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Floral visitors, their frequency, activity rate and Index of Visitation Rate in the strawberry fields of Ribatejo, Portugal: selection of potential pollinators. Part 1

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Abstract: **This study was carried out in one of the most important strawberry (*Fragaria* × *ananassa* Duch.) producing regions of Portugal, the Ribatejo, and aims to describe the quantitative component of visits by strawberry floral visitors under open field conditions. The main objectives were: (1) to assess the flower-visiting insects of the strawberry crop; (2) to evaluate the percentage of frequency (F) and activity rate (AR) in order to determine an Index of Visitation Rate (I_{VR}) for the different categories of visitors. This study allowed us to access the vast spectrum of flower-visiting insects of the strawberry crop and to characterize their visits regarding parameters such as F and AR, used to calculate I_{VR}. Based on the referred index it was possible to highlight three categories of insect visitors: Syrphidae (Diptera), *Apis mellifera* L. (Hymenoptera) and native bees (Hymenoptera). Other aspects were evaluated such as no. ind/flower throughout three different phases of the blooming period and field conditions. All the parameters allowed us to gather a set of information inherent to each of these categories, which will be useful for conservation and management procedures aiming at adequate pollination of the strawberry crop.**

1. Introduction

Flower-visiting insects are involved in two agroecosystem services that are considered critical to human survival (Daily, 1997): pollination (Williams, 1995; Kearns *et al*., 1998; Marco and Coelho, 2004; Dewenter *et al*., 2005; Ghazoul, 2005; Potts *et al*., 2006; Diekotter *et al*., 2007) and pest control (Kruess and Tscharntke, 1994). Although animal pollinators justify between 15 and 30% of the global food production (McGregor, 1976; Roubik, 1995) and bees are considered the most important pollinating taxon (Delaplane and Mayer, 2000), Europe and other regions of the world are witnessing a decline in the number of pollinators and consequently in the services that they provide (Potts, 2004).

In Europe, pollination by honey bees (*Apis mellifera* L.) was estimated to be worth more or less 4.25 billion Euros, and pollination by other taxon approximately 0.75 billion Euros (Borneck and Merle, 1989). *A. mellifera* is considered the most frequently used pollinator for the vast majority of the agriculture crops that require insect pollination (McGregor, 1976; Free, 1993), but we cannot disregard the important role that populations of unmanaged or wild pollinators, originating from semi-natural habitats existing in the vicinity of these crops, can have in their productivity (Kremen *et al*., 2004; Ricketts, 2004; Greenleaf and Kremen, 2006; Morandin and Winston, 2006; Potts *et al*., 2006). Not just wild bees are included within the class of wild pollinators, but also other groups of non-bee flower-visiting insects like flies (Diptera), moths and butterflies (Lepidoptera), beetles (Coleoptera), true bugs (Heteroptera) and even thrips (Thysanoptera).

Factors such as the introduction of parasitic mites, pesticide misuse, and africanisation phenomenon have been responsible for the decline of managed and feral

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European honey bees in the United States and other countries like France and Germany (Matheson *et al*., 1996). Therefore, costs related to the introduction and maintenance of their colonies in agricultural areas have been rising (Sugden, 1993). Another problem that has been discussed in several studies is the negative impact of the massive introduction of *A. mellifera* colonies on the native pollinator populations (Goulson, 2003). This scenario reflects the vulnerability of agriculture when depending on a single pollinator species, and therefore reinforces the urge to find alternative non-*Apis* pollinators which will assure the ecological services to both natural and agro-ecosystems (Allen-Wardell *et al*., 1998; Kearns *et al*., 1998). More recently, "Colony Collapse Disorder" (CCD) has created a very serious problem for beekeepers and could threaten the pollination industry (Johnson, 2008).

There are several studies that highlight the important role that pollinator insects have on the pollination of strawberry (*Fragaria* × *ananassa* Duch.). These studies report a smaller percentage of misshapen fruits (Free, 1968; Pion *et al*., 1980; Svensson, 1991; Bigey *et al*., 2000; López-Medina, 2002; López-Medina *et al*., 2006), earlier production (Paydas *et al*., 2000) and a higher percentage of fertilized ovules (achenes) which increases the weight of the berries (Pion *et al*., 1980; Chagnon *et al*., 1989, 1993). The honey bee is recognized as the main pollinator of the strawberry crop (Nye and Anderson, 1974; Goodman and Oldroyd, 1988; Chagnon *et al*., 1989; Svensson, 1991; de Oliveira *et al*., 1991; Free, 1993), but the native entomofauna may also play a significant contribution to its pollination (de Oliveira *et al*., 1991; Chagnon *et al*., 1993; Malagodi-Braga, 2002).

Native pollinators are particularly useful because they are more adapted to regional conditions and, therefore, they assure the pollination of the flowers even when abiotic factors do not allow the foraging activity of honey bees (de Oliveira *et al*., 1991). Several studies have assessed pollinator entomofauna of the strawberry crop. Honey bees, wild bees and hoverflies stand out among the visiting insects (de Oliveira *et al*., 1991; Malagodi-Braga, 2002), although strawberry flowers are also visited by beetles, wasps, thrips, butterflies and other insects (Nye and Anderson, 1974; McGregor, 1976; Malagodi-Braga, 2002). Some studies question the introduction of beehives in localities where the native pollinator populations are large (Chagnon *et al*., 1993).

According to Dobrynin (1998), insect-pollinated crops may be supplied with sufficient pollinators, either by protecting and increasing the number of pollinators in natural habitats, or by artificially rearing and managing them. These measures require selection of potential pollinators for a specific crop. In order to establish a successful selection for a particular crop, the first step is to undertake studies to identify all the flower-visiting insects and describe the quantitative and qualitative components of their visits. It is possible that, although a plant receives different visitors, only some of these may be effective in pollination. The quantitative component is represented by pollinator abundance or visitation frequency, and the qualitative component is mainly represented by pollination effectiveness (Herrera, 1987, 2000).

This study was carried out in one of the most important strawberry producing regions of Portugal, the Ribatejo (Costa *et al*., 2008). Although pollinator insect importance has been recognized among strawberry growers in the Ribatejo, through preliminary studies in that region (Albano *et al*., 2005 a, b, c) an assessment of the strawberry flower-visiting insect spectrum was still required. In response to this need, the present study was undertaken to describe the quantitative component of visits of strawberry floral-visitors: (1) to assess the flower-visiting insects of the strawberry crop under open field conditions in the Ribatejo and (2) to evaluate the percentage of frequency (F) and activity rate (AR) in order to determine an Index of Visitation Rate (I_{VR}) for the different categories of visitors.

2. Materials and Methods

Field work

The Ribatejo region, where this study was carried out, is one of the most important strawberry producing regions of Portugal (Costa *et al*., 2008). It is typically divided into several fields of diverse horticultural crops, including strawberries, surrounded by different proportions of semi-natural land and areas of less intensively managed agriculture. During the 2003 blooming period, a total of four fields (A, B, C and D), ranging in size from 2 to 4 ha, with 'Camarosa' strawberry in open field conditions were analysed. Fields A and B were located in a more intensive agricultural area, dominated by the most popular crops in Ribatejo: field tomatoes, melon, vineyards and strawberries. These two fields were 2 to 3 km from the urban centre of a local village (Almeirim). The proximity of fields A and B (1.5 km away) made it possible for flowers of field B to be visited by honey bees belonging to the beehives that were set up in field A. Fields C and D were more distant from urban centres and were surrounded by more natural areas of land than A and B. Field C was surrounded by pine and eucalyptus forest. Field D was located within a large farm composed of 600 ha of cork oak forest, managed for cork harvesting and cattle grazing.

One apiary, consisting of a total of six beehives, was setup in field A at the beginning of the blooming period. In the other fields there were no beehives and, therefore, the flowers in these crops may have been visited only by the native entomofauna or, possibly, by honey bees coming from neighbouring beehives.

In all the fields, Integrated Pest Management (IPM) procedures were adopted for crop protection; planting occurred in the second week of October 2003, with a plant density of approximately 60,000 plants/ha. Plants were planted in double-rows, at a distance of 30 cm from each other, growing on black plastic mulching; a drip irrigation system was used.

Depending on the year, the blooming period for the cultivar Camarosa, in open-field conditions in the Ribatejo region, may extend from late January to June. In 2003, blooming started in early February and we started our observations in March. Each field was sampled on eight or nine different dates, always between 11:00 and 15:00, on sunny days, with low wind speed. Samples, for each field and date, were used to record the number of flower-visiting insects through five walking transects of 50 m each, within a 5-min period (during which no captures were made). The flower-visiting insects were grouped into the following taxonomic categories: 1. Coleoptera; 2. Diptera: a) Syrphidae b) other Diptera; 3. Hymenoptera: a) *Apis mellifera* b) native bees c) other Hymenoptera - ants and parasitoids; 4. Heteroptera and 5. Lepidoptera. In addition to these categories, minute insects, such as thrips with poor pollen transportation ability, were sometimes observed, but they were not included because it would imply the use of a different methodology.

For each field and date, five more transects, of 50 m each and within a 5-min period, were done to collect insect samples for later identification. In the laboratory, insects belonging to each of the categories described above were identified to family level. The most frequent families from each category were identified, whenever possible, to the genus or species level. On each sampling date we recorded the number of open flowers from five samples of 1-m sections of a row. These flower samples were chosen at random throughout the walking transects.

To assess the mean number of flowers that a visiting-insect category visited per minute (activity rate - AR), arrival and departure of the visiting-insects were registered using a voice recorder. Individuals belonging to each of the categories were recorded for at least 1 min of foraging activity on strawberry flowers. Approximately 30 individuals were observed for each category. The recording periods were in May 2003 on sunny days between 10:00 and 14:00. This method enabled later calculation of the number of visits per minute (visits/min). For the categories of visiting insects with an AR less than 1 visit/min, the following classes were created: <0.1; 0.1 to 0.5; and 0.5 to 1 visits/min.

Data analysis

Data were standardised by converting the number of individuals in each category into the number of individuals per flower (no. ind/flower). For each field, the number of individuals belonging to a visiting-insect category relative to the total number of insects included in the census (relative frequency) were calculated. The percentage of frequency (F) was obtained by multiplying each of the relative frequency values by 100. One-way Anovas were used to compare the means of the no. ind/flower for each category between fields, whenever the normality and homogeneity assumptions were verified. If the assumptions were not verified, even after testing several transformations, the non-parametric Kruskal-Wallis test was applied. If significant differences between farms were detected, treatment means were then compared using Tukey's pairwise comparisons, or the multiple comparison tests, depending on whether Anova or Kruskal-Wallis had been used.

Three phases were established to analyse the no. ind/flower for each category throughout the blooming period: first phase (March and April, characterized by having an average of 9.73 flowers/m), second phase (May with an average of 13.04 flowers/m) and third phase (June with an average of 8.98 flowers/m). To compare the no. ind/flower for the different blooming phases considered, the Kruskal-Wallis test was used. The significance level used for all the tests was 5%. Statistical tests were performed with STATISTICA (StatSoft, Inc., 2004), version 7.0.

Using the data obtained for the percentage of frequency (F) and activity rate (AR), through the methodology described above, an Index of Visitation Rate (I_{VR}) adapted from Talavera *et al.* (2001) was calculated for the different flower-visiting insect categories that were established. The I_{VR} for each insect category was calculated based on the AR and on the F average of all the fields observed.

$$I_{VR} = F \times AR$$

Where:

F= percentage of frequency= relative frequency (number of individuals belonging to a visiting-insect category relative to the total number of insects included in the census) × 100;

AR= activity rate (mean number of flowers that a visiting-insect category visited per minute).

3. Results

Insect visitors, percentage of frequency (F) and variation in the no. ind/flower

The spectrum of visitors in the Ribatejo strawberry fields was composed mainly of Coleoptera, Diptera, Hymenoptera, Heteroptera and Lepidoptera. In Table 1, the list of insect visitors is shown.

The Coleoptera showed the highest F (58.04±11.22%) (Fig. 1 a). Within the Coleoptera, the most frequent families were the Nitidulidae (31.95±7.02%), Oedomeridae (12.12±9.68%) and Dermestidae (6.70±6.35%). The no. ind/flower belonging to the Nitidulidae family did not differ between the sampled fields (Fig. 2). For the other two families, significant

Table 1 - List of insect visitors detected in the strawberry fields of Ribatejo, Portugal

Order	Most frequent families and species detected	Other families and functional groups
Coleoptera	Nitidulidae	Apionidae
	Epuraea sp.	Anthribidae
	Meligethes sp.	Bruchidae
	Oedomeridae	Byrrhidae
	Ischnomera sp.	Cantharidae
	Oedemera sp.	Chrysomelidae
	Dermestidae	Coccinellidae
	Anthrenus sp.	Corylophidae
	Attagenus sp.	Curculionidae
		Elateridae
		Scarabaeidae
		Scraptiidae
		Melyridae
		Mordellidae
Diptera	Sirphidae	Anthomyiidae
	Eupeodes corollae Fabricius	Bombyllidae
	Eristalis tenax Linnaeus	Empididae
	Eristalis arbustorum Linnaeus	Muscidae
	Eristalinus megacephalus Rossi	Tachinidae
	Eristalinus taeniops Wiedemann	
	Helophilus trivitattus Fabricius	
	Melanostoma mellinum Linnaeus	
	Sphaerophoria scripta Linnaeus	
	Sphaerophoria rueppellii Wiedemann	
	Syritta pipiens Linnaeus	
	Syritta flaviventris Macquart	
	Calliphoridae	
	Stomorhina lunata Fabricius	
Hymenoptera	Apidae	Formicidae
	Apis mellifera Linnaeus	Parasitoids
	Native bees	
	Apidae	
	Ceratina sp.	
	Halictidae	
	Halictus sp.	
	Lasioglossum sp.	
	Andrenidae	
	Andrena sp.	
	Megachilidae	
	Osmia sp.	
Heteroptera	Anthocoridae	---
	Orius sp.	
Lepidoptera	Pieridae	---

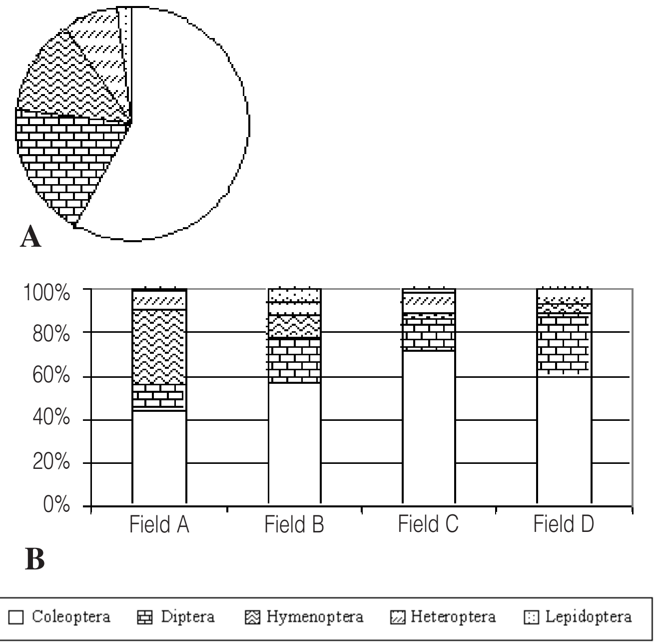

Fig. 1 - Percentage of frequency (F) for each visiting-insect order, including all fields analysed (a) and the distribution of the percentage of frequency of each insect categories for each field (b).

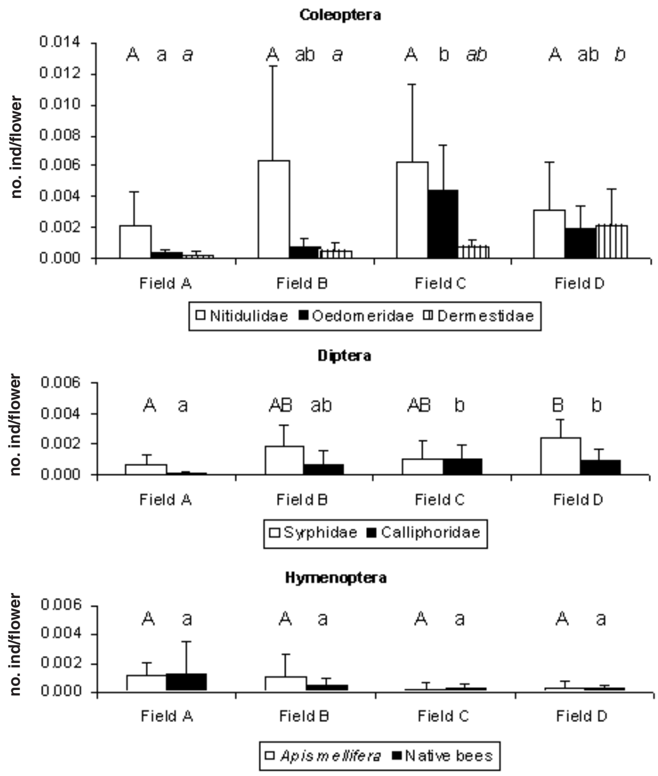

Fig. 2 - Mean (± SD) number of individuals/flower (no. ind/flower) for the main categories of flower-visiting insects for Coleoptera, Diptera and Hymenoptera orders in the four fields analysed (Bars of the same insect order with different letters are significant different to p<0.05).

differences were found between fields (Oedomeridae: H (3, 34) =13.42028, p<0.01; Dermestidae (F=5.35, df=3, p<0.01) (Fig. 2). For these three families, the no. ind/flower also differed statistically for the observed blooming phases (Nitidulidae: H (2, 34) =21.30 p< 0.0001; Oedomeridae: H (2, 34) =6.03, p< 0.05; Dermestidae: H (2, 34) =12.85 p<0.01), and a generalized increasing trend in the number of insects throughout

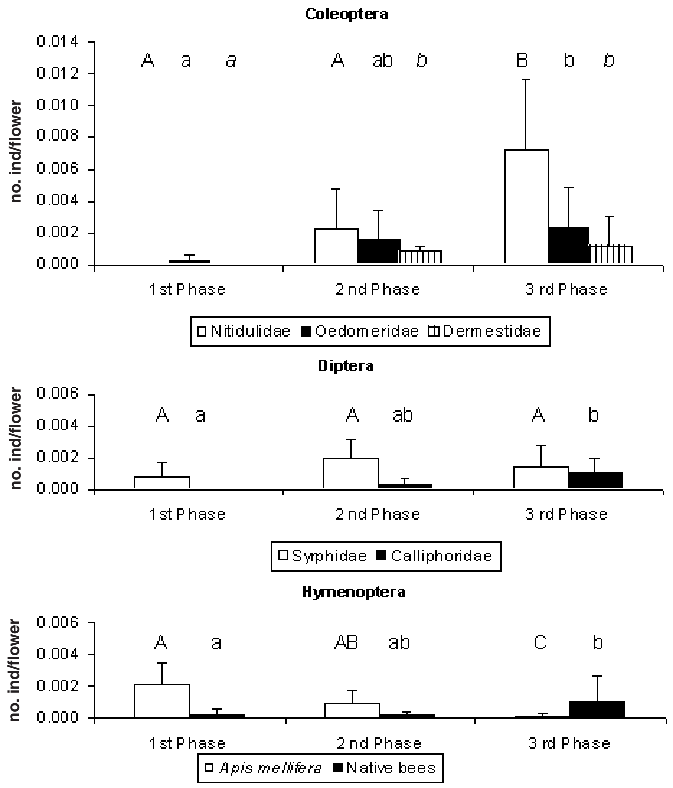

Fig. 3 - Mean (± SD) number of individuals/flower (no. ind/flower) for the main categories of flower-visiting insects for Coleoptera, Diptera and Hymenoptera orders in the observed blooming phases - first phase (1st phase), second phase (2nd phase) and third phase (3rd phase). (Bars of the same insect categories with different letters are significant different to p<0.05).

the blooming phases was observed (Fig. 3).

Diptera was the second most frequent order (18.96±7.40%) (Fig. 1 a). In this order, two families were noticeable: the Syrphidae, with an F of 10.99±4.81%, was mostly represented by the genus *Eristalis* Latreille, and the Calliphoridae (4.42±2.83%), which was totally represented by *Stomorhina lunata* Fabricius. In the Syrphidae family, the no. ind/flower differed statistically between the observed fields (F= 3.58, df=3, p <0.05), due to the significant differences found between fields A and D (Fig. 2). The no. ind/flower for this family did not differ statistically for the observed blooming phases, although it is notable that, during the first phase, this category was less detected (Fig. 3). Significant differences were also found between fields in the no. ind/flower of the Calliphoridae family (H (3, 34) =11.95, p < 0.01), due to the fact that fields C and D showed a higher no. ind/flower than field A (Fig. 2). The no. ind/flower from this family differed statistically for the observed blooming phases (H (2, 34) =13.24, p< 0.01), becoming higher as blooming progressed (Fig. 3).

The Hymenoptera order was mainly represented by *A. mellifera* (6.09±6.36%) and native bees (6.23±7.99%), and had a F of 13.16±14.63% (Fig. 1 a). The most frequent family of native bees detected was Halictidae with a F of 5.01±5.97%. Other families of native bees were detected very occasionally. The large standard deviations recorded for F in the Hymenoptera order are related to the large heterogeneity that F showed in the several fields (Fig. 1b). Significant differences were not found between fields for the no. ind/flower for *A. mellifera* and native bees, but a trend for higher values was observed in fields A and B (Fig. 2). The no. ind/flower of *A. mellifera* differed significantly among the observed blooming phases (H (2, 34) =17.79, p <0.001) showing a gradual decrease throughout the blooming period (Fig. 3). For the native bees, significant differences were also found in the no. ind/flowers throughout the observed blooming phases (H (2, 34) =10.13, p < 0.01), but in this case the opposite trend occurred (Fig. 3).

The Heteroptera order was totally represented by genus *Orius* Wolff with a F of 7.91±1.68%. The no. ind/flower for *Orius* sp. did not differ between fields, but differed statistically throughout the several phases (H (2, 34) =13.35, p < 0.01) showing a higher no. ind/flower during the third phase.

The Lepidoptera order corresponded only to 1.92±2.36% of the totality of the detected visitors. No significant differences were found in the no. ind/flower between fields or observed blooming phases.

Activity rate (AR)

The categories with lower values for AR were the several families of Coleoptera, the Heteroptera - *Orius* sp. and the Diptera - Calliphoridae (Table 2).

A. mellifera showed the highest AR (Table 2). The Syrphidae family showed a AR value (Table 2) between *A. mellifera* and native bees.

Index of visitation rate (IVR)

According to the I_{VR} results, which combine information from F and AR, three categories of visitors were noticeable: Syrphidae (Diptera), *A. mellifera* (Hymenoptera) and native bees (Hymenoptera) (Table 2). The remaining categories had relatively lower I_{VR}.

Table 2 - Means (± SD) of percentage of frequency (F), activity rate (AR) and correspondent Index of Visitation Rate (I_{VR}) for the main categories of flower-visiting insects detected in the strawberry fields of Ribatejo, Portugal

Visitor category	Percentage of frequency (F)	Activity rate (AR) (visits per minute)	Index of Visitation Rate (I_{VR})
Coleoptera-Nitidulidae	31.95±7.02%	<0.1	<3.20
Coleoptera-Oedomeridae	12.12 ±9.68%	<0.1	<1.21
Coleoptera-Dermestidae	6.70 ±6.35%	<0.1	<0.67
Diptera-Syrphidae	10.99 ±4.81%	4.55±2.35	50.00
Diptera-Calliphoridae	4.42 ±2.83%	(0.5-1)	(2.21-4.42)
Hymeoptera-*Apis mellifera*	6.09 ±6.36%	7.45±2.22	45.37
Hymenoptera-native bees	6.23 ±7.99%	3.59±1.92	22.37
Heteroptera-*Orius* sp.	7.91 ±1.68%	(0.1-0.5)	(0.79-3.96)
Lepidoptera	1.92 ±2.36%	----	----

4. Discussion and Conclusions

The visitor spectrum of the strawberry crop is quite varied, including members from several orders - Coleoptera, Heteropera, Hymenoptera, Diptera and Lepidoptera. The less specialised characteristics of the strawberry flower - radial symmetry, open dish-shape flower, easily accessible nectar, exposed anthers - attract a diverse number of floral visitors (Malagodi-Braga, 2002). Other surveys of the visiting entomofauna in this crop have also revealed a large diversity of floral visitors (Nye and Anderson, 1974; McGregor, 1976; de Oliveira *et al*., 1991; Malagodi-Braga, 2002).

Regarding the I_{VR} parameter the categories Coleoptera, Calliphoridae (Diptera) and Heteroptera obtained very low values ($I_{VR}< 5$) and, therefore, it can be concluded that their potential as pollinators of this crop is relatively low. Although the Coleoptera order is very frequent, it showed the lowest I_{VR} of all the detected categories because of its very low AR. This result is in agreement with several other studies that have shown that beetles are poor pollinators, more often behaving as pollen predators but occasionally accidental pollinators (Proctor *et al*., 1996). In line with what other studies have indicated, the F of this category may be overestimated due to the sampling method used (Talavera *et al*., 2001). The fact that the Coleoptera remain on the same flower for long periods of time increases their probability of being detected all the way through a transect, in comparison with other categories that showed quite higher values of AR.

Regarding the Heteroptera category (i.e. true bugs) - *Orius* sp., although the F was comparable to native bees and *A. mellifera*, its low AR resulted in a relatively low I_{VR}.

In the Diptera order, the Syrphidae family obtained the highest I_{VR} and the Calliphoridae family was among the ones with lower I_{VR} due to its low AR. Sometimes families or genera within single orders may differ widely in frequency of pollination (Herrera, 1987).

Syrphidae showed the highest I_{VR} because this family simultaneously obtained high F and considerable AR rates. Although the principal aim of this study was not the comparison between the four fields analysed, we verified that, regarding this category, the differences found between the no. ind/flower in fields A and D (the former being the higher) seem to indicate that the more natural surroundings of field D probably contributed to this result. It was also verified that, although field B was located in a more agriculturally intense area, it in fact showed a considerable no. ind/flower for this category. This may be related to the fact that, in this field, weeds had been allowed to grow in the space between crop rows. Likewise, Kleijn and van Langevelde (2006) detected that the flower abundance and the area of semi-natural habitats within 500-1000 m were significantly related to species richness of hoverflies. In addition to its high I_{VR}, the Syrphidae category had the advantage of being present during all the observed blooming phases, being more abundant during the second and third phases, coincident with a decrease of the no. ind/flower of *A. mellifera*.

A. mellifera showed the second highest I_{VR} as a consequence of the highest AR. Differences between fields did not appear statistically significant but, the fields closest to the installed beehives (fields A, where they were installed, and B) showed a higher no. ind/flower. Similar results were obtained for other crops like squash and pumpkin, probably reflecting the lack of affinity of honey bees for these crops (Shuler *et al*., 2005). As our data suggests, another difficulty faced by the use of *A. mellifera* colonies was that pollinators are only active on the target crop during a first phase (after the installation), and then diverge gradually to forage on more attractive floral resources (Free and Smith, 1961). In response to this problem, some authors like Stern *et al*. (2004) have indicated that a useful technique to increase the number of honey bees visiting the target crop is the sequential introduction of colonies throughout the blooming. With this method, Stern *et al*. (2004), working on pear, obtained an increase of the fruit set and yield by 50-80%. In conclusion, *A. mellifera* may be an interesting pollinator for this crop, but it implies the use of several management techniques in order to maintain and enhance the number of foragers on the target crop for longer periods (Currie, 1997; Ohishi, 1999), especially in the case of a less attractive crop such as strawberry (Darrow, 1966; McGregor, 1976).

Native bees had a F comparable to *A. mellifera*, but its AR was lower, resulting in the third highest I_{VR}. Regarding the pollination of this crop, which has a long blooming period, this category had the disadvantage of being almost nonexistent in the first phase of the period. This fact is in accordance with typical life cycles of most Halictinae (sub-family of genus *Halictus* Latreille and *Lasioglossum* Curtis, the most frequent native bees detected), which survive the unfavourable winter season as adult hibernating females and emerging with good weather in the spring to establish nests (Michener, 2000). Several studies indicate that the abundance and diversity of this category of visitors is positively related to the proportion of natural habitat in the vicinity of field sites (e.g. Kremen *et al*., 2004; Ricketts, 2004; Chacoff and Aizen, 2006; Morandin and Winston, 2006), but in the present study it was not possible to detect differences in the no. ind/flower between fields. Nevertheless, it was verified that fields A and B, located in a more agriculturally intense area, showed a tendency to have a higher no. ind/flower. This apparently contradictory result may reflect the trend, already found in other studies, for field locations that are managed for agriculture, such as the case in olive groves under active management to be an important support for more abundant and diverse bee communities than other locations where the olive groves had been abandoned (Potts *et al*., 2006). These authors concluded that managed, frequently cultivated olive groves will increase the abundance and diversity of ruderal species and also avoid specific species domination. In fact, flower diversity and abundance were identified in several studies as important elements structuring bee communities (e.g. Steffan-Dewenter and Tscharntke, 1997; Potts *et al*., 2006).

For the first time in Portugal, this study has shown the vast spectrum of flower-visiting insects of the strawberry crop under open field conditions in the Ribatejo and characterized their visits regarding parameters such as F and AR, used to calculate I_{VR}. Based on this index, it was possible to highlight three categories of insect visitors: Syrphidae, *A. mellifera* and native bees. Other aspects were evaluated, such as no. ind/flower throughout the observed blooming phases, and field conditions. All the parameters allowed us to gather a set of information inherent to each of these categories of visitors which will be useful for conservation and management procedures aiming at adequate pollination of the strawberry crop.

The frequencies of the visitors vary between regions, fields and years, and therefore the results obtained in this study should not be directly extrapolated to other cases, without a pilot study to evaluate the visiting entomofauna of a particular location. Information from the study regarding the quantitative component of the visits of several categories of visitors, together with the comparative study of the pollination effectiveness of the referred categories in Albano *et al*. (2009) will both allow for a selection of the potential pollinators of the strawberry crop in the Ribatejo region and provide practical recommendations for the producers regarding the most adequate management of these pollinators.

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References

ALBANO S., DE OLIVEIRA D., SALVADO E., QUARESMA M., BORGES P., MEXIA A., 2005 a - *Avaliação da importância dos insectos polinizadores na melhoria da produção na cultura do morango*. - Actas da Associação Portuguesa de Horticultura, II Colóquio Nacional da Produção de Morango e Pequenos Frutos, São Teotónio, Portugal, pp. 121-129.

ALBANO S., SALVADO E., BORGES P., MEXIA A., 2005 b - *Análise comparativa dos vários agentes de polinização na cultura do morangueiro*. - Actas do V Congresso Ibérico de Ciências Hortícolas, Porto, Portugal, pp. 20-25.

ALBANO S., SALVADO E., DUARTE S., MEXIA A., BORGES P.A.V., 2009 - *Pollination effectiveness of different strawberry floral visitors in Ribatejo, Portugal: selection of potential pollinators. Part 2*. - Adv. Hort. Sci., 23(4): 246-253.

ALBANO S., SALVADO E., MEXIA A. 2005 c - *Polinização*, pp. 99-105. - In: PALHA M.G. (coord.) *Manual do morangueiro*. Ed. Projecto PO AGRO DE&D nº 193.Tecnologias de produção integrada no morangueiro visando a expansão da cultura e a reconquista do mercado, Oeiras, Portugal, pp. 128.

ALLEN-WARDELL G., BERNHARDT T., BITNER R., BURQUEZ A., CANE J., COX P.A., DALTON V., FEINSINGER P., INGRAM M., INOUYE D., JONES C.E., KENNEDY K., KEVAN P., KOOPOWITZ H., MEDELLIN R., MEDELLIN-MORALES S., NABHAN G.P., PAVLIK B., TEPEDINO V., TORCHIO P., WALKER S., 1998 - *The potential consequences of pollinator declines on the conservation of biodiversity and stability of crop yields*. - Conserv. Biol., 12(1): 8-17.

BIGEY J., LONGUESERRE J., FAVE C., VAISSIERE B., PERRIGAULT M., 2000 - *Efficacité pollinisatrice des bourdons en culture hors-sol chauffée en fonction de l'alimentation de la ruche*. - Comptes-Rendus resumes de l'activite fraise 1999/2000. CIREF, pp. 67-68.

BORNECK R., MERLE B., 1989 - *Essai d'une evaluation de l'incidence économique de l'abeille pollinisatrice dans l'ágriculture européenne*. - Apiacta, 24(1): 33-38.

CHACOFF N.P., AIZEN M.A., 2006 - *Edge effects on flower-visiting insects in grapefruit plantations bordering premontane subtropical forest*. - J. Appl. Ecol., 43(1): 18-27.

CHAGNON M., GINGRAS J., DE OLIVEIRA D., 1989 - *Effect of honey bee (Hymenoptera: Apidae) visits on the pollination rate of strawberries*. - J. Econ. Entomol., 82(5): 1350-1353.

CHAGNON M., GINGRAS J., DE OLIVEIRA D., 1993 - *Complementary aspects of strawberry pollination by honey and indigenous bees (Hymenoptera)*. - J. Econ. Entomol., 86(2): 416-420.

COSTA J.M., ALMEIDA D., OLIVEIRA C.M., 2008 - *Portuguese fruit producers*. - Fruit & Veg. Tech., 8(2): 28-30.

CURRIE R.W., 1997 - *Pollination constraints and management of pollinating insects for crop production,* pp. 121-151. - In: SHIVANNA K.R., and V.K. SAWHNEY (eds.) *Pollen biotechnology for crop production and improvement*. Cambridge University Press, Cambridge, UK, pp. 448.

DAILY G.C., 1997 - *Nature's services. Societal dependence on natural ecosystems*. - Island Press, Washington, DC, USA, pp. 412.

DARROW G.M., 1966 - *The strawberry: History, breeding and physiology*. - Holt. Rinehart and Winston, New York, USA, pp. 447.

DE OLIVEIRA D., SAVOIE L., VINCENT C., 1991 - *Pollinators of cultivated strawberry in Québec*. - Acta Horticulturae, 288: 420-424.

DELAPLANE K.S., MAYER D.F., 2000 - *Crop pollination by bees*. - CABI Publishing, Oxon, UK, pp. 344.

DEWENTER I.S., POTTS S.G., PACKER L., 2005 - *Pollinator diversity and crop pollination services are at risk*. - Trends Ecol. Evol., 20(12): 651-652.

DIEKOTTER T., HAYNES K.J., MAZEFFA D., CRIST T.O., 2007 - *Direct and indirect effects of habitat area and matrix composition on species interactions among flower-visiting insects*. - Oikos, 116(9): 1588-1598.

DOBRYNIN N.D., 1998 - *Alfalfa pollinators in the Central black-soil region of Russia and ecological bases of their protection, management, and utilization*. - Thesis, Russian Academy of Sciences, Moscow, Russia [In Russian].
FREE J.B., 1968 - *Pollination of strawberries by honey bees*. - J. Hortic. Sci., 43: 107-111.
FREE J.B., 1993 - *Insect pollination of crops*. - 2nd Edition, Academic Press, London, UK, pp. 768.
FREE J.B., SMITH M.V., 1961 - *The foraging behaviour of honeybees from colonies moved into a pear orchard in full flower*. - Bee World, 42(1): 11-12.
GHAZOUL J., 2005 - *Buzziness as usual? Questioning the global pollination crisis*. - Trends Ecol. Evol., 20(7): 366-372.
GOODMAN R.D., OLDROYD B.P., 1988 - *Honeybee pollination of strawberries (*Fragaria *x* ananassa *Duchesne)*. - Aust. J. Exp. Agric., 28(3): 435-438.
GOULSON D., 2003 - *Effects of introduced bees on native ecosystems*. - Annu. Rev. Ecol. Evol. Syst., 34(1): 1-26.
GREENLEAF S.S., KREMEN C., 2006 - *Wild bee species increase tomato production and respond differently to surrounding land use in Northern California*. - Biol. Conserv., 133(1): 81-87.
HERRERA C.M., 1987 - *Components of pollinator 'quality': comparative analysis of a diverse insect assemblage*. - Oikos, 50(1): 79-90.
HERRERA C.M., 2000 - *Measuring the effects of pollinators and herbivores: evidence for non-additivity in a perennial herb*. - Ecology, 81(8): 2170-2176.
JOHNSON R., 2008 - *Recent honey bee colony declines*. - CRS Report for Congress, 28 May, pp. 19. - Available in: http://www.fas.org/sgp/crs/misc/RL33938.pdf [15 Sep. 2009].
KEARNS C.A., INOUYE D.W., WASER N.M., 1998 - *Endangered mutualisms: the conservation of plant-pollinator interactions*. - Annu. Rev. Ecol. Evol. Syst., 29(4): 83-112.
KLEIJN D., VAN LANGEVELDE F., 2006 - *Interacting effects of landscape context and habitat quality on flower visiting insects in agricultural landscapes*. - Basic Appl. Ecol., 7(3): 201-214.
KREMEN C., WILLIAMS N.M., BUGG R.L., FAY J.P., THORP R.W., 2004 - *The area requirements of an ecosystem service: crop pollination by native bee communities in California*. - Ecol. Lett., 7(11): 1109-1119.
KRUESS A., TSCHARNTKE T., 1994 - *Habitat fragmentation, species loss, and biological control*. - Science, 264(11): 1581-1584.
LÓPEZ-MEDINA J., 2002 - *Análisis y evaluación agronómica de las deformaciones de fruto en fresa (*Fragaria *x* ananassa *Duch.). Posibles soluciones. Resultados preliminares 2002*. - Work document for internal use. [In Spanish].
LÓPEZ-MEDINA J., PALÁCIO VILLEGAS A., VAZQUEZ-ORTIZ E. 2006 - *Misshaped fruit in strawberry, an agronomic evaluation*. - Acta Horticulturae, 708: 77-78.
MALAGODI-BRAGA K.S., 2002 - *Estudo de agentes polinizadores em cultura de morango (*Fragaria *x* ananassa *Duchesne-Rosaceae)*. - Thesis, Instituto de Biociências, Universidade de São Paulo, São Paulo, Brazil [In Portuguese].
MARCO J.R.P., COELHO F.M., 2004 - *Services performed by the ecosystem forest remnants influence agricultural cultures pollination and production*. - Biodiversity Conserv., 13(7): 1245-1255.
MATHESON A., BUCHMANN S.L., O'TOOLE C., WESTRICH P., WILLIAMS I.H., 1996 - *The conservation of bees*. - Academic Press, Harcourt Brace, London, UK, pp. 254.
MCGREGOR S.E., 1976 - *Insect pollination of cultivated crop plants*. - Available in: http://www.beeculture.com/content/pollination_handbook/strawberry-1.html [9 Mar. 2009].
MICHENER C.D., 2000 - *The bees of the world*. - The Johns Hopkins University Press, USA, pp. 913.
MORANDIN L.A., WINSTON M.L., 2006 - *Pollinators provide economic incentive to preserve natural land in agroecosystems*. - Agric., Ecosyst. and Environ., 116(3-4): 289-292.
NYE W.P., ANDERSON J.L., 1974 - *Insect pollinators frequenting strawberry blossoms and the effect of honey bees on yield and fruit quality*. - J. Am. Soc. Hortic. Sci., 99(1): 40-44.
OHISHI T., 1999 - *Appropriate management of honeybee colonies for strawberry pollination*. - Honeybee Science, 20(1): 9-16.
PAYDAS S., ETI S., KAFTANOGLU O., YASA E., DERIN K., 2000 - *Effects of pollination of strawberries grown in plastic greenhouses by honeybees and bumblebees on the yield and quality of the fruits*. - Acta Horticulturae, 513: 443-451.
PION S., DE OLIVEIRA D., PARADIS R.O., 1980 - *Agents pollinisateurs et productivité du fraisier 'Redcoat'*. - Phytoprotection, 61: 72-78.
POTTS S.G., 2004 - *European pollinator iniciative: assessing the risks of pollinator loss*. - Proc. First European Conference of Apidology (EURBEE'04), Udine, Italy, pp. 68.
POTTS S.G., PETANIDOU T., ROBERTS S., O'TOOLE C., HULBERT A., WILLMER P., 2006 - *Plant-pollinator biodiversity and pollination services in a complex Mediterranean landscape*. - Biol. Conserv., 129(4): 519-529.
PROCTOR M., YEO P., LACK A., 1996 - *The natural history of pollination*. - Harper Collins, London, UK, pp. 487.
RICKETTS T.H., 2004 - *Tropical forest fragments enhance pollinator activity in nearby coffee crops*. - Conserv. Biol., 18(1): 1-10.
ROUBIK D.W., 1995 - *Pollination of cultivated plants in the tropics*. - Food and Agriculture Organization of the United Nations, Rome, Italy, pp. 196.
SHULER R.E., ROULSTON T.H., FARRIS G.E., 2005 - *Farming practices influence wild pollinator populations on squash and pumpkin*. - J. Econ. Entomol., 98(3): 790-795.
STEFFAN-DEWENTER I., TSCHARNTKE, T., 1997 - *Early succession of butterfly and plant communities on set-aside fields*. - Oecologia, 109(2): 294-302.
STERN R.A., GOLDWAY M., ZISOVICH A.H., SHAFIR S., DAG A., 2004 - *Sequencial introduction of honeybee colonies increases cross-pollination, fruit-set and yield of 'Spadona' pear (*Pyrus communis *L.)*. - J. Hortic. Sci. and Biotechnol., 79(4): 652-658.
SUGDEN E.A., 1993 - *The africanized honey bee phenomenon: potential societal interactions*. - Am. Bee. J., 132: 691-692.
SVENSSON B., 1991 - *The importance of honeybee-pollination for the quality and quantity of strawberries (*Fragaria *x* ananassa*) in central Sweden*. - Acta Horticulturae, 288: 260-264.
TALAVERA S., BASTIDA F., ORTIZ P.L., ARISTA M., 2001 - *Pollinator attendance and reproductive success in* Cistus libanotis *L. (Cistaceae)*. - Int. J. Plant Sci., 162(2): 343-352.
WILLIAMS C.S., 1995 - *Conserving Europe's bees: why all the buzz?* - Trends Ecol. Evol., 10(8): 309-310.