted to visitors for different and limited periods. The absence of cross pollen may reduce fruit production, as the controlled self-pollinated flowers set no fruits. Bierzychudek (1981) stated that if cross-pollinated plants produce more seeds than self-pol-

linated plants, then reproduction is limited by visitor activity. More fruitset in panicles caged with introduced bees may indicate the good contribution of bees in cashew pollination. Higher fruitset of plants caged with bees as compared with those of open pollinated trees may be the effect of a higher bee density. Pollen compatibility and behavior of bees may also be factors for variation of fruitset in cashew. Holanda-Neto *et al.* (2002) suggested that low fruitset in cashew is due to self incompatibility. In conclusion, bees are the efficient pollinators of cashew and ants are not pollinating agents of cashew, rather they seriously decrease pollen viability, which may result in low cashew production.

Acknowledgements

Thanks are due to Director, NBRI, Lucknow for encouragement and CSIR, New Delhi for providing financial support in form of Research Associate award.

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