Scientia Horticulturae 204 (2016) 138–144

Contents lists available at ScienceDirect

Scientia Horticulturae

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

Comparing the pollination services of honey bees and wild bees in a watermelon field

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ARTICLE INFO

Article history:
Received 30 November 2015
Received in revised form 3 April 2016
Accepted 4 April 2016
Available online 16 April 2016

Keywords:
Apis mellifera
Lasioglossum
Pollination
Pollination services
Watermelon
Wild bee

ABSTRACT

Field studies of pollination services of honey bees and wild bees were carried out at a watermelon crop in western Crete. Specifically, pollination treatment by honey bee or mining bee species was applied to female flowers of a watermelon plant. There were also three other treatments; a no-visit treatment, an open-pollinated treatment and a 'hand' pollination treatment. Comparisons were based on the number of single bee visits to treated flowers, fruit abortion rates, seed sets as influenced by bee type and the quality characteristics of the developed fruit. The main representative genus of wild bees in the studied area was *Lasioglossum*. Whilst it was possible that a single visit from either bee type effected pollination, wild bees needed a significantly lower mean number of visits to effect pollination than honey bees. In particular they spent three times as long at each flower compared to *Apis mellifera*. None of the studied quality characteristics of the developed watermelon fruits (mean weight, brix, number of seeds per fruit and weight of seed) differed significantly for both tested pollinators. The current study provides theoretical and practical evidence to the growers of watermelon crop of the existence of alternative pollinator species that can be targeted for development and management because of their high pollination efficiencies. Therefore the results support the hypothesis that the native bee community can provide an equivalent service to that of managed honey bee pollinators for watermelon, a crop that has heavy pollination requirements.

1. Introduction

Pollinators play an important functional role in most terrestrial ecosystems and provide a key ecosystem service (Ashman et al., 2004). Estimates showed that up to 90% of all flowering plant species rely on pollination by insects (Richards, 1986; Buchmann and Nabhan, 1996). Insects, particularly bees, are the primary pollinators for the majority of the world's angiosperms (Ollerton et al., 2012). Without this service, many interconnected species and processes functioning within both wild and agricultural ecosystems could collapse (Kearns et al., 1998). The European or western honey bee *Apis mellifera* L. (Hymenoptera: Apidae) is the most common managed pollinator worldwide. Bees stand out as the dominant pollinating group in nearly all geographical regions (Kearns, 1992). But, as demand for pollinator-dependent crops increases, honey bees may not be able to meet pollination requirements (Aizen and Harder, 2009; Breeze et al., 2014). It is known that honey bee visitation rates can be a limiting factor in the commercial production of cucumber, watermelon, and other crops in the Curcubitaceae (Brett and Sullivan, 1972; McGregor, 1976). Another complicating factor is that blossoms from neighboring weeds, native vegetation, and other commercial crops may be more attractive to honey bees than watermelon or cucumber blossoms (Brett and Sullivan, 1972).

Thus, increased attention has been placed on wild bees as alternative pollinators. Wild bees currently play a significant role in crop pollination, and are estimated to provide $150 billion in pollination services globally (Gallai et al., 2009). Several studies show that many wild bees are also efficient pollinators of crops (Klein et al., 2007; Winfree et al., 2008; Breeze et al., 2011). Recently, Garibaldi et al. (2013) reported positive associations of fruit set with

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http://dx.doi.org/10.1016/j.scienta.2016.04.006
0304-4238/

wild-insect visits to flowers in 41 crop systems worldwide. In this meta-analysis of 29 studies conducted around the world found that fruit set significantly increased with visitation rates and species richness of wild pollinators. Agroecosytems with greater richness of wild bees may also be more likely to contain the most effective pollinator species which act complementary during the day, season, along extreme climatic conditions and disturbance levels. Bees vary in pollen load, pollen deposition rates, and in floral constancy, foraging distances etc. all of which determine a pollinator's efficacy (Delaplane and Mayer, 2000; Mitchener, 2000). Greater wild bee diversity may result in redundancy that provides stability in climatic or human induced disturbances (Winfree and Kremen, 2009; Bartomeus et al., 2013). For instance, organic farms of California that are located near native habitats could receive adequate pollination from wild bees alone (Kremen et al., 2002a,b). It is obvious, as intensification increases, pollination services decrease by 3- to 6-fold due to low biodiversity of species.

That visits by wild pollinators may increase fruit set, even where substantial quantities of managed bees are present, suggests that the pollination contribution of wild bees is unique and additive to that of managed bees (Carvalheiro et al., 2010). In agro-ecosystems where populations of wild bees were high, these unmanaged insects were estimated to fully pollinate crops (Kremen et al., 2002a,b; Winfree et al., 2007; Rader et al., 2012). But, in regions where wild bee abundance or diversity was low, the estimated pollination by wild bees was insufficient to achieve an acceptable crop yield without managed bees (Scott-Dupree and Winston, 1987; Kremen et al., 2002a,b).

Watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai; Cucurbitaceae] is a crop that has been well documented for its dependence on insect pollinators for fruit and seed set due to its monoecious flowering condition of separate staminate (male) and pistillate (female) flowers (Free, 1993; Adlerz, 1996). In fact, numerous studies have even shown that watermelon plants in exclusion cages will not set fruit (Adlerz, 1996; Stanghellini et al., 1998). Each female watermelon flower also requires approximately 500–1000 viable pollen grains for complete fertilization of ovules (Adlerz, 1996; Kremen et al., 1998) and it has been found to require at least 6–8 honey bee visits for successful pollination (Adlerz, 1996; Stanghellini et al., 1997). Many watermelon growers rent honey bee colonies to ensure that maximum fruit set and development occurs. However, Kremen et al. (2002b) recorded 28 native solitary and two native social bee species which pollinated watermelon in North America.

Although the visitation patterns of honey bee on watermelon have been studied (Njorogea et al., 2004; Gikungu, 2006; Kasina, 2007; Karanja, 2010), it is important to compare its performance with that of other important wild bee pollinators. Stebbins (1970) defined clearly the two key components of pollinator actions that shape pollinator performance: the 'frequency' and 'effectiveness' of flower visits. While 'frequency' is usually simply defined as the number of visits per flower per unit time, the 'effectiveness', is open to various, and sometimes contrasting, interpretations. Keys et al. (1995) defined the term 'pollination efficiency' as 'the relative ability of an insect to pollinate flowers effectively as measured by seed/fruit production per some unit of measure'. Mayfield et al. (2001) defined 'pollination effectiveness' as the amount of pollen transferred to a virgin flower after a single visit, and the resulting seed set. Javorek et al. (2002) measured 'pollination effectiveness' in terms of floral visitation rate, percentage of flowers pollinated and pollen deposition.

In this study, the performance of both wild bees and managed bees is evaluated by taken into consideration the number of flower visits per plant; number of visits which resulted in pollination (development of a fruit); fruit abortion rates; time spent on each female flower and quality characteristics of the developed fruits in a watermelon field.

2. Materials and methods

2.1. Watermelon crop

Watermelon seedlings were produced under greenhouse conditions (April of 2013 and 2014) and then were transplanted at the two and three true-leaf stage into the open field. The experiment was a randomized complete block design with 45 replications in 2013 (a total of 225 plants) and 25 replications (a total of 150 plants) in 2014. Each block consisted of 5 plants (1 m distance between plants within block and 3 m distance between blocks) and blocks of plants were installed in the field at 3 planting dates (mid, end of May and mid of June) of each year.

Mulching was applied to the plants across the lines of the field in order to prevent growing of wild plants. During the whole studied period, weeds were controlled by hand. No pest control practice was applied during 2013 whilst during 2014 a fungicide treatment was applied to the plants just after planting. In addition, fertilizer was applied twice during the establishment stage of the plants. Overhead drip irrigation was used to ensure that plants received at least 45 l water per plant per week throughout the growing season.

2.2. Experimental area

The experimental field (35° 29′ 31. 96″N–24° 02′ 59. 29″ E elev 5m) was situated on the island of Crete (southern part of Greece) in Souda region (Chania, Crete). The size of the field was about 20 m wide and 33.5 m in length (less than 0.1 ha) and it was surrounded by an organic orchard of citrus and lemon varieties as well as many aromatic plants within 500 m radius of the trial. There are various native weeds within the orchard, as well as at the boundaries.

The experiment was conducted for two successive growing years (May–September) of 2013 and 2014. Mean temperature for May, June, July, August and September of 2013 and 2014 was 21.9, 23.8, 26.1, 26.4, 24.6 and 20.1, 24.6, 26.6, 27.6, 24.7 °C respectively. The average daily pan evaporation during the experiment was 12.5 mm.

Organic matter content, pH and electrical conductivity (EC) of the top 0.3 m of soil were 2.15%, 8.1, and 0.49 mmhos/cm, respectively. Soil texture was silt 38.83%, clay 36.47% and sand 23.98%.

2.3. Evaluation of pollinators

Initially observations of each female flower were performed daily from 8:00 to 12:00 am This period was chosen because of the following factors: known pollen viability, stigma receptivity (Sedgley and Buttrose, 1978; Njorogel et al., 2010) and honey bee (Ambrose et al., 1995) or mining bee (Njorogel et al., 2010) foraging activity. No pollination was possible after this time as the female flowers began to close and honey bee foraging activity is reduced.

Once the female flower appeared on each watermelon plant (in the bud stage), it was carefully isolated within a small net cage (a plastic vase with a lid/cap, diameter of 10 cm, with a hole of 8 diameter which was covered with a net) in order to prevent any contact of stigmas with pollinating insects.

cages were removed and individual flowers were given their designated pollination treatment. Each treatment was randomly applied to all female flowers of a single plant of each block. The following five pollination treatments were applied:

1) '*control*' when the stamens of a male flower were lightly brushed on the anther of a female flower by hand,