Saudi Journal of Biological Sciences (2017) **24**, 180–191

King Saud University

Saudi Journal of Biological Sciences

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Nectar secretion dynamics and honey production potentials of some major honey plants in Saudi Arabia

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Received 17 October 2015; revised 20 April 2016; accepted 2 May 2016
Available online 10 May 2016

KEYWORDS

Bee plant;
Floral phenology;
Honey;
Melliferous plants;
Nectar secretion;
Nectar sugar

Abstract The contribution of a bee plant species to honey production depends on the plant's nectar secretion quality and quantity, which is mainly governed by biotic and abiotic factors. The aim of the current study, was to investigate the nectar secretion dynamics and honey production potential of 14 major bee plant species of the target area. We examined the quantity and dynamics of nectar sugar per flower five times a day using a nectar sugar washing technique and direct measuring of nectar with calibrated capillary tubes. The average nectar sugar amount of the species varied from 0.41 mg/flower to 7.7 mg/flower ($P < 0.0001$). The honey sugar per flower was used to extrapolate the honey production potential per plant and per hectare of land. Accordingly the honey production potential of the species observed to vary from 14 kg/hectare in *Otostegia fruticosa* to 829 kg/hectare in *Ziziphus spina-christi*. The nectar secretion dynamics of the species generally showed an increasing trend early in the morning, peaking toward midday, followed by a decline but different species observed to have different peak nectar secretion times. Generally, the tree species secreted more nectar sugar/flower than the herbs. The nectar secretion amount of the species was positively correlated with the ambient temperature, indicating the adaptation of the species to hot climatic conditions. However, different species were observed to have a different optimum temperature for peak nectar secretion. Despite the limited rainfall and high temperature of the area, many plants were found to have good potential for honey production. The monetary value of honey

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Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.sjbs.2016.05.002

per hectare of the studied honeybee plant species can be of equal or greater than the per-hectare monetary value of some cultivated crops that require numerous inputs. In addition, the information generated is believed to be useful in apiary site selection and to estimate the honey bee colony carrying capacity of an area.

1. Introduction

Honey bee plants are those plant species that provide bees with food sources in the form of nectar and/or pollen. According to Crane (1990), only 16% of the world's flowering plant species contribute to honey bees as food sources. Moreover, not all bee plants are equally important to bees and honey production. Indeed, only 1.6% of the world's honey bee plants are the sources of most of the world's honey (Crane, 1990). This indicates that for every geographical region there are very few important honey source plants and it is of paramount importance to characterize them according to their degree of importance in honey production. Several studies have been performed on different plant species to quantify nectar secretion and to explore its dynamics, mainly in relation to pollination biology, floral phenology and biophysical environmental factors (e.g., Petanidou and Smets, 1996; Castellanos et al., 2002; Galetto and Bernardello, 2004). Moreover, quantitative studies on the nectar secretion of various melliferous plants have been conducted (Pesti, 1976; Mohr and Jay, 1990; Nepi et al., 2001; Farkas and Orosz-Kovács, 2003; Horváth and Orosz-Kovács, 2004; Zajácz et al., 2006). In addition, based on thorough studies of dynamics of nectar secretion and total soluble solids (TSS) concentration, it has been possible to estimate the honey production potentials of some major honey source plants such as *Trifolium pratense* L. (red clover) (883 kg of honey/ha/flowering season; Szabo and Najda, 1985); *Asclepias syriaca* L. (milkweed) (500–600 kg honey/ha/flowering season; Zsidei, 1993) and *Phacelia tanacetifolia* Benth (60–360 kg honey/ha/flowering season; Nagy, 2002). In addition, Crane et al. (1984) reported that the honey production potential of different *Tilia* (lime) species ranged from 90 to 1200 kg honey/ha. Moreover, Kim et al. (2011) estimated the amount of nectar secreted per flower and per tree for *Crataegus pinnatifida* Bunge (Chinese hawthorn).

Nonetheless, most of the studies have focused on melliferous plant species of temperate and subtemperate regions. Many important honey source plants of the tropics, subtropics and arid climatic zones, their nectar secretion potentials and their significance for honey production have not yet been well studied and documented. In Saudi Arabia, approximately 2200 flowering plants are reported to exist (Collenette, 1999; Chaudhary, 1999). The families *Fabaceae*, *Lamiaceae* and *Rhamnaceae*, which account for a significant share of the flowering plants of the country, are generally known as good sources of nectar for honey bees. Among these, some species from the genus *Acacia*, *Lamaceae* (*lavandula*), *Ziziphus* and others are known for being very good sources of honey. However, detailed characterization of the species, particularly the amount and dynamics of their nectar secretion are lacking.

The genus *Acacia* comprises more than 1200 species that are distributed in tropical and subtropical parts of the world, extending into the deserts of Africa and the Middle East and into large areas of the Arabian Peninsula (Wickens, 1995; Tandon and Shivanna, 2001; UNESCO, 1977; Walter and Breckle, 1986). The species are drought-tolerant and endures in the rainfall belts of 50–400 mm/annum (Wickens, 1995; Le-Houérou, 2012). Moreover, these species have multipurpose uses as important sources of firewood, timber, forage, gum, tannins, fiber, folk medicine, and food, and they are also useful for environmental protection and soil and water conservation (Boulos, 1983; Wickens, 1995; Midgely and Turnbul, 2003). They also contribute to the conservation of large numbers of herbivorous vertebrates and invertebrates (Krüger and McGavin, 1998) as well as many species of nectarivorous insects. Different species of *Acacia* have been reported as important honey bee forages in many semiarid regions of the tropics (Wickens, 1995; Stone et al., 1996, 1998). About 10 *Acacia* species, such as: *Acacia origena* Hunde, *Acacia johnwoodii* Boulos, *Acacia tortilis* Forssk., *Acacia asak* (Forssk.) Willd., *Acacia ehrenbergiana* Hayne, *Acacia etbaica* Schweinf., *Acacia oerfota* (Forssk.) Schweinf., *Acacia gerrardii* Benth. and others, have been reported to exist in Saudi Arabia, but their roles in honey production have not been quantified and documented.

The other important honey source plant family is *Lamiaceae*, which encompasses approximately 7200 species. This family is one of the most cosmopolitan in distribution, covering large areas in the world (Martin et al., 2013). According to recent studies, the *Lamiaceae* family is represented by 76 species in Saudi Arabia, most of which are useful for their medicinal values and antimicrobial properties (Abbasi et al., 2010; Dulger and Dulger, 2012; Raja, 2012; Venkateshappa and Sreenath, 2013; Saqib et al., 2014). Within *Lamiaceae*, the genus *Lavandula* is particularly important because it is naturally occurring and extensively cultivated in many parts of the world (Chu and Kemper, 2001; Boning, 2010; Lalande, 1984). The species grows well in arid and semiarid parts of the world and even in areas vulnerable to desertification (Azcón and Barea, 1997). Some of the species in genus *Lavendula* are used in cosmetics, food processing and aromatherapy (Welsh, 1995; Chu and Kemper, 2001; Lis-Balchin, 2003). Many species from *Lamiaceae* are known as good sources of high quality monofloral honey with a characteristic aroma and flavor (Tsigouri and Passaloglou-Katrali, 2000; Nicoleta, 2008; Nicoleta and Ion, 2007; Forler, 2013). Monofloral honeys from *Lavandula* sp. fetch premium prices ($50/kg) in specialty food stores (Forler, 2013).

Five *Lavandula* species (*Lavandula atriplicifolia* Benth, *Lavandula citriodora*, *Lavandula coronopifolia* Poir, *Lavandula stricta* Del., *Lavandula dentata* L. and *Lavandula pubescens*, Decne) grow naturally in Saudi Arabia (El-Karemy and Zayed, 1992; Rahman et al., 2003). The country is known as one of the main geographical area of *Lavandula* species diversity and endemism and has been suggested to be the center of