Acta Oecologica 37 (2011) 413–417

Contents lists available at ScienceDirect

Acta Oecologica

journal homepage: www.elsevier.com/locate/actoec

Original article

The role of native flower visitors in pollinating *Opuntia ficus-indica* (L.) Mill., naturalized in Sicily

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ARTICLE INFO

Article history:
Received 3 August 2010
Accepted 10 May 2011
Available online 1 June 2011

Keywords:
Cactus pearOutcrossing
Flower insects
First and second blooms
Fruit quality
Alien plant

ABSTRACT

The role of insects in pollination and consequently in fruit set and quality was assessed in two commercial orchards of the cactus pear, *Opuntia ficus-indica* (L.) Mill., in Agrigento Province, Sicily. In 1997, insects visiting flowers were sampled during May–June (the first bloom) and July (the second bloom, induced by the "scozzolatura" practise). More than 50 insect species belonging to 10 orders were collected in May–June, while only five species of Hymenoptera Apoidea were collected in July. The quality of fruits arising from the second bloom showed that Hymenoptera alone were able to guarantee effective pollination. To verify the role of insects in pollination in 1996 (during only the second bloom), and in 1997 and 2009 (during both blooms), 60 single flowers were marked during each bloom; 30 of them covered with paper sleeves (which prevented natural pollination), while the others were not covered. After withering, fruits produced by marked flowers were analyzed in laboratory: in all years and blooms, the total number of seeds, the number of developed seeds, and the weight and the percentage of pulp were significantly lower for covered flowers than for non-covered flowers. The results are consistent with the hypothesis that native insects effectively carry out the pollination of cactus pear flowers.

1. Introduction

Cactus pear (*Opuntia ficus-indica* (L.) Mill.) was imported from Central America into Europe in the 16th century. The first record of cactus pear in Italy dates to the second half of the 16th century (Barbera and Inglese, 2001), while the first Sicilian record dates to the end of 17th century (Cupani, 1713). In Sicily, the species is now naturalized, i.e., it has become part of the traditional landscape of the island. Cactus pear is considered an invasive species in many small Italian islands (Pretto et al., 2010) and in some Sicilian environments, where it grows on rock faces (Gianguzzi et al., 1996) or on vulcanic soils (unpubl. data). It is also considered invasive in other Italian regions and in some European countries where conditions are favourable (Spain, Portugal, France, and Greece); cactus pear has been included in the "Delivering Alien Invasive Species Inventories for Europe" (DAISIE: http://www.europe-aliens.org/speciesFactsheet.do?speciesId=7300).

Seeds of the cactus pear are dispersed by the many animals that feed on its fruits (Padrón et al., 2011). In Sicily, starlings (*Sturnus unicolor*), which regularly breed in rock faces, could play an important role in seed dispersal. Negative effects of prickly pear invasion on the environment and agriculture have been documented in the Karoo region of South Africa, where seed dispersal is thought to be mainly due to primates and two corvid species, *Corvus capensis* and *C. alba* (Dean and Milton, 2000). *Opuntia stricta* (Haw.) Haw is another *Opuntia* species that has become naturalized in Sicily; its distribution has recently increased from a few hectares (Mazzola et al., 1988) to tens of hectares (Orlando and Viviano, 2007). Species adapted to poor and arid soils such as cactus pear are probably more dependent on mutualistic symbiosis with bacteria (plant growth promoting rhizobacteria) and mycorrhizal fungi (Quatrini, 1997; Cui and Nobel, 1992).

In addition to being considered an invasive species, cactus pear in Sicily is also cultivated in specialised orchards. The area of these orchards increased from 6526 ha in 1983 to 8168 ha in 2000 (Crescimanno, 2001). The cactus pear fruits produced in these orchards are marketed mostly in Italy, Central Europe, and Canada (Crescimanno, 2001).

In Italy, Inglese et al. (1995) studied the physiology of cactus pear and the agronomic techniques needed to obtain high quality fruits. With respect to insects that interact with cactus pear in Italy, only phytophagous species have been investigated (Longo and Rapisarda, 1995).

Insect pollination of plants in the genus *Opuntia* has been studied only under natural conditions in native countries (Osborn et al., 1988; Pimienta-Barrios, 1990; Reyes-Agüero et al., 2006);

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doi:10.1016/j.actao.2011.05.006

nothing is known about pollination in commercial orchards. Cactus pear is characterised by hermaphroditic flowers, autogamy, and cleistogamy (Rosas and Pimienta-Barrios, 1986; Pimienta-Barrios, 1990; Nerd and Mizrahi, 1995; Reyes-Agüero et al., 2006).

The aim of this study was to identify the insects visiting flowers in cactus pear orchards in Sicily and to evaluate their role in pollination and consequently in the production of high quality fruits.

2. Materials and methods

The study was carried out in commercial orchards of *Opuntia ficus-indica* "Gialla" in the areas of Santa Magherita Belice and Montevago (Agrigento Province) (37° 44′ N). Insects on cactus pear flowers were collected in 1997 during the first and second bloom by manually enclosing them in small containers (3 cm in diameter). The second bloom is produced by the plants after the "scozzolatura", i.e., after fruits and cladodes produced during the first bloom (May–June) are removed. The aim of the scozzolatura, which is performed within the first 10 days of June, is to induce the production in July of new cladodes and flowers that will produce fruits that will ripen in autumn. Insects on flowers were sampled between 9:00 and 13:00 on three sunny days during each bloom. On each sampling day, at least 30 flowers in full bloom were sampled. Insects were then separated and identified, usually to species. The Shannon–Wiener index ($H' = -\Sigma p_i \ln p_i$, in which p_i is the proportion of individuals found in the ith species) was calculated for the two samples (insects caught during the first and second bloom). Also calculated was the Sørensen quantitative index ($C_N = 2J_N/(aN + bN)$, where aN and bN are the number of individuals in the samples a (insects caught during the first bloom) and b (insects caught during the second bloom), and J_N is the sum of the lower of the two abundances of the species found in both samples (Magurran, 1988). PRIMER software (PRIMER-E Ltd, UK) was used for the statistical analyses.

The effects of natural pollination on fruit quality and seed set were determined in 1996 (second bloom) and in 1997 and 2009 (first and second bloom). The experiment included two treatments: covered flowers and non-covered flowers. Covered flowers were enclosed in paper sleeves, such that only spontaneous self-pollination was possible. Covered flowers were marked and covered before they had opened; this was accomplished by removing all flowers except one from a cladode, and then covering the entire cladode in a paper sleeve. Non-covered flowers were also marked before they had opened but were not covered and were therefore exposed to pollination by insects and other animals. For each bloom studied, each treatment was represented by 30 flowers on 10 different plants of the same orchard. After the bloom, all flowers were left uncovered. At maturity, all the fruits from marked flowers were collected and examined in laboratory, where the numbers of developed and aborted seeds per fruit and the weight and pulp percentage per fruit were recorded. Data were analysed using the t test ($p < 0.05$).

3. Results

In total, 314 insects were collected on cactus pear flowers. These insects represented more than 50 species and 10 orders (Tables 1–3). The most represented orders were Coleoptera and Hymenoptera (54% and 22%, respectively, of all insects collected belonged to these orders).

Among Coleoptera, mostly Cetoniidae and Oedemeridae were collected (Table 1). Among Heteroptera, *Orius laevigatus* (Fieber) was the dominant species. Hymenoptera were represented mostly by Apoidea, the most abundant species being *Apis mellifera* L.; low numbers of Ichneumonoidea, Chalcidoidea, and Formicoidea were also found.

All of the recorded insect species were present on flowers during the first bloom (May–June) but not during the second bloom, and insect abundance and species richness were higher in the first than in the second bloom (Fig. 1), as confirmed by the Shannon index values, which was 3.01 for the first bloom and 0.96 for the second bloom. Only five of the 14 species of Apoidea that were caught in the first bloom were caught in July (Table 2), i.e., were caught on the flowers produced in the second bloom (after "scozzolatura"). The species caught in July were all medium to large

Table 1
Coleoptera collected on cactus pear flowers during the first bloom in 1997.

Family		Species	No. of specimens
Scarabaeoidea	Melolontidae	*Paratriodonta cinctipennis* (Lucas)	6
	Cetoniidae	*Cetonia aurata sicula* (Aliquò)	4
		Aethiessa floralis (Fabricius)	2
		Potosia cuprea incerta (Costa)	2
		Oxytyrea funesta (Poda)	27
		Tropinota hirta (Poda)	2
Oedemeridae		*Oedemera nobilis* (Scopoli)	1
		Oedemera flavipes (Fabricius)	7
		Oedemera simplex (L.)	34
		Oedemera barbara (Fabricius)	6
Cerambycidae		*Corymbia cordigera* (Fuesslins)	1
		Stenopterus ater (L.)	1
		Phytoecia sp.	1
Chrysomelidae		*Lachnaia paradoxa* (Olivier)	6
		Tituboea biguttata (Olivier)	2
		Sp. 1	1
Alleculidae		*Omophlus lepturoides* (Fabricius)	1
		Omophlus sp.	3
Lampyridae		*Lampyris* sp.	2
Melyridae		*Divales bipustulatus* (Fabricius)	15
		Sp. 1	1
Mycteridae		*Mycterus* sp.	2
Cebrionidae		*Cebrio melanocephalus* Germar	1
Cleridae		*Trichodes alvearius* (Fabricius)	1
Coccinellidae		*Coccinella septempunctata* L.	2
		Sp. 1	1
Anobiidae		Sp. 1	1
Curculionidae		Sp. 1	3
Total			136

Table 2
Hymenoptera collected on cactus pear flowers during the first and second blooms (May–June and July 1997, respectively).

Family	Species	No. of specimens	
		1st bloom	2nd bloom
Apidae	*Apis mellifera* L.	20	35
	Bombus terrestris (L.)	9	5
	Bombus hortorum (L.)	1	1
	Bombus pascuorum siciliensis (Tkalcu)	1	4
	Xylocopa violacea (L.)	2	4
	Ceratina cucurbitina (Rossi)	1	–
Halictidae	*Halictus fulvipes* (Klug)	2	–
	Halictus scabiosae (Rossi)	5	–
	Lasioglossum interruptus opacum (Pérez)	3	–
	Evylaeus smeathmanellus (Klug)	1	–
Megachilidae	*Rhodanthidium sticticum* (Fabricius)	1	–
	Rhodanthidium septemdentatum (Latreille)	3	–
Vespidae	*Polistes gallicus* (L.)	2	–
Chalcidoidea		1	–
Formicoidea		1	–
Ichneumonoidea		1	–
Sphecoidea		1	–
Total		56	49

Table 3
Other insects collected on cactus pear flowers during the first bloom in 1997.

Order	Family	Species	No. of specimens
Lepidoptera	Pieridae	*Pieris rapae* (L.)	1
	Nymphalidae	*Vanessa atalanta* (L.)	1
Heteroptera	Anthocoridae	*Orius laevigatus* (Fieber)	40
		Orius niger Wolff	1
	Miridae	*Taylorlygus pallidulus* (Blanchard)	1
	Pentatomidae	*Graphosoma semipunctatum* (Fabricius)	1
Orthoptera	Tettigoniidae	*Tettigonia viridissima* L.	1
Dermaptera	Labiduridae	*Labidura riparia* (Pallas)	1
	Forficulidae	*Forficula auricularia* L.	2
		Forficula decipiens Gené	3
Homoptera	Cercopidae	*Philaenus spumarius* L.	1
	Cicadellidae	*Eupteryx zelleri* (Kirschbaum)	2
		Sp. 1	2
	Issidae		3
Neuroptera	Chrysopidae		3
Thysanoptera			4
Diptera			6
Total			73

in size: *Apis mellifera*, *Bombus terrestris* (L.), *Bombus hortorum* (L.), *Bombus pascuorum siciliensis* (Tkalcu), and *Xylocopa violacea* (L.). The similarity index (i.e., the Sørensen quantitative index) was low ($C_N = 22.93$), confirming the high differences between the insect visitors of the two blooming periods.

In the experiment with covered and non-covered flowers, the average number of seeds per fruit, the number of well-developed seeds per fruit, and fruit weight were significantly higher for non-covered than for covered fruit for the second bloom in 1996 (the first bloom was not studied in that year) and for both blooms in 1997 and 2009 (Table 4).

4. Discussion

Although many *Opuntia* spp. are usually considered self-compatible, self pollination has been experimentally demonstrated in only a few species (*Opuntia robusta*: Del Castillo, 1986, *Opuntia streptacantha*, *Opuntia cochinera*, and *Opuntia rastrera*: Trujillo and Gonzalez, 1991). For *Opuntia ficus-indica*, cleistogamy and parthenogenesis are considered possible (Rosas and Pimienta-Barrios, 1986; Weiss et al., 1993; Reyes-Agüero et al., 2006), but our research suggests that these phenomena rarely occur. Furthermore, the average value of the ratio between the number of pollen grains and the number of ovuli is 520, meaning that this plant can be

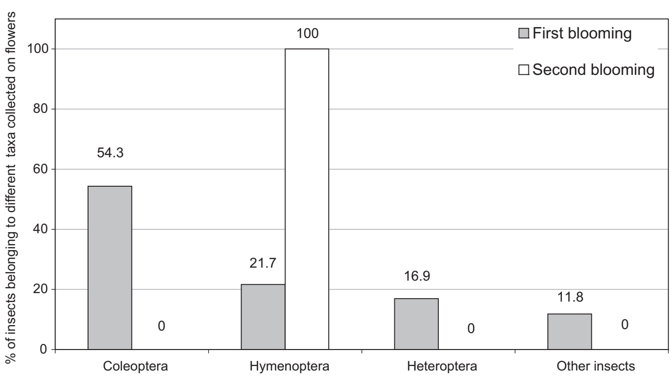

Fig. 1. Percentage of insects belonging to different taxa. Insects were collected on flowers of *Opuntia ficus-indica* during the first and second blooms of 1997. In the second bloom, Hymenoptera were represented exclusively by Apoidea; Heteroptera were mostly *Orius laevigatus*.

included among the species characterized by facultative xenogamy (Cruden, 1976). Further study could determine whether the ratio of pollen to ovuli varies among cactus pear populations (native or introduced), as has been found in other plant species (Cruden, 1977, 2000). Regarding fruit characteristics, the number of ovuli in cactus pear fruits ranged from 222 to 310, which is in agreement with the observations of Nerd and Mizrahi (1994) and Pimienta-Barrios (1990).

Mutualistic relationships between pollinators and several invasive plant species have been studied by many authors (Parker, 1997; Grabas and Laverty, 1999; Barthell et al., 2001; Larson et al., 2002; Brown and Mitchell, 2001; Chittka and Schürkens, 2001; Parker and Haubensak, 2002; Waites and Agren, 2004; Simpson et al., 2005; Morales and Aizen, 2006; Jesse et al., 2006). In a few cases, specific pollinators are essential for the production of fertile seeds and consequently for the naturalization of the plant species. This has been the case for *Ficus microcarpa* L. (Moraceae), an ornamental tree that was imported into Europe from Asia in the 19th century and that was naturalized in Italy and Malta only after the accidental introduction of some specific pollinators (Lo Verde et al., 1991; Domina and Mazzola, 2002; Lo Verde et al., 2007; Lo Verde and Porcelli, 2010).

Many other alien plants are characterized by a floral morphology compatible with the activity of native pollinators, making colonization of the new areas by these plant species quite likely. The success and distribution of an introduced plant species depends on, among other factors, its capacity to attract native pollinators and produce fertile seeds. Cactus pear flowers are attractive to insects, while fruits are regularly eaten by many passerine species who then contribute to seed dispersal; in many natural environments in Sicily, cactus pear plants regularly arise from dispersed seed, and as noted earlier, the species is sometimes considered invasive.

In Sicily, cactus pear is cultivated in three major localities (Santa Margherita Belice, San Cono, and Etna districts) and also in small plots scattered over the entire island. In commercial *Opuntia* orchards, insect pollination is generally considered important for the production of quality fruits (Del Mandujano et al., 1996; McFarland et al., 1989; Del Castillo and Gonzalez-Espinoza, 1988; Pimienta-Barrios, 1990). Many insect species are known to visit the flowers of *Opuntia* spp., mostly to feed on their pollen. Among them, hymenopteran are always the richest group (more than 100 species), followed by coleopterans and lepidopterans. In some regions, birds are effective pollinators of *Opuntia* flowers (Beutelspacher, 1971; Grant and Hurd, 1979; Grant et al., 1979; Parfitt and Pickett, 1980; Grant and Grant, 1979a, 1981; Garcia, 1984; Spears, 1987; Del Castillo and Gonzalez-Espinoza, 1988; Osborn et al., 1988; Huerta, 1995; Del Mandujano et al., 1996; Schlindwein and Wittmann, 1997; Diaz and Cocucci, 2003). In the orchards where the current study was carried out, all the insects collected on flowers of the two bloom periods were native species. Their abundance and diversity were greater during the May–June bloom than during the July bloom. High abundance and diversity during the first bloom might be explained by the fact that, in May and June, many univoltine species, including several Coleoptera species, are present in the field as adults and must feed on plants before reproducing. In contrast, many Apoidea actively search for pollen during the time of second bloom (July). Coleoptera, particularly Scarabaeoidea, Melyridae, and Nitidulidae, are ubiquitous and abundant on flowers of several *Opuntia* species. They are considered potential pollinators, particularly for self-compatible species, but their role in cross pollination is usually considered minimal because they rarely move from flower-to-flower and also may fail to contact the flower stigmas (Grant and Connell, 1979; Grant and Grant, 1979b; Grant et al., 1979; Grant and Hurd, 1979;

Table 4
Number of seeds per fruit and characteristics of fruits that developed from 30 flowers that were covered (no pollination by insects or other animals) or non-covered (possible pollination by insects and other animals) during the second bloom of 1996 and the first and second blooms of 1997 and 2009. Values with different letters in each column and for each year are significantly different (*t* test, $p < 0.05$).

Year/Treatment	First bloom					Second bloom				
	No. of seeds per fruit (mean ± s.d.)	No. of normal seeds (mean ± s.d.)	Percentage of normal seed	Fruit		No. of seeds per fruit (mean ± s.d.)	No. of normal seeds (mean ± s.d.)	Percentage of normal seed	Fruit	
				Weight (g)	Pulp (%)				Weight (g)	Pulp (%)
1996										
Non-covered						310a ± 25	279a ± 13	90	91.6a ± 25	53
Covered						191b ± 82	122b ± 23	74	58.3b ± 20	34
1997										
Non-covered	222a ± 58	73a ± 49	33	72a ± 20	52	291a ± 18	175a ± 43	60	90a ± 23	54
Covered	181b ± 80	9b ± 67	5	31b ± 29	22	182b ± 93	60a ± 33	33	54b ± 21	33
2009										
Non-covered	344a ± 99	196a ± 148	41	98a ± 29	51	340a ± 35	176a ± 20	49	144a ± 69	58
Covered	287b ± 83	107b ± 61	13	44b ± 27	25	210b ± 69	130b ± 28	39	119b ± 69	25

Garcia, 1984; Del Castillo and Gonzalez-Espinoza, 1988; McFarland et al., 1989; Del Mandujano et al., 1996). Adults of Cetoniidae and Oedemeridae, the most abundant Coleoptera families represented in our samples, are well known to be attracted by flowers of many plant species. Species belong to Cetoniidae usually remain on flowers for a long period, while those belonging to Oedemeridae fly from flower-to-flower every few minutes. Further observations are required to confirm their effectiveness in *Opuntia* pollination.

Many Apoidea are regularly found on *Opuntia* spp. flowers, but only a few species (mostly Anthophoridae, Megachilidae, Andrenidae, and Colletidae) are considered effective pollinators (Grant et al., 1979; Grant and Grant, 1979a; Schlindwein and Wittmann, 1997; Grant and Hurd, 1979; Parfitt and Pickett, 1980; McFarland et al., 1989; Del Castillo and Gonzalez-Espinoza, 1988; Schlindwein, 1995). Their effectiveness is due to their continuous flying from flower-to-flower and also to their body movements, which result in contact between the insect abdomen and the flower stigma. Moreover, the abundant hairs on the body surface of these species of Apoidea facilitate the collection and release of pollen grains. *Apis mellifera*, the most abundant Apidae found during both bloom periods, is a generalist pollinator and is recognized worldwide as an important species for apiculture and for pollination of cultivated plants; it also appears to play an important role in pollinating several species of invasive plants (Jesse et al., 2006).

Among the other orders, only *Orius laevigatus* (Fieber) was abundant on cactus pear flowers. This anthocorid regularly uses pollen as a food source, and its role as a pollinator in Sicily has been recognized for *Lantana camara* L. (which was introduced as ornamental plant) and for *Anona* spp. (which is present in small experimental orchards) (Sinacori and Mineo, 1995; Caleca et al., 1998).

Although less abundant than insects in the first bloom, insects in the second bloom period were able to guarantee effective pollination of flowers, i.e., the fruits produced from the second bloom developed normally. The larger size of these fruits in comparison with those of the first bloom seems to be due to a physiological reaction of the plants to the "scozzolatura" practise (Inglese et al., 1996; Schirra et al., 1999). This interpretation is supported by the higher fruit weight in 1997 and 2009 for fruits from the second bloom than for those from first bloom, in spite of the similar number of seeds per fruit for both blooms (see Table 4). The data also suggest that, regardless of bloom period, fruit features and quality vary from year to year.

Data on the insects visiting the flowers of the second bloom seem to confirm that, although cactus pear flowers attract many insect species, only a few of them are effective pollinators. These insects can therefore be considered to have an oligolectic relationship with the plant (Grant and Grant, 1979a; Schlindwein and Wittmann, 1997; Simpson and Neff, 1987; Reyes-Agüero et al., 2006). The activity of such pollinator specialists evidently helps ensure the production of quality cactus pear fruits (Barbera et al., 1994).

Acknowledgements

We greatly thank the entomologists who contributed to identification of the insect species: V. Aliquò (Palermo), M. Bologna (Roma), I. Sparacio (Palermo) (Coleoptera); V. Nobile (Catania) (Hymenoptera); A. Carapezza (Palermo) (Heteroptera); A. Guglielmino (Viterbo) (Homoptera); B. Massa (Palermo) (Dermaptera); and P. Parenzan (Palermo) (Lepidoptera). Thanks to P. Inglese (Palermo) and to the anonymous referees for their suggestions concerning the first draft of the paper. The research was funded by the Università degli Studi di Palermo (Progetti di Ateneo, ex 60%) and POP 94/99, "Fruttiferi tropicali e subtropicali".

G. Lo Verde conducted the entomological work and T. La Mantia conducted the agronomic work both in the field and in the laboratory. Both authors equally contributed to the paper.

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