Saudi Journal of Biological Sciences (2017) **24**, 1741–1750

King Saud University

Saudi Journal of Biological Sciences

www.ksu.edu.sa
www.sciencedirect.com

ORIGINAL ARTICLE

Pollination ecology of *Acacia gerrardii* Benth. (Fabaceae: Mimosoideae) under extremely hot-dry conditions

Abdulaziz Saad Alqarni, Awad Mohamed Awad *, Hael Saeed Ahmed Raweh, Ayman Ahmad Owayss

Department of Plant Protection, College of Food and Agriculture Sciences, King Saud University, P.O. Box 2460, Riyadh 11451, Saudi Arabia

Received 22 May 2015; revised 9 September 2015; accepted 10 September 2015
Available online 21 September 2015

KEYWORDS

Acacia;
Apis mellifera;
Ants;
Flowering;
Insect visitors;
Megachilids;
Saudi Arabia;
Subtropical

Abstract Talh trees (*Acacia gerrardii* Benth.) are acacias that are native to the arid and semiarid Africa and west Asia. We investigated the flowering biology, pod set and flower visitors of Talh and discussed the role of these visitors in pollen transfer. The Talh trees blossomed laterally on the nodes of one-year-old twigs. Each node produced 21 flower buds seasonally. Each flower bud opened to a flower head (FH) of 60 florets. The bagged FHs podded significantly ($p \leqslant 0.05$) less than did the unbagged FHs. The FHs were visited by 31 insect species (25 genera, 16 families and 5 orders). The major taxa were honeybees, megachilids, butterflies, ants, beetles and thrips. Each of honeybees, megachilids and beetles showed a significant ($p \leqslant 0.05$) hourly pattern, while each of butterflies, ants and thrips had no hourly pattern ($p > 0.05$). Furthermore, some birds and mammals touched the Talh FHs. Talh trees evolved a mass flowering behavior to face pre- and post-flowering obstacles. Megachilids seemed to play the major effort of zoophily because of their relatively high numbers of individuals and species and their effective movement behavior on the FH surface. Nevertheless, honeybees and other insects and vertebrate taxa also contributed to the pollen transfer. These results greatly contribute to our understanding of the pollination ecology of acacias, especially Arabian acacias.

1. Introduction

Acacias are woody flora that are spread throughout Africa, Australia, Asia, and America and have been introduced into Europe. Acacias are key components in arid and semi-arid environments (Ross, 1981) and produce timber, fruits, fodder and some plant secondary compounds (Midgely and

* Corresponding author. Cell: +966 560467433; fax: +966 114678366.
E-mail address: amawad@ksu.edu.sa (A.M. Awad).
Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.sjbs.2015.09.019
1319-562X

Turnbull, 2003). Acacias are used in traditional medicine worldwide (Ross, 1981), contribute to biomass and support the diversity of invertebrate and vertebrate herbivores (Kruger and McGavin, 1998).

Approximately 16 acacia species are indigenous to the Arabian Peninsula, and other species have been introduced from Australia and Mexico. Acacias are used as animal forage, fodder, and honeybee forage among others (Aref et al., 2003) and are considered the most successful survivors in arid regions (Ibrahim and Aref, 2000).

Talh trees (*Acacia gerrardii*) are native to the subtropical environments in Africa and west Asia (Dharani, 2007). These trees are considered among the most widespread acacias in the Arabian Peninsula (at least in the Saudi area) and provide people with shade and fodder, provide domestic animals with feed, and provide honeybees with nectar and pollen (Aref et al., 2003). From the flowers of *A. gerrardii,* honeybees produce one of the most desirable honeys in Saudi Arabia (Al-Khalifa and Al-Arify, 1999). Talh is the Arabic name for *A. gerrardii* and was used in this study (Bahaffi and Al-Lihaibi, 2005). Talh honey is one of the most consumed honeys in Saudi Arabia. Many beekeepers collect Talh honey from late July-early August each year.

The pollination ecology of acacias has been relatively well studied in Australia (Ford and Forde, 1976; Bernhardt and Walker, 1984; Bernhardt et al., 1984; Knox et al., 1985; Bernhardt, 1987; Vanstone and Paton, 1988; Sedgley et al., 1992; Sedgley and Harbard, 1993; Jusaitis et al., 2009; Gibson et al., 2011) and somewhat in Africa (Tybrik, 1989, 1993; Kruger and McGavin, 1998; Stone et al., 1996; Stone et al., 1998; Fleming et al., 2006, 2007) and America (Baranelli et al., 1995). However, this ecology has either been sparsely or not at all studied elsewhere (Stone et al., 2003). Although acacias are the major flora species in the Arabian Peninsula, their pollination ecology, flowering biology, pod set and flower visitors have not been explored.

The aim of this study was to investigate the flowering biology, pod set and flower visitors of Talh trees. This study is part of a research project that explores the nectar secretion dynamics and pollination ecology of Talh trees and the interaction of these trees with honeybees.

2. Materials and methods

2.1. Study region

Field investigations were performed in Rawdhat–Khoraim oasis, a naturally preserved area in central Saudi Arabia. This lies approximately 25°32′ North and 47°17’ East and is 1817 feet above sea level. This region is extremely hot-dry during the summer and is relatively cold during the winter. Talh (*A. gerrardii*) trees constitute a prime tree population among many tree species. In general, the plant cover is rich compared to the surrounding desert (Alfarhan, 2001). Talh trees in the study region depend on surrounding estuaries during the autumn, winter and spring. The field investigations were repeated in 2011 and 2012 to generate more realistic general mean values. Laboratory tasks were performed in the labs and museum of the Plant Protection Department, King Saud University, Riyadh, Saudi Arabia.

2.2. Tested plants

Five random Talh trees, all of reproductive age, were randomly selected. These trees were studied for two years. The selected trees were labeled with plastic tags that were fixed onto their trunks. These trees were unprotected and therefore reachable to all potential flower visitors.

2.3. Flowering biology

Fifteen nodes were randomly selected from each selected tree in April 2011 and 2012. The nodes were selected from one-year-old twigs because Talh trees blossoms on twigs of this age. The nodes were labeled using small plastic tags that were fixed with a piece of metallic thread and were observed weekly from April-August 2011 and 2012. The flower buds that budded on the selected nodes were counted, documented and cut. The total number of yearly flower buds of each selected flowering node was calculated. The described methods were improved from those of Baranelli et al. (1995) and Adgaba et al. (2012).

Twenty flower heads (FHs) were selected and cut from each selected tree during the mid-bloom season (July) in 2011 and 2012. The florets of each selected FH were counted to document the number of florets per FH (Baranelli et al., 1995; Fleming et al., 2007). Each counted floret was immediately removed to avoid double counting because the FH of Talh is composed of very condensed florets.

2.4. Pod set

Two flowering twigs (one-year-old) were randomly selected from each selected tree in late April when the first flower buds appeared. The selected twigs were at least three meters above ground to be unreachable by camels (Fleming et al., 2007), which are common in the study area during the flowering season. From each selected twig, 10 flowering nodes were selected, and the remaining nodes were removed using a sharp cutter. One of the two selected twigs at each selected tree was bagged using pollination bags (made of bridal veil), while the other was unbagged. The purpose of this procedure is to compare the pollinator-accessed (unbagged) and the pollinator-unaccessed (bagged) twigs. The selected pollinator-unaccessed (P-unaccessed) and pollinator-accessed (P-accessed) twigs were labeled using small plastic tags that were bound with metallic threads. The selected twigs were checked weekly to ensure that no damage occurred, and the bags did not directly touch the FHs. After the bloom season in late August, the number of pods at each selected node were counted and documented. The ratios of the pods/flowering node and pods/FH were calculated. The average ratio of buds per node of each selected tree was treated as the number of FHs per each selected node of the same tree. This procedure was used assuming that all the flower buds opened and produced FHs.

The described procedures were applied twice: in 2011 and 2012. These procedures were modified from those previously described (Sedgley et al., 1992; Baranelli et al., 1995; Raju and Rao, 2002; Jusaitis et al., 2009). Generally, these experiments were designed to document the pod set percentage of Talh FHs and to compare the percentages of each P-accessed and P-unaccessed FH. Consequently, the contribution of insect pollination was evaluated.

2.5. Insect visitors

Two trapping methods were used to catch the pollinating insect taxa: modified long hand sweeping nets and a modified hand-picking procedure. The caught insects were killed, pinned and carded and were identified at the King Saud Museum of Arthropods (KSMA).

2.5.1. Sweeping

The active flying insect visitors of the selected trees were swept using a modified sweeping net that was approximately 3 meters long. The sweep net was used carefully and did not touch the swept tree, otherwise the net could snag on the spines. This process was performed during the mid-bloom season of Talh trees in July 2012 and 2013. The sweeping was performed three times: forenoon, noon and afternoon (730 h, 1130 h and 1530 h). The sweeping lasted for 10 min at each selected daytime and at each selected tree. The caught insects were killed using ethyl acetate, mounted, carded and prepared for identification. These methods were modified from those of Bernhardt (1987), Sedgley et al. (1992), Kruger and McGavin (1998), Stone et al. (1998) and Fleming et al. (2007).

2.5.2. Picking

A simple modified picking procedure was used to collect three insect groups visiting Talh FHs. These groups are ants, beetles and thrips. A total of 20 FHs were shaken with the fingers directly into an opened killing jar. Each shaken FH was immediately cut and put on the same killing jar. The selected FHs and their insect contents were left inside the killing jar for a few minutes to ensure that all the insects were killed. The selected FHs were inspected, and the above mentioned three groups were isolated, mounted, carded and prepared for the identification. The described work was performed at each selected daytime and for each selected tree. The same investigation was performed in 2011 and 2012.

The caught insect groups were wingless (ants) or long-resting inside the FHs (beetles and thrips). Therefore, these insects cannot be caught using sweeping methods. These procedures were modified from those Bernhardt (1987), Sedgley et al. (1992), Kruger and McGavin (1998), Stone et al. (1998) and Fleming et al. (2007).

2.5.3. Insect identification

The caught insects were sent to KSMA, King Saud University, Riyadh, Saudi Arabia. These insects were identified to the species, genus or family level when possible. A list of the collected taxa was prepared. The three groups of swept insects, including honeybees, megachilids and butterflies, were counted and documented. The other three groups of picked insects, including ants, beetles and thrips, were also counted and documented.

2.6. Avian visitors

The birds resting, nesting or feeding on Talh trees were observed with the naked eye. These birds were observed during the flowering season of Talh trees in 2011 and 2012. The birds' behaviors on the Talh trees and their interaction with the FHs were explored and described according to Fleming et al. (2007). A bird expert identified the bird species.

2.7. Mammalian visitors

Rawdhat–Khoraim oasis is a preferred grazing site for goats, sheep and camels. The interactions of these species with the Talh FHs were observed in 2011 and 2012. The role of these mammals in the pollination of Talh trees was documented (Fleming et al., 2006, 2007).

2.8. Data processing and statistical analysis

Data were documented in Excel 2013. This software was used to calculate the ratios and mean values and to design the charts. The insect visitor's investigations had completely randomized blocks designs, while the pod set determination had a completely randomized design. The obtained data were statistically tested and analyzed using SPSS (Statistical Package for the Social Sciences) 21®. The Kolmogorov–Smirnov and Levene tests were used to check the obtained data for normality and homogeneity of variances, respectively. The variances among the mean values were tested using ANOVA.

3. Results

3.1. Flowering biology

Talh trees blossomed laterally on one-year-old twigs. The nodes of such twigs produced flower buds (FBs). Consequently, in this study, these nodes were called "flowering nodes." These flowering nodes (FNs) gave their FBs during the bloom season gradually from late April until early August. The FN produced 21 ± 2.5 FBs/FN/blooming season. The tested trees showed significant ($p \leqslant 0.05$) variations within a range of 18–24 FBs/FN/BS.

The FB began as small, spherical and green with a very short pedicel and grew gradually in size and pedicel length until it was clearly yellowish with a long pedicel one day before opening. The FB opened around dawn, producing FH. The FH was whitish yellow in color and globose in shape. The FH had a condensed mean of 60 ± 2.4 min florets. The florets of a FH began to open at dawn and were totally opened within approximately one hour. The tested trees showed significant ($p \leqslant 0.05$) differences in the number of florets/FH with mean values ranging from 56–65 florets/FH. Two extrafloral nectaries (EFNs) were observed on each compound leaf, secreting a droplet of sticky extrafloral nectar especially in the morning.

3.2. Pod set

The unbagged FNs fruited 2.22 ± 0.15 pods/FN, which significantly ($p \leqslant 0.05$) decreased to 1.81 ± 0.13 pods/FN in the bagged FNs. The unbagged FNs fruited 3.49 ± 0.42 pods/100 FBs, while this value significantly ($p \leqslant 0.05$) decreased in the bagged FNs to 2.85 ± 0.35 pods/100 FBs. (Fig. 1). The fruited percentage of pods per FB of the bagged FNs was significantly ($p \leqslant 0.05$) less than that of the unbagged FNs during (Fig. 2).

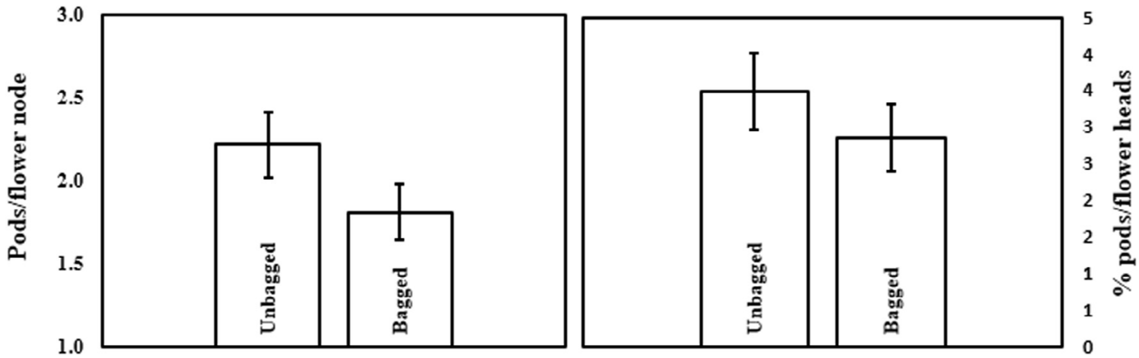

Figure 1 Pod set rates (mean ± SE) of Talh trees (*Acacia gerrardii*) in the pollinator-accessed (unbagged) and pollinator-un-accessed twigs during subtropical summers in Rawdhat–Khoraim oasis, Riyadh, Saudi Arabia.

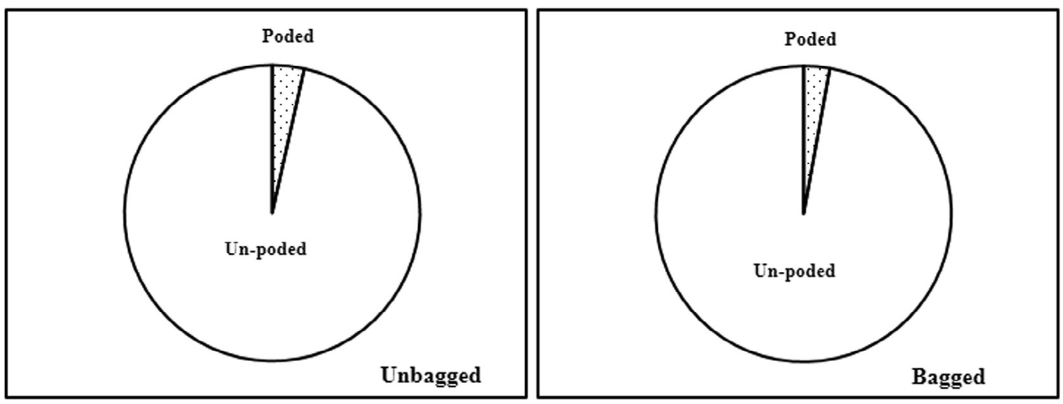

Figure 2 Pod set rates (total ratios of podded and un-podded flower heads {FHs}) of Talh trees (*Acacia gerrardii*) in the pollinator-accessed (unbagged) and pollinator-un-accessed twigs during subtropical summers in Rawdhat–Khoraim oasis, Riyadh, Saudi Arabia.

3.3. Insect visitors

The FHs were visited by many insect species shortly after their opening at dawn until withering around sunset. We observed wide variations in the target diet (pollen, nectar, flower organs or insect-preys) of these insects when feeding on Talh FHs.

There were 31 insect species belonging to approximately 25 genera, 16 families and 5 orders. The most numerous visiting species were hymenopterans. Formicidae was the most species-rich family to visit Talh FHs, with five species (Table 1).

3.3.1. Swept insect visitors

The major swept taxa visiting the Talh FHs were honeybees, megachilids and butterflies. Interesting variations were noticed among the swept taxa, daytimes and years. The observed taxa fed specifically on one or more of the following: pollen, nectar, flower organs, and FBs. The species can be organized in descending order sorted as honeybees, megachilids and butterflies. They were sorted according to the significant ($p \leqslant 0.05$) differences in their general mean values. The honeybees (two species) contributed solely more than did the megachilids and butterflies combined, contributing between half and two-thirds of the total number of the major swept taxa. The butterflies (more than one species) contributed to approximately ten percent of the major swept taxa (Fig. 3).

The honeybees (*Apis mellifera* and *Apis florea*) gave a general mean of 7.6 ± 1.1 bees/10 sweeping minutes. The honeybees visited Talh FHs with significantly ($p \leqslant 0.05$) larger numbers at forenoon and in the afternoon (9.1 ± 1.2 and 11.4 ± 2.5, respectively) than at noon (2.3 ± 0.4). The swept honeybees at forenoon or in the afternoon were 3–5 times more numerous than were the swept ones at noon (Fig. 4). The honeybees visited the EFNs in low numbers and their visits increased after the flowering season.

The megachilid bees that visited the Talh trees were *Chalicodoma riyadensis, Megachile amabilis, Megachile* sp.1 and *Megachile* sp.2. These bees foraged on Talh FHs with a general mean of 3.7 ± 0.6 bees/10 sweeping minutes. Their foraging was significantly ($p \leqslant 0.05$) greater at forenoon (6.6 ± 1.2 bees/10 sweeping minutes) than at noon and in the afternoon (2.9 ± 0.5 and 1.6 ± 0.5 bees/10 sweeping minutes). The megachilid bees foraged at forenoon in numbers two and four times greater than at noon and in the afternoon, respectively (Fig. 4). These megachilids gathered pollen from the FHs using their scopa with fast movements around the FHs.

The swept butterflies were two gossamer-winged butterfly species belonging to Lycaenidae, including *Lampides boeticus* and another unidentified species. The butterflies visited the Talh FHs at a general mean of 1.3 ± 0.2 BFs/ 10 SMs. The butterflies' foraging peak came around forenoon with a mean that was not significantly ($p > 0.05$) greater than that at the other measured daytimes (Fig. 4).

Table 1 The insect visitors of the Talh tree (*Acacia gerrardii*) flower heads (FHs) during the summer seasons of 2011–2012 in Rawdhat–Khoraim oasis, Riyadh, Saudi Arabia. (P) refers to the picked insects, while (S) refers to the swept insects.

Order	Family	Species	Trapping
Coleoptera	Anthicidae	*Omonadus floralis*	P
	Chrysomelidae	*Chaetocnema pulla*	P
		Tituboea sp.	P
	Dermestidae	*Anthrenus verbasci*	P
		Attagenus posticalis	P
		Attagenus sp.	P
	Melyridae	*Malachius* sp.	P
	Scarabaidae	*Pentaria* sp.	P
Diptera	Bombyliidae	*Hemipenthes* sp.	S
	Chloropidae	Species 1	S
		Species 2	S
	Apidae	*Apis florea*	S
		Apis mellifera	S
Hymenoptera	Carbonidae	*Cerceris tricolorata*	S
	Formicidae	*Camponotus sericeus*	P
		Cataglyphis arenarius	P
		Cataglyphis edinensis	P
		Monomarium sp.1	P
		Monomarium sp. 2	P
	Halictidae	*Cgylalictus punjabensis*	S
		Lasioglossum sp.	S
		Palaruslaetus	S
	Megachilidae	*Chalicodoma riyadhense*	S
		Megachile amabilis	S
		Megachile decosa	S
		Megachile sp.	S
	Sphecidae	*Sphex pruinosus*	S
	Vespidae	*Chlorodymerus chlorofiens*	S
Lepidoptera	Lycaenidae	*Lampides boeticus*	S
		Species 1	
Thysanoptera	Unidentified	Species 1	P

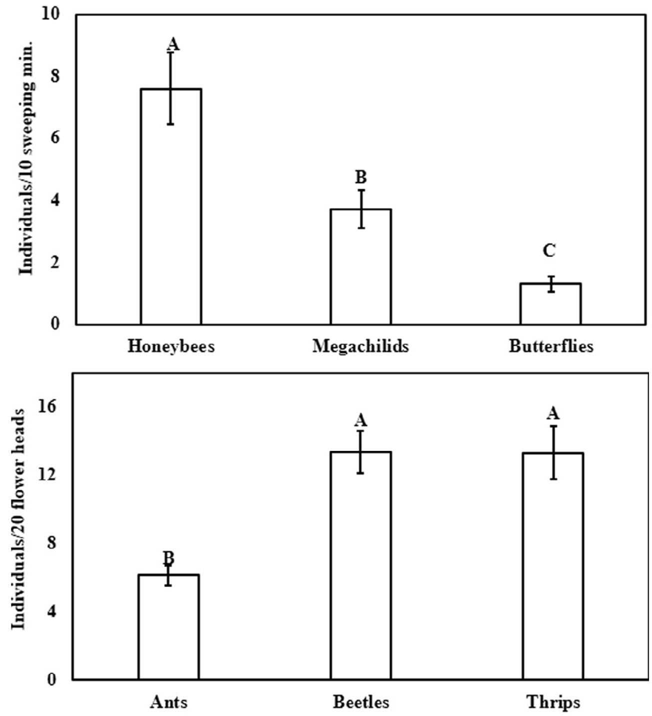

Figure 3 Seasonal averages (mean ± SE) of the total swept and picked insect individuals visiting flower heads (FHs) of Talh trees (*Acacia gerrardii*) during subtropical summers in Rawdhat–Khoraim oasis, Riyadh, Saudi Arabia. *The mean values with the same letter in the same bar chart are not significantly ($p > 0.05$) different.

The peak number of the total swept individuals was recorded at forenoon. The mean significantly ($p \leqslant 0.05$) decreased at noon (Fig. 5). Every major swept taxa showed slight differences between 2011 and 2012. Additionally, similar differences were recorded between the total number of swept individuals between 2011 and 2012. However, these variations were not significant ($p > 0.05$).

The swept insects included 17 species belonging to approximately 14 genera, 9 families and 3 orders. Hymenoptera was the most frequent order, and Megachilidae was the most frequent family visiting the Talh FHs among the swept families. Four megachilid species belonging to two genera were swept from the Talh FHs (Table 1).

3.3.2. Picked insect visitors

The general picked insect mean was 32.8 individuals/20 FHs. The peak number was picked at noon with significantly higher numbers than those that were picked at forenoon or in the afternoon (Fig. 5). The major picked taxa were ants, beetles and thrips. The beetles contributed the largest percent at 41%. The thrips came second without significant ($p > 0.05$) differences. The ants were significantly the least picked taxon with only 19% (Fig. 3).

The ant visitors of Talh FHs were *Camponotus sericeus, Cataglyphis edinensis, C. arenarius* and two *Monomarium* species. The ants foraged on the FHs and EFNs. Although the ants do not have a long proboscis, they were observed reaching the deep nectar. The ants sucked from the surfaces of the EFNs. The small ant species inserted their bodies completely inside the FH, while the large species pushed their heads down between the florets to get the nectar. The ants foraged over the tree leaving obvious tracks on the tree trunk and collected resin and extrafloral nectar in addition to foraging on the FHs. The picked ants foraged constantly throughout the day without significant ($p > 0.05$) differences between the day-times. The picked ants mean was 6.1 ± 0.6 ants/20 FHs, i.e., approximately 1 ant/4 FHs (Fig. 6).

The picked beetles are listed in Table 1. These beetles rest inside and between the florets. The dermestid beetles fall down if they are interrupted (thanatosis). The beetles aggregated collectively (more than one species inside the same FH), and the peak number of picked beetles occurred at noon with approximately 1 beetle/1 FH (19 individual/20 FHs). Their abundance decreased in the afternoon (Fig. 6).

The picked thrips belong to an unidentified species and were found inside and between the florets. Their general mean was 13.3 ± 1.6 individual/20 FHs. The thrips aggregated inside some of the FHs. Their numbers changed insignificantly ($p > 0.05$) throughout the day (Fig. 6).

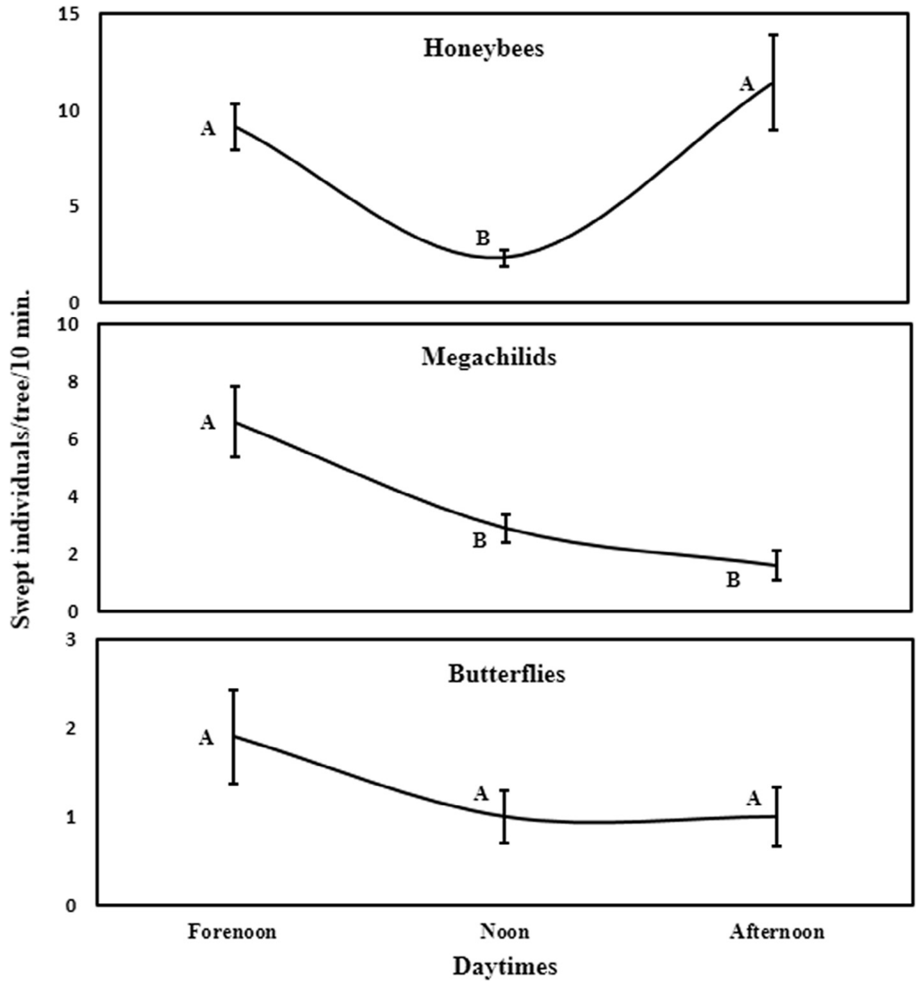

Figure 4 Hourly rates (mean ± SE) of the major swept insect taxa visiting flower heads (FHs) of Talh trees (*Acacia gerrardii*) during subtropical summers in Rawdhat–Khoraim oasis, Riyadh, Saudi Arabia. *The mean values with the same letter in the same line chart are not significantly ($p > 0.05$) different.

The picked insects included 14 species belonging to 11 genera, 7 families and 3 orders. Coleoptera and Formicidae were the most frequent order and family, respectively (Table 1).

3.4. Avian visitors

The avian visitors of the Talh trees and their visiting behaviors are documented in Table 2.

3.5. Mammalian visitors

Camels, sheep and goats contacted Talh FHs during their grazing. These livestock animals eat hall twigs, leaves, FHs and dropdown FHs. Some rodent species contacted the Talh FHs during their movements.

4. Discussion

Talh trees (*A. gerrardii*) evolved a mass flowering behavior with a huge number of FHs/tree and a huge number of florets/FH. Consequently, these trees have a law pod set rate. Zoophily is significantly present in the pollination of the studied species. Self-pollination or anemophily are most likely present. The flower visitors play a significant role in enhancing the pod set. Some wind and self-pollination may occur. These trees recruit insects, birds and mammals.

The data show a mass flowering behavior in the Talh trees. These results confirm the recent findings of Awad et al. (in press), who demonstrated a yield of 148 ± 14 FHs/m^2/day in the same species. Our obtained number of florets per FH in *A. gerrardii* (60 florets/FH) is similar to that of *A. nilotica* (92 floret/FH) and *A. senegal* (84 florets/FH) (Stone et al., 2003). These three species are present in Africa and the Arabian Peninsula. Talh trees seem to have evolved a mass flowering behavior in response to encountering many reproductive obstacles during their reproduction. This evolutionary context could be explained by three findings from this study: the extremely low pod set percentage in the naturally pollinated (unbagged) FHs, the high number of species and individuals of the non-pollinating visitors of the FHs (ants, beetles, thrips, birds, and mammals); although these visitors could serve somewhat in the cross pollination, they are not pollination specialists (Stone et al., 2003), and the serious infection of the seed with the bruchid beetles observed in the field study. In conclusion, the tree faces pre- and post-fruiting obstacles that are

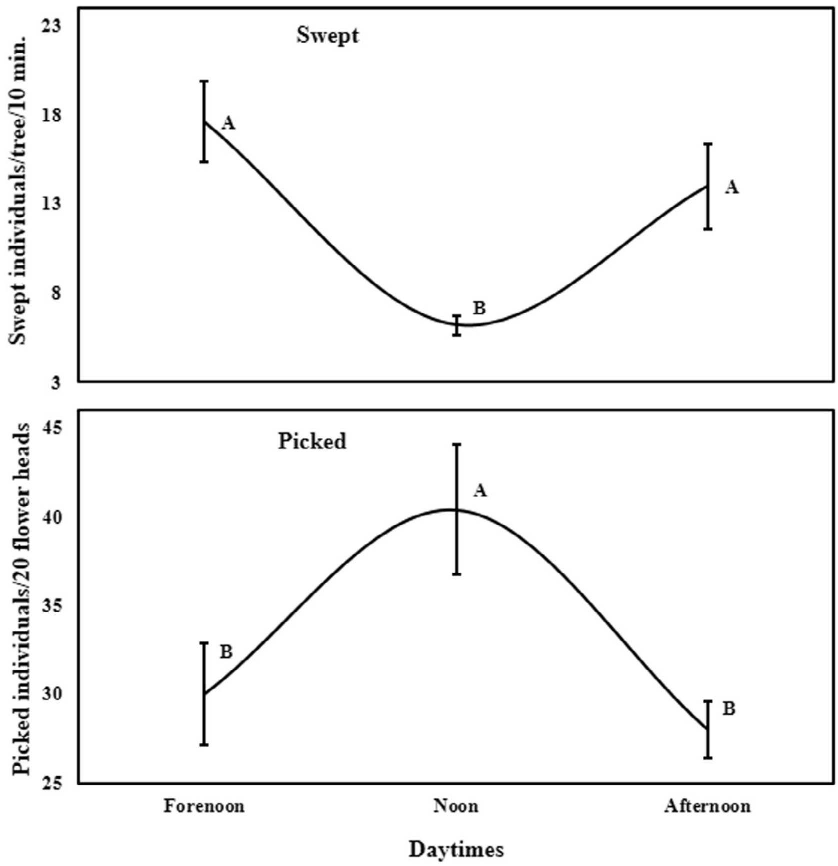

Figure 5 Hourly rates (mean ± SE) of the total swept and picked insect individuals visiting flower heads (FHs) of Talh trees (*Acacia gerrardii*) during subtropical summers in Rawdhat–Khoraim oasis, Riyadh, Saudi Arabia. *The mean values with the same letter in the same line chart are not significantly ($p > 0.05$) different.

expected to have driven the species to evolve a mass flowering behavior (this aspect has been discussed by Baranelli et al. (1995). Awad et al. (in press) illustrated the mass flowering behavior of Talh trees as an evolutionary defense because the tree is threatened by many factors during its reproduction. Stone et al. (2003) referred to the mass flowering behavior in acacias and suggested the FHs themselves could represent a reward for pollinators. Therefore, some large mammals and birds feed directly on some FHs and pollinate others.

The low pod set rate of Talh trees (in the unbagged twigs) has long been demonstrated in acacias. The low pod set rate has been stated in *A. caven* (Baranelli et al., 1995), *A. sinuata* (Raju and Rao, 2002) and *A. whibleyana* (Jusaitis et al., 2009).

The significant decrease in the pod set rate in the bagged FHs strongly demonstrates the role of zoophily in the pollination of Talh trees. The most frequent visitors of Talh FHs from thrips to mammals boost zoophily (Bernhardt, 1987). Similar findings have been previously published (Fleming et al., 2007). The nectar richness of Talh FHs that was reported by Awad et al. (in press) supports our conclusion of zoophily in Talh trees. Two groups of the swept insects (honey and megachilid bees) likely play primary roles in pollen transfer because of their long distance flying behavior compared to the other groups, which rarely move between trees. In addition, these bees (honey and megachilid bees) are specialist pollinators, while the picked insects (beetles, ants, and thrips) are mostly flower threats. Baranelli et al. (1995) stated that *A. caven* involves a great sacrifice of floral resources, which is also likely to be present in *A. gerrardii*.

Melittophily seems to play a main role among zoophilies because of the large number of species and individuals that were observed visiting Talh FHs. Additionally, bees are the most frequent pollination specialists among the visitors of Talh FHs. Bees can get the deep nectar of Talh trees. The melittophily in nectar-rich acacias has been observed by Raju and Rao (2002) and has been stated for Australian acacias in general (Bernhardt, 1987).

Our data suggest that Talh FHs are megachilid-pollinated FHs because the most bee species visit Talh FHs. Additionally, the pollen-gathering behavior of megachilids on the spherical FHs of Talh trees is likely to be more effective than honeybee behavior in pollen transformation. The megachilids somersault around the FH surface and skim rapidly over the anthers. The specialty of megachilids on acacias has been suggested by Tybirk (1989) and Stone et al. (2003). The nectar-rich dense FHs of Talh trees are likely to recruit the great megachilids (e.g., *Megachile amabilis*) because these bees are energetically restricted to such flowers. This fact has been demonstrated in acacias (Heinrich and Heinrich, 1983; Bernhardt and Walker, 1984).

Butterflies reach the deep nectar with their long proboscis. However, we believe that psychophily does not play an important role in the pollination of Talh FHs. Only two species of butterflies, unlike bees, have been recorded and in relatively

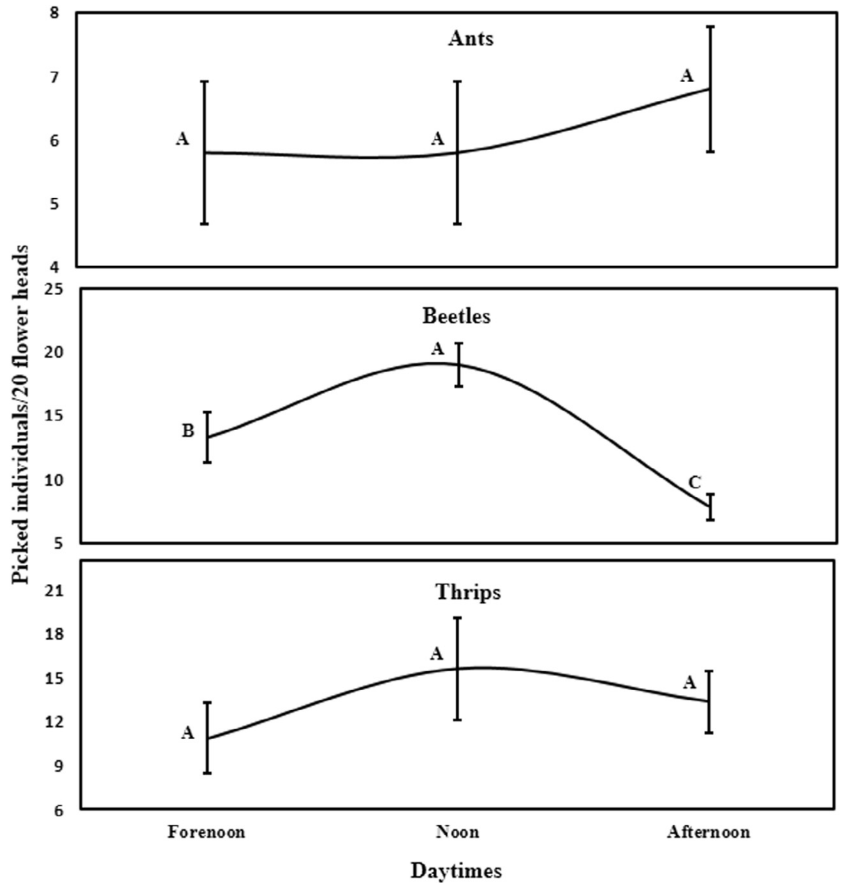

Figure 6 Hourly rates (mean ± SE) of the major picked insect taxa visiting flower heads (FHs) of Talh trees (*Acacia gerrardii*) during subtropical summers in Rawdhat–Khoraim oasis, Riyadh, Saudi Arabia. *The mean values with the same letter in the same line chart are not significantly ($p > 0.05$) different.

Table 2 The avian visitors of Talh trees (*Acacia gerrardii*) during the flowering season (summer 2011–2012) in Rawdhat–Khoraim, Riyadh, Saudi Arabia.

Common name	Scientific name	Family	Visitation behavior
Eurasian collared dove Black scrub robin	*Streptopelia decaocto* *Cercotrichas podobe*	Columbidae Muscicapidae	Nesting and resting inside tree canopy and directly contacting the FHs
White-eared bulbul White-spectacled bulbul	*Pycnonotus leucotis* *Pycnonotus xanthopygos*	Pycnonotidae Pycnonotidae	Nesting, resting and feeding (on flower heads (FHs), ants and other insects) inside the tree canopy. Directly contacting some FHs while eating some others
House sparrow Eurasian blackcap	*Passer domesticus* *Sylvia atricapilla*	Passeridae Sylviidae	Nesting, resting and feeding (on ants and other insects) inside the tree canopy. Directly contacting the FHs
Palestine sunbird	*Cinnyris osea*	Nectariniidae	Nesting, resting and feeding (on nectar and some insects) inside the tree canopy and directly contacting the FHs

lower numbers. Butterflies are also not true pollinators because they feed only on nectar and transform pollen accidently (Stone et al., 2003).

Ants present little pollen transfer service in Talh trees because ants are not pollination specialists. No lepidopteran infection was observed on Talh leaves during the flowering season, which could demonstrate ant-guarding behavior on acacias, although this behavior needs to be tested.

Beetles are unlikely to serve as effective pollinators in Talh or in acacias in general (Stone et al., 2003). The beetles visiting Talh FHs are clearly different than the beetles that have been caught from other acacias (Tybirk, 1989, 1993; Willmer and Stone, 1997; Tandon et al., 2001). This result could be interpreted in a bio geographical context.

Birds may play a significant role in transferring pollens for long distances (Stone et al., 2003). Ornithophily has long been documented in flowering plants (Stiles, 1978). Our ornithophily hypothesis in Talh trees agrees with previous observations in acacias (Ford and Forde, 1976; Knox et al., 1985; Vanstone and Paton, 1988).

The pollination service by mammals has been suggested in acacias. Giraffes serve as pollinators in *Acacia nigrescens* (Du Toit, 1990). Camels might serve similar to giraffes because these animals are similar in body shape and in feeding behavior. If camels act as pollinators for high branches, smaller livestock animals (sheep and goats) might act as pollinators for branches closer to the ground. In contrast, Fleming et al. (2006, 2007) demonstrated a negative role for angulate mammals in the pollination of *A. nigrescens*. The role of such mammals in the pollination of acacias needs further study (Stone et al., 2003).

The significant diurnal pattern variations of the insect visitors of Talh FHs could be easily argued to coincide with the variations in the nectar secretion rate, pollen release time (Stone et al., 2003), temperature and relative humidity (Raju and Rao, 2002). Our results counteract those of Fleming et al. (2007), who stated no diurnal significant pattern in the flower visitation of *A. nigrescens*, possibly due to different weather conditions. Our study was conducted in an extremely dry-hot region, especially in the afternoon. The temperature and relative humidity at noon are 42 °C and 9%, respectively (the Weather Underground web site).

Despite the results of this present study, some issues require further investigation. Many previous studies have dealt with the EFNs of acacias (e.g., Bernhardt and Walker, 1984). In this study, EFNs were present, and honeybees and ants visited them. However, their nectar secretion dynamics and roles in pollinators recruiting and in ant repelling are interesting ecological insights that require better understanding. In general, the quantity and quality of the nectar that is secreted by these glands is unknown for the majority of acacia species (Stone et al., 2003). The interactions among the different flower visitors of Talh need to be studied in more detail. The remaining Arabian acacias still need to be tested for their pollination ecology.

A wide range of flower visitors seems to contribute to pollen transfer in one plant species. Insects, birds and mammals might contribute in various quantitative and qualitative pollination efforts. These results will greatly assist in understanding the pollination ecology of the Arabian acacias and of worldwide acacias in general.

Talh trees are mass flowering acacia with a huge number of FHs on each tree and a huge number of florets on each FH. These trees have fruit pods that are open-pollinated more often than are unopened-pollinated, providing conclusive evidence that zoophily significantly and positively affects the pollination of Talh trees. This zoophily could be performed with insects, birds or mammals. Talh trees seem to be megachilid-pollinated trees, although other visitors might also contribute. This conclusion depends on the large number of species and individuals and the pollen-gathering behavior of the megachilids visiting these trees.

Acknowledgments

This Project was funded by the National Plan for Science, Technology and Innovation (MAARIFAH), King Abdulaziz City for Science and Technology, Kingdom of Saudi Arabia, Award Number (12-AGR2510-02). Thanks to the members of the King Saud Museum of Arthropods (KSMA) for their valuable assistance in insect identification, and to Mr. Mohamed Gamal for birds identification. Great help was given by the beekeepers Mr. Faiz Ergaf and Mr. Mohamed Assodi during the field work.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.sjbs.2015.09.019.

References

Adgaba, N., Awad, M.A., Al-Ghamdi, A., Alqarni, A.S., Radloff, S. E., 2012. Nectar of Ziziphus spina-christi (L.) Wild (Rhamnaceae): Dynamics of secretion and potential for honey production. In: J. Apicult. Sci. 56, 5–15.

Alfarhan, A.H., 2001. A floristic account on Raudhat Khuraim Central Province Saudi Arabia. Saudi J. Biol. Sci. 8, 80–103.

Al-Khalifa, A.S., Al-Arify, I.A., 1999. Physicochemical characteristics and pollen spectrum of some Saudi honeys. Food Chem. 67, 21–25.

Aref, M.I., Elkhalifa, K.F., El-Juhany, L.I., 2003. A dendrological key identification of *Acacia* species growing in Saudi Arabia and Northrn Sudan. J. King Abdulaziz Univ. Meteorol. Environ. Arid Land Agric. Sci. 14, 87–94.

Awad, M.A., Owayss, A.A., Alqarni, A.S., in press. Evaluation of *Acacia gerrardii* Benth. (Fabaceae: Mimosoideae) as a honey plant under extremely hot-dry conditions: Flowering phenology, nectar yield and honey potentiality. J Anim Plant Sci.

Bahaffi, S.O., Al-Lihaibi, S.S., 2005. Determination of volatile organic compounds in local honey by Gas Chromatography-Mass Spectrometry. Commun. Fac. Sci. Univ. Ank. Series B V 51 (2), 1–12.

Baranelli, J.L., Cocucci, A.A., Anton, A.M., 1995. Reproductive biology in Acacia caven (Mol.) Mol. (Leguminosae) in the central region of Argentina. Bot. J. Linn. Soc. 119, 65–76.

Bernhardt, P., 1987. A comparison of the diversity, density and foraging behaviour of bees and wasps on Australian *Acacia*. Ann. Mo. Bot. Gard. 74, 42–50.

Bernhardt, P., Kenrick, J., Knox, R.B., 1984. Pollination biology and the breeding system of *Acacia retinodes* (Leguminosae: Mimosoideae). Ann. Mo. Bot. Gard. 74, 42–50.

Bernhardt, P., Walker, K., 1984. Bee foraging on three sympatric species of Australian *Acacia*. Int. J. Entomol. 26, 322–330.

Dharani, N., 2007. Field guide to acacias of East Africa, 1st ed. Struik Random House Publishers, Cape Town, South Africa.

Du Toit, J.T., 1990. Giraffe feeding on *Acacia* flowers: predation or pollination? Afr. J. Ecol. 28, 63–68.

Fleming, P.A., Hofmeyr, S.D., Nicolson, S.W., 2007. Role of insects in the pollination of *Acacia nigrescens* (Fabaceae). S. Afr. J. Bot. 73 (1), 49–55.

Fleming, P.A., Hofmeyer, S.D., Nicolson, S.W., Du Toit, J.T., 2006. Are giraffes pollinators or flower predators of *Acacia nigrescens* in Kruger National Park, South Africa? J. Trop. Ecol. 22, 1–7.

Ford, H.A., Forde, N., 1976. Birds as possible pollinators of *Acacia pyncnatha*. Aust. J. Bot. 24, 793–795.

Gibson, M.R., Richardson, D.M., Marchante, et al., 2011. Reproductive biology of Australian acacias: important mediator of invasiveness? Diversity and Distributions 17 (5): 911-933.

Heinrich, B., Heinrich, M.J.E., 1983. Heterothermia in foraging workers and drones of the bumblebee, *Bombus terricola*. Physiol. Zool. 56, 563–567.

Ibrahim, A.A.M., Aref, I.M., 2000. Host status of thirteen *Acacia* species to *Meloidogyne javanica*. J. Nematol. 32 (45), 609–613.

Jusaitis, M., Sorensen, B., Polomka, L., 2009. Population structure, flowering and seed production in the endangered whibley wattle, *Acacia whibleyana* (Leguminosae: Mimosoideae). Open Conserv. Biol. J. 3, 4–13.

Knox, R.B., Kenrick, J., Bernhardt, P., Marginson, R., Beresford, G., Baker, I., Baker, H.G., 1985. Extrafloral nectaries as adaptations for bird pollination in *Acacia terminalis*. Am. J. Bot. 72, 1185–1196.

Kruger, O., McGavin, G.C., 1998. The insect fauna of *Acacia* species in Mkomazi Game Reserve, north east Tanzania. Ecol. Entomol. 22, 440–444.

Midgely, S.J., Turnbull, J.W., 2003. Domestication and use of Australian acacias: case studies of five important species. Aust. Syst. Bot. 16, 89–102.

Raju, A.J.S., Rao, S.P., 2002. Pollination ecology and fruiting behavior in *Acacia sinuata* (Lour.) Merr. (Mimosaceae), a valuable non-timber forest plant species. Curr. Sci. India 82, 1466–1471.

Ross, J.H., 1981. An analysis of the African *Acacia* species: their distribution, possible origins and relationships. Bothalia 13, 389–413.

Sedgley, M., Harbard, J., Smith, R.M.M., Wickneswari, R., Griffin, A. R., 1992. Reproductive biology and interspecific hybridization of *Acacia mangium* and *Acacia auriculiformis* A. Cunn. ex Benth (Leguminosae, Mimosoideae). Aust. J. Bot. 40 (1), 37–48.

Sedgley, M., Harbard, J., 1993. Pollen storage and breeding system in relation to controlled pollination of four species of *Acacia* (Leguminosae, Mimosoideae). Aust. J. Bot. 40, 601–609.

Stiles, G.F., 1978. Ecological and evolutionary implications of bird pollination. Am. Zool. 18 (4), 715–727.

Stone, G.N., Raine, N.E., Prescott, M., Willmer, P.G., 2003. Pollination ecology of acacias (Fabaceae, Mimosoideae). Aust. Syst. Bot. 16, 103–118.

Stone, G.N., Willmer, P., Rowe, J.A., 1998. Partitioning of pollinators during flowering in an African acacia community. Ecology 79, 2808–2827.

Stone, G.N., Willmer, P., Nee, S., 1996. Daily partitioning of pollinators in an African *Acacia* community. Proc. R. Soc. Lond. B Biol. 263 (1375), 1389–1393.

Tandon, R., Shivanna, K.R., Mohan-Ram, H.Y., 2001. Pollination biology and breeding system of *Acacia senegal*. Bot. J. Linn. Soc. 135, 251–262.

Tybirk, K., 1989. Flowering, pollination and seed production of *Acacia nilotica*. Nord J. Bot. 9, 375–381.

Tybirk, K., 1993. Pollination, breeding system and seed abortion in some African acacias. Bot. J. Linn. Soc. 112, 107–137.

Vanstone, V.A., Paton, D.C., 1988. Extrafloral nectaries and pollination of *Acacia pycnantha* Benth. by birds. Aust. J. Bot. 36, 519–531.

Willmer, P.G., Stone, G.N., 1997. How aggressive ant-guards assist seed-set in *Acacia* flowers. Nature 388, 165–167.