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**Type:**

Original paper

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# Floral phenology, nectar secretion dynamics and honey production potentials of two lavender species (*Lavendula dentata, and L. pubescens*) in southwestern Saudi Arabia

**Running head:** Nuru et al. Honey production potentials of lavender species

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**Abstract**

The aim of the current study was to determine the floral phenology, nectar secretion dynamics and honey production potentials of two naturally growing lavender species *(L. dentata and L. pubescens),* which are some of the major sources of honey in southwestern Saudi Arabia. In both species, each individual flower remains open for only one day. However, flowering is continuous; that is, when open flowers on a spike are shaded, new flowers emerge. Such flowering pattern might be advantageous to the plant to minimize competition for pollinators and promote efficient resource allocation. The flowering periods of the two species overlap. Both species  secreted increasing amounts of nectar from early morning to late afternoon, with the mean maximum volumes of accumulated nectar from bagged flowers occurring at 1500h for *L. pubescens* (0.50 ± 0.24 µl/flower) and at 18:00 h for *L. dentata* (0.68 ± 0.19 µl/flower). The volume of the nectar that became available between two successive measurements (three-h intervals) varied from 0.04 µl/flower to 0.28 µl/flower for *L. pubescens* and from 0.04 µl/flower to 0.35 µl/flower for *L. dentata*, reflecting the variation in the dynamics of nectar secretion by these species and indicating the size of the nectar that may be available for flower visitors at given time intervals. The distribution of nectar secretions appears to be an adaptation of the species to reward pollinators for longer duration. Based on the mean amount of nectar sugar secreted by the plants, the honey production potentials of the species are estimated to be 4973.34 mg and 3463.41 mg honey/plant for *L. dentata* and *L. pubescens*, respectively.

**Key words:** Lavendula, flower morphology, flowering period, nectar  secretion, Saudi Arabia

## Introduction

The majority of lavender species are indigenous to the mountainous regions of the western Mediterranean countries, the islands of the Atlantic, Turkey, Pakistan and India (Chu and Kemper, 2001). Moreover, they are native to northern, eastern and southern Africa; the Arabian Peninsula; Bulgaria; and Russia (Boning, 2010).

Lavender species survive, and can thrive, in arid and semi-arid regions of the world, even in areas threatened by desertification (Azcón and Barea, 1997), and it is known as extremely drought resistant once established. Species of lavender prefer gravelly, slightly alkaline and limestone-based soils (Boning, 2010), and certain species (*Lavendula dentata* and *L. pubescens)* because of their thick branching from the base, are useful in soil erosion control.

Today, lavender species are extensively cultivated throughout the world, particularly in France, Bulgaria, Russia, Italy, Spain, England, the USA, and Australia (Lalande, 1984; Boning, 2010). They are grown commercially for the extraction of essential oils, which are used in perfumery, in cosmetics, as ingredients in numerous cottage industry products, in food processing, as massage products, as culinary herbs and as ornamental plants (Lis-Balchin, 2003). Certain types of lavender oil have also been shown to have antimicrobial and antifungal properties (Chu and Kemper, 2001; Lis-Balchin, 2003), and the oils from the plants are also widely used in aromatherapy (Welsh, 1995; Lis-Balchin, 2003).

Several species of lavender are visited frequently by honeybees, and where there is dense growth, the plants serve as sources of premium mono-floral honeys with characteristic physical properties such as a flowery, pleasant, very fine aroma and delicate floral scent with an evident of lavender component (Forler, 2013). Numerous countries, including France, Spain, Italy, Bulgaria, England, the former members of USSR and Yugoslavia, Australia, the USA, Canada, South Africa, and Tanzania are known for the production of lavender honeys (Forler, 2013). Lavender honeys can command a premium price of approximately $50/kg in specialty food stores.

In Saudi Arabia, there are five naturally growing lavender species: *L. atriplicifolia* Benth, *L. citriodora*, *L. coronopifolia* Poir., *L. stricta* Del., *L. dentata* L. and *L. pubescens* Decne (El-Karmy and Zayed, 1992; Rahman et al., 2003). The country is known as one of the main geographical areas of lavender species diversity and endemism, and it has been suggested as a center of origin for the genus (Miller, 1985). Uses of *L. dentata*, *L. coronopifolia*, *L. pubescens*, and *L. stricta* as medicinal plants in Saudi Arabia have been reported (Rahman et al., 2003). Within the country, *Lavandula* species such *L. dentata* and *L. pubescens* are widely distributed in the mountainous regions of Taif, Albaha and Asir and serve as sources of high-quality lavender honeys, locally known as "*Seyfi honey*," that sell for a premium price of $50-120/kg.

The majority of the studies on lavender species have been limited to cultivated and commercial cultivars, whereas the growth and honey production of the species under their natural conditions, particularly in the semiarid areas of the Arabian Peninsula remain unaddressed. Despite the natural occurrence of multiple lavender species in the region and their remarkable ability to withstand extreme drought conditions, their ecological and socio-economic values, floral biology, nectar secretion dynamics and honey production potentials have not been documented.

Based on detailed studies on the dynamics of nectar secretion, including the amount and sugar concentration, it has been possible to estimate the honey production potentials of several important honey source plants, e.g., *Asclepias syriaca* L. (500-600 kg honey/ha/flowering season) (Zsidei, 1993), *Trifolium pretense* L. (883 kg of sugar/ha/flowering season) (Szabo and Najda, 1985), and *Phacelia tanacetifolia* Benth (60-360 kg honey/ha/flowering season) (Nagy, 2002). Moreover, Crane et al. (1984) reported the honey production potential of different lime species (*Tilia* spp.) range from 90 to 1200 kg honey/ha. Recently, Kim et al. (2011) quantified the amount of nectar secreted per flower and per tree for *Crataegus pinnatifida* Bunge. Moreover, the amount and dynamics of nectar secretion have been used to estimate the honey production potential of *Ziziphus spina-christi* (Nuru et al., 2012). In this general context, the aim of the current study was to determine the floral phenology, nectar secretion dynamics and honey production potentials of the two major naturally growing *Lavandula* species (*L. dentata*, and *L. pubescens*) which are used as important sources of honey in regions of southwestern Saudi Arabia.

## Materials and methods

### Study site and species description

The study was conducted in the area of Baljurashi, Al-Baha region, Saudi Arabia, at 19°52'06.819" N and 41°36'48.218" E, at 2050 meter above sea level. The study area is categorized under the highland physiographic and climatic conditions. The humidity ranges from 52%-67%, and the rainfall ranges from 229-581 mm/annum with a mean temperature of 22.9°C (Al-Baha Meteorological Station, 2012). The studied species are mainly growing on gentle to steeply sloping lands in shallow, rocky, limestone-based soil types (Fig. 1 A & B). The plants, in some locations, occur as dominant vegetation type while in other sites grow in association with various species such as *Olea chrysophylla* Lam., *Juniperus procera* Hochst., *Psiadia punculata* (DC.) Vatke., *Dodonaea angustifolia* L.f., *Maytenus spp.* and *Acacia origena* Asfaw. Both *L. pubescens* and *L. dentata* grow naturally with almost overlapping distributions under the same environmental conditions. *L. dentata* is much branched, bushy shrub type up to 75 cm tall. Leaves are aromatic, sessile, linear, up to 35 mm long 3 mm wide with strongly revolute-margined. Inflorescences are dense with terminal spike, up to 7 cm long. *L. pubescence* is also densely spreading perennial herb, up to a meter tall, branches glandular-pubescent. Leaves petiolate, deeply dissected into short, oblong-linear lobules. Inflorescences are dense, with branched or unbranched terminal spikes. Both species are characterized by their remarkable adaptation to long dry periods via the suppression of their physiological activity during this period both the leaves and spikes look like completely dry however, when there is sufficient moisture, they rapidly resume their growth and produce numerous new young shoots and flowering buds.

### Floral and plant morphological features

The morphological features of the flowers, such as the shape of flower and their arrangements were observed and described. Moreover, the number of flower lobs and the depth of the corolla tubes were characterized by measuring 10 flowers per plant and 50 flowers/species.

The mean length and number of spike per plant was determined by counting all spikes from 20 (*L. pubescens*) and 10 (*L. dentata*) plants. The mean number of flowers per plant was obtained by counting the mean number of spikes per plant and multiplying by the mean number of flowers/spike.The mean number of flowers/spike was obtained by counting the number of flowers per spike ($N$ = 51 for *L. dentata* and $N$ = 76 for *L. pubescence*). In addition to the floral features, the plant morphological features such as: plant height, crown height and crown diameter were determined by measuring 63 and 47 individuals of *L. dentata* and *L. pubescens*, respectively.

**Flower phenology and flowering period distribution**

To determine the phenology of flowers, three individual plants per species were labeled. From each plant, eight mature flower buds/day were marked in late afternoon to be monitored the following day. When marking, all of the previously opened flowers from the spike were carefully removed to prevent confusion. On the next morning, development of flower buds was monitored every 2 h from 06:00 to 18:00. The observations were replicated for three consecutive days (a total of 72 flowers/species). The time of flower opening and flower abscission, and the life span of a single flowering were recorded.

The flowering period patterns (commencement, peak, and end) and total duration of flowering were determined by monitoring and recording the flowering periods for each species. For this purpose, a proportional sampling was performed; 20 and 10 individual plants of *L. pubescens* and *L. dentata*, respectively, were selected and labeled before the commencement of flowering. During selection, an effort was made to choose plants representative of differing land gradations (flat, gently sloped and steeply sloped lands), ages and branching conditions. For each labeled plant, the number of shoots (spikes) that initiated flowering was recorded every week from the commencement of flowering until the end of flowering. The peak flowering was considered as the time at which more than 50% of the potential flower buds were in the stage of blooming.

**Amount and dynamics of nectar secretion**

The amount of nectar secreted per flower and its dynamics were determined for a total of six individual plants (three plants/species). The amount of nectar was estimated five times per day at

06:00, 09:00, 12:00, 15:00 and 18:00. The flower buds were bagged a day before opening using bridal-veil netting (Wyatt et al., 1992). From each plant and at each sampling time, the amount of nectar was measured in ten flowers (a total of 50 flowers/day/plant). The nectar volume measurement was repeated for three consecutive days (total of 450 flowers/species). Each flower was measured only once. The volume of nectar contained in the flower was determined by directly removing the nectar using 1 µl capillary tubes (Drummond Scientific Company, USA). Then the volumes of nectar were compared between the species.

**Honey production potential**

The honey production potential was estimated by multiplying the mean number of flowers/plant by the mean amount of nectar sugar/flower. The mean mass of sugar in the secreted nectar was calculated from the volume and concentration of the solution measured using a pocket refractometer (ATAGO, No. 3840, Japan). The honey production potential per plant was calculated by multiplying the mean number of spikes per plant by the mean number of flowers/spike and then multiplying by mean nectar sugar/flower following the method described by Kim et al. (2011). These data were used to estimate the honey production potential/plant and to further extrapolate the honey production potential/ha for each species. The estimation of the number of plants per hectare was based on considering the maximum number of plants that can be found in densely grown natural fields or commercially cultivated fields. The estimation was also based on the mean canopy diameter of each species and the space required between plants. For the determination of the mean canopy diameter; 63 and 47 individual plant crown dimensions were measured for *L. dentata* and *L. pubescens*, respectively.

**Weather data**

In addition to the above-described observations, weather data such as the temperature, and relative humidity (RH) of the area were recorded at each sampling time using an Environment Meter (N09AQ, UK).

**Statistical analyses**

One-way ANOVA t-test and f-test results were computed to compare means between the species and among the times of day, respectively; Two-way ANOVA was employed to determine the effect of the interaction between the time of day and species. Correlation and regression analyses were performed to explore the relationship of nectar secretion with the morphological and weather condition parameters. The JMP-5 statistical software (SAS, 2002) was employed for the analyses.

## Results

### Flower morphology and arrangement

The flowers of *L. pubescens* arise from an elongated spike that varies from 4.6 to 18.0 cm in length, with a mean length of 9.7 cm (Fig. 2). Some of the spikes are branched and a single spike contains, on average, 64.0 flowers. The corolla are deep blue and are bilabiate, with upper lip 2-lobed and the lower 3-lobed. The total length of the corolla varies from 10.0 to 15.0 mm, with a mean of 12.6 mm, of which, approximately 8 - 10 mm forms the corolla tube. Pistil bicarpellate, style branches flat. Stamens 4, concealed in the corolla tube, didynamous, the anterior pair longer. The anthers are located 2-3 mm below the mouth of the corolla tube.

The inflorescence in *L. dentata* (Fig. 3) is dense with terminal spike. The length of the spike ranges between 3.5 and 6.2 cm (mean of 4.5 cm). A single spike contains, on average, 91.0 small flowers. Corolla bilabiate, with 5-lobed limb. The corolla tube is about 4-5 mm in depth. The total length of the corolla varies between 6 and 9 mm (mean of 7.6 mm). Stamens 4, and are concealed in the corolla tube, didynamous, the anterior pair longer. Pistil bicarpellate, style branches flat.

### Flower phenology and Flowering period (season) distribution

From the 72 total flower buds marked per species, 63 and 59 were observed to open in the morning (06:00) for *L. pubescens* and *L. dentata*, respectively indicating in both species the peak opening time is morning. All of the remaining flowers from both species opened by 10:00. From 16:00 to 18:00, 65 of the *L. pubescens* and 57 of *L. dentata* labeled flowers wilted and dropped their petals, and the remaining few flowers lasted up to 18:00, indicating that a single flower generally stays for less than one day. Between 12:00 and 18:00, a number of new flowers were observed to open from buds other than the labeled ones, indicating that, in both species, the opening of flowers is continuous, that is when 5-7 previously opened flowers/spike shade off, about the same number of new flowers/spike sequentially open with a certain degree of overlaps among individual flowers opening times; hence, the time of flower opening is not restricted within a day.

Although the two species grow under the same ecological conditions, there was a slight difference in the timing of flowering. Plants of *L. pubescens* started to flower slightly earlier than those of *L. dentata* (Fig. 4). *Lavendula pubescens* commenced flowering in winter in mid-December. The species continued to flower throughout January and March, with peak flowering occurring in February, and flowering ended after the first week of March lasting for about 80 days.

*Lavendula dentata* commenced and finished flowering relatively later in the season than *L. pubescens*, starting flowering in the first week of January and attaining its peak between the second week of February and the first week of March. The plants continued flowering until the third week of March, and flowering ended at the end of March, indicating that *L. dentata* exhibits an extended flowering period lasting for about 90 days. The peak flowering periods of the two species were observed to overlap. In both species when there is moisture stress, the buds on the spike stop growing and flowering, but when there is sufficient rainfall, the buds resume growth and flowering.

**Morphometric values of the two species**

The study results show the presence of significant differences in morphological measures (Table 1) between studied species. On average, the plant heights and crown dimensions of *L. pubescens* were 38% and 33% lower, respectively, than those of *L. dentata*. However, *L. pubescens* was significantly ($P < 0.003$) wider in terms of crown diameter than *L. dentata*. The number of flowers on *L. dentata* was significantly ($P < 0.001$) greater than those on *L. pubescens*. The mean numbers of flower buds per plant were slightly greater on *L. dentata* than on *L. pubescens*. Moreover, the results revealed the presence of a significant ($P < 0.001$) positive correlation ($r > 0.61$) between the number of flowers and other morphological features, such as plant height, crown height, crown diameter, and crown volume.

**Nectar secretion dynamics and amount.**

The study results indicate the presence of significant variation ($P < 0.001$) in the mean amount of nectar secreted/flower over the course of the day in both species (Table 2). Moreover, the total amount of nectar secreted by *L. dentata* was significantly higher (P < 0.001) than *L. pubescence* , and the interaction between the time of day and species was significant (P < 0.001).

In both species, the period of nectar secretion started in the early morning (06:00) and extended into the late afternoon, with maximum accumulated volumes of nectar of 0.50 ± 0.24 µl/flower and 0.68 ± 0.19 µl/flower recorded at 15:00 and 18:00 for *L. pubescens* and *L. dentata*, respectively. Regarding the trends in the amount of nectar secreted, the accumulated volume increased until 18:00 in the case of *L. dentata*. A similar trend was noted until 15:00 for *L. pubescens*, but there was a decreasing trend between 15:00 and 18:00 (Table 2).

Generally, the mean secreted nectar volume/flower and the mean maximum accumulated nectar volume/ flower at the end of the day were greater in *L. dentata* than *L. pubescence* (Table 2).

The amount of nectar calculated as the difference between two successive measurements (3 h intervals) varied from 0.04 µl/flower to 0.28 µl/flower for *L. pubescens* and from 0.04 µl/flower to 0.35 µl/flower for *L. dentata.* These values indicate the variation in nectar secretion of studied species and their nectar volume that might be available for flower visitors at given time intervals (Table 2).

## Nectar dynamics in relation to weather conditions

For both *L. pubescens* and *L. dentata*, the nectar amount per flower significantly increased with an increase in temperature (P < 0.001; Table 3). Moreover, the nectar amount in *L. dentata* tended to increase (P < 0.004) with an increase in relative humidity. However, in the case of *L. pubescens*, though not statistically significant (P > 0.05), the nectar volume tended to decrease with an increase in relative humidity. The highest nectar volumes were recorded at a mean temperature of 35.7°C and 28.7% RH for *L. pubescens* and at 28.3°C and 37.7% RH for *L. dentata*. This finding indicates that the two species may have different optimum weather conditions for peak nectar secretion.

## Honey production potentials of the species

The mean maximum volumes of accumulated nectar/flower recorded were 0.68 ± 0.19 µl at 18:00 for *L. dentata* and 0.50 ± 0.24 µl at 15:00 for *L. pubescens.* Considering the mean maximum nectar volumes and their respective nectar sugar concentrations; 0.22 mg and 0.16 mg of nectar sugar/flower were recorded for *L. dentata* and *L. pubescens*, respectively.

Moreover, the mean numbers of spikes/plant,were 204 for *L. dentata* and 277 for *L. pubescens*, and the mean numbers of flowers per spike, were 90.87 and 64.08 for *L. dentata* and *L. pubescens* respectively. Hence the mean numbers of flowers/plant were estimated to be 18,537 for *L. dentata* and 17,750 for *L. pubescens*. Based on the mean numbers of flowers/plant; the estimated amounts of nectar sugar per plant were then calculated to be 4078.14 mg and 2840 mg for *L. dentata* and *L. pubescens*, respectively. Assuming 18% of a honey is water; from the average amount of nectar sugar recorded by the individual plants; *L. dentata* and *L. pubescens* can produce 4973.34 mg and 3463.41 mg honey/plant.

Based on the mean canopy diameter of each species (Table 1) and the space required between plants; the numbers of plants estimated to grow per hectare of land were 10249.8 and 6936.6 for *L.dentata* and *L.pubescense* respectively. According to the above-described computations, the expected nectar sugar for *L. dentata* and *L. pubescens*, were 41.8 kg/ha and 19.7 kg/ha respectively. Consequently, *L. dentata* and *L. pubescens* can yield an estimated 51.0 kg honey/ha and 24.1 kg honey/ha respectively. Thus, the expected honey production potential of *L. dentata* is twice that of *L. pubescens*.

## Discussion

### Floral morphology and phenology

The floral morphologies of the two lavender species appear suitable to the body size of small insects such as honeybees to easily alight on flowers and collect nectar. The corolla tube of *L. dentata* is relatively short (4 -5 mm); hence, the smallest indigenous honeybee (*Apis mellifera jemenitica*), with a proboscis length of 5.277 ± 0.210 mm (Ruttner, 1988), can easily access the nectar. Though the corolla tube of *L. pubescens* is relatively longer than the proboscis lengths of indigenous honeybees, however, the bees observed to collect nectar which might be with the help of the capillary action of the style. Similarly, despite their short proboscis lengths, honeybees managed to draw nectar as far as 11.65 mm by taking advantage of the capillary action of the style to access the corolla tube of cardamom (Venkateshalu and Vivek, 1997). However, honey bees prefer to collect nectar (greater frequency) from *L. dentata* than *L. pubescens* flowers (personal observation), possibly because the corolla tube length matches well with their proboscis length. The location of nectar and the proboscis length are known to be important factors in determining the associations between flowers and flower-visiting insects (Martina et al., 2009). In general, the pollen grains of the two species are not easily dislodged and are not thus dusted onto the bodies of honeybees to be packed into their pollen baskets. Nevertheless, the visiting of honeybees may provide a sufficient level of pollination via mechanical dislodging and the movement of the proboscis through the corolla tubes.

In terms of flower phenology, interestingly, only a few (5-7) flowers open at a time per spike, and when these flowers are near wilting, other new flower buds prepare to open. This sequential opening of a few flowers at a time might be an adaptation of the species for the economic allocation of sufficient synthesized energy (in the form of nectar) to attract flower visitors and might also act to minimize competition among flowers for pollinators. The display of only a few flowers at a time by plants has been reported to impart an advantage in terms of maximizing pollen export (Klinkhamer et al., 1994), whereas plants that display greater numbers of flowers at a time may attract a greater number pollinators but are reported to experience substantial pollen transport losses (Biernaskie and Cartar, 2004). In this context, both species might be well adapted for efficient pollen transfer.

The individual flowers of each species are present for a considerable length of time (9 h and 12 h in *L. pubescens* and *L. dentata*, respectively). Moreover, their nectar secretion dynamics follow the life span of the flower. Floral longevity has been reported to play an important role in reproductive ecology, influencing the total number of visits by pollinators and the amount and diversity of pollen received (Ashman and Schoen, 1996).

**Blooming season distribution**

The flowering of the two species is very long and lasts for approximately two to three months while the spikes continue to grow and a few flowers open at a time. This flowering strategy is advantageous to the plant for resource distribution and for effective pollination. Moreover, the elongated flowering period is useful in relation to beekeeping in that the bees have considerable time to collect and store nectar. The contribution of a longer flowering period to increased honey production has been well documented (Burge et al., 2006). The overlap in the flowering duration and the periods of peak flowering of the two species might be attributed to their similar physiological responses to environmental stimuli.

### Morphometric values

Despite sharing similar habitats, the morphometric values of plant height: crown height and canopy volume, which are measures of biomass, were generally greater for *L. dentata* compared to *L. pubescens*. The higher number of flowers per spike in *L. dentata* than in *L. pubescens* may be associated with the higher biomass of the former species. Furthermore, the current study revealed a strong positive correlation between the evaluated morphological parameters and the number of flowers, which is in agreement with Zhang et al. (2013), who reported a significant positive correlation between the number of flowers and the aboveground biomass in *Stellera chamaejasme*. The higher biomass of *L. dentata* is expected to supply greater nectar and pollen resources and, thus, attract a greater number of flower visitors.

### Amount and dynamics of nectar secretion and effect of weather conditions

Even though a single flower was used for one time measurement, from the mean accumulated amounts of nectar recorded for different flowers at different times of day, it was clear that both species continue to secrete nectar throughout the day, for approximately 9 h and 12 h for *L. pubescens* and *L. dentata*, respectively. Under natural conditions, while the flowers remain open, it is expected that flower visitors can consume the nectar. Thus, for each species, the increases in the amounts of nectar recorded over time in caged flowers (Table 2) indicates the additional amount of nectar secreted by the flowers during the interval between two consecutive measurement times. Generally the mean amount of nectar secreted per flower of *L. dentata* was significantly ($P < 0.0001$) higher than the amount of nectar secreted per flower of *L. pubescence.* Moreover at the end of the flower stage *L. dentata* had more accumulated nectar amount than *L. pubescence* (Table 2).

In addition, the maximum nectar secretion attainment time varied between the two species (Table 2) which may be related to the variation in life span of their flowers. The decline in the amount of nectar in bagged *L. pubescens* flowers after 15:00 (Table 2) might be attributable to the reabsorption of secreted nectar by the plants. The reabsorption and modification of unconsumed nectar is considered a strategy for the partial recovery of the energy cost invested in nectar production for numerous species (Nepi and Stpiczyńska, 2008; Nepi et al., 2011).

The mean temperature (35.7°C for *L. pubescens* and 28.3°C for *L. dentata*) and relative humidity (28.7% for *L. pubescens* and 37.7% for *L. dentata*) at which the highest nectar volumes were recorded might be considered the optimal weather conditions for maximum nectar secretion and effective pollination for each species. Although the two species have overlapping flowering periods, they have different optimum humidity and temperature levels for the secretion of maximum nectar, which may be an adaptation of the two co-existing and co-flowering species to minimize competition for pollinators. The temporal partitioning of floral resources as a mechanism of minimizing competition for pollinators has been well documented for several sympatric and co-flowering plant species (Ollerton and Lack, 1992; Stone *et al*., 1998).

The positive correlations between the amount of nectar and the air temperature of the area might indicate the adaptation of these species to warm climatic conditions. Similarly, positive correlations between ambient temperature and nectar secretion amount have been recorded for numerous nectar-secreting species *Trifolium repens,* (Jakobsen and Kristjansson, 1994)*, Thymus capitatus*, *(*Petanidou and Smets, 1996), and *Ziziphus spina-christi*, (Nuru et al., 2012). .

**Honey production potential**

In general, under natural conditions, the amounts of honey obtained per ha of land (51.0 kg/ha from *L. dentata* and 24.1 kg/ha from *L. pubescens*) are relatively greater than the honey production values of 20.14 kg/ha and 23.02 kg/ha recorded for *Nepeta deflersiana* and *Otostegia fruticosa*, respectively *(*Al-Ghamdi et al, 2015 unpublished).

In addition, because lavender honey is a specialty item, its high market price as well as the possibility of enhancing the vegetative performance of lavender species with improved agronomic practices may indicate additional premium production potentials for these lavender species. In this regard, further research on the potential for the planting and adaptation of these species to both degraded lands and backyards, with the integration of beekeeping, would be useful for the assessments of its ecological and economic values. Moreover, in both species, flowers were observed to open in succession (day and night) without having definite time of opening. In this regard, further observations on the presence of nocturnal visitors (if any) might be important.

## Conclusion

Based on the dynamics and the amounts of nectar secreted per flower and per plant, the two lavender species can be considered as potential honey source plants for the region. In general, the importance of the species is significant not only in terms of serving as sources of specialty honey but also in terms of their ecological values, attributed to their ability to thrive under low moisture and poor soil conditions and to contribute to ecosystem functioning and the maintenance of insect diversity under these conditions.

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## References

Azcón R., Barea, J. (1997) Mycorrhizal dependency of a representative plant species in Mediterranean shrublands (*Lavandula spica* L.) as a key factor to its use for revegetation strategies in desertification-threatened areas. Applied Soil Ecology 7 (1): 83–92. http://dx.doi.org/10.1016/S0929-1393(97)00013-9, Accessed, Nov, 2013.

Ashman T., Schoen D. J. (1996) Floral Longevity: Fitness Consequences and Resource Costs. In: Lloyd D.G., Barrett S.C.H. (Eds) Floral Biology. Springer US, pp 112-139.

Biernaskie J. M., Cartar R. V. (2004) Variation in rate of nectar production depends on floral display size: a pollinator manipulation hypothesis. Functional Ecology 18:125–129.

Boning C. R. (2010) Florida's Best Herbs and Spices: Native and Exotic Plants Grown for Scent and Flavor. Pineapple, PR INC, 229 pp. Accessed, December, 2013.

Burge G., Bycroft B., Leach M. (2006) Extending the flowering period of Manuka. New Zealand Institute for Crop and Food Research Limited, New Zealand. 10 pp.

http://maxa.maf.govt.nz/sff/about-projects/search/03-055/extending-flowering-of-manuka.pdf . Accessed, March, 2014.

Chu C. J., Kemper K. J. (2001) Lavender (Lavandula spp.) The Longwood Herbal Task Force and The Center for Holistic Pediatric Education and Research). 32pp. Available at: URL http://www.longwoodherbal.org/lavender/lavender.pdf . Accessed, December. 2013.

Crane E., Walker P., Day R. (1984) Directory of Important World Honey Sources. International Bee Research Association, London, pp. 384.

El-Karemy Z. A., Zayed K. M. (1992) Distribution of Plant Communities Across Al Abna Escarpment, SW Saudi Arabia. Phyton (Horn, Austria) 32 (1): 79-101

Forler S. (2013) Lavender Honey. http://www.honeytraveler.com/single-flower-honey/lavender-honey/. Accessed on December 2013.

Jakobsen H., Kristjansson K. (1994) Influence of temperature and floret age on nectar secretion in *Trifolium repens* L. Annals of Botany 74: 327-334.

Kim M. S., Kim S. H., Han J., Kang M. S., Park Y. K. (2011) – Honeybee visit and nectar secretion characteristics of the Chinese Hawthorn *Crataegus pinnatifida* Bunge. Journal of Apiculture, The Apicultural Society of Korea, 26(1): 11-14.

Klinkhamer P. G. L., de Jong T. J., Metz A. J. (1994) Why plants can be too attractive – a discussion of measures to estimate male fitness. Journal of Ecology 82: 191–194.

Lalande B. (1984) Lavender, lavandin and other French oils. Perfumer & Flavorist 9:117-121.

Lis-Balchin M. (2003) Lavender: The Genus Lavandula, CRC Press, Science, UK 296 pp. Available at: URL http://books.google.ca/books/about/Lavender.html?id=TmvkY60iESkC

Martina S., Klinkhamer P. G. L., Waser N. M., Stang I., Meijden E. (2009) Size-specific interaction patterns and size matching in a plant –pollinator interaction web. Annals of Botany 103: 1459–1469, DOI:10.1093/aob/mcp027

Miller A. G. (1985) The genus Lavendula in Arabia and Tropical NE Africa. Notes Royal Botany Garden. Edinburgh. 42 (3): 503 -528.

Nagy Z. (2002) Egyrenépszerűbb növényünk a facélia III. *Méhészet,* 50(4): 22. In. Nectar production for the Hungarian Honey Industry. Reviewed by Farkas, A. and Zajácz, E. (2007) *European Journal of Plant Science Biotech.* Global Science Book:125 -151.

Nepi M., Stpiczyńska M. (2008) The complexity of nectar: secretion and resorption dynamically regulate nectar features. Naturwissenshaften 95:177–184.

Nepi M., Cresti L., Guarnieri M., Pacini E. (2011) Dynamics of nectar production and nectar homeostasis in male lowers of *Cucurbita pepo* L. International Journal of Plant Science 172(2):183–190, DOI: 10.1086/657648

Nuru A., Awad M. A., Al-Ghamid A. A., Alqarni, A. S., Radloff S. E. (2012) Nectar of *Ziziphus spina-christi* (L.) WILLD (Rhamnaceae): dynamics of secretion and potentials for honey production. Journal of Apicultural Science 56 (2): 49-59, DOI: 10.2478/v10289-012-0023-9

Ollerton J., Lack A. J. (1992) Flowering phenology: an example of relaxation of natural selection? Trends in Ecology and Evolution **7**: 274–276.

Petanidou T., Smets E. (1996) Does temperature stress induces nectar secretion in Mediterranean plants? New Phytologist ?, 133: 513-518.

Rahman M. A., Mossa J.S., Al-Said M.S., Al-Yahya M. A. (2003) Medicinal plant diversity in the flora of Saudi Arabia 1: a report on seven plant families. Fitoterapia 75: 149–161.

Ruttner F. (1988) Biogeography and taxonomy of Honey bees. Springer-Verlag; Berlin, Germany. 284 pp.

SAS (2002) SAS Institute Inc., JMP-5 Statistical Software, Version 5.Cary, NC, USA.

Stone G. N., Willmer P.G., Rowe J.A. (1998). Partitioning of pollinators during flowering in an African Acacia community. Ecology 79: 2808 -2827.

Szabo T. I., Najda H. G. (1985). Flowering, nectar secretion and pollen production of some legumes in the Peace River Region of Alberta, Canada. Journal of Apicultural Research 24(2): 102-106.

Venkateshalu V.V.B., Vivek H. R. (1997) Significance of style in cardamom corolla tubes for honey-bee pollinators. Current Science 73 (3): 287-290.

Welsh C. (1995) Three essential oils for the medicine cabinet. Alternative Health Practitioner 3:11-15.

Wyatt R., Broyles S. B., Derda G. S. (1992) - Environmental influences on nectar production in milkweeds (*Ascelapias syriaca* and *A. exaltata*). American Journal of Botany, 79: 636-642.

Zhang Q. Zhao, C., Dong X., Ma X., Hou Z. Li Y. (2013) Relationships between flower size, flower number, and plant size of *Stellerachamaejasme*population along an altitude gradient of degraded alpine grassland in Northwest China. Chinese Journal of Plant Ecology 32(12): 3160-3166.

Zsidei B. (1993) - Méhészeti ismeretek. Fazekas és fiai nyomdája, Szarvas, In: Nectar production for the Hungarian Honey Industry. Reviewed by Farkas, A. and Zajácz, E. (2007) European Journal of Plant Science and Biotechnology. Global Science Book, 125 -151.

Table 1: Plant and flower morphometric parameters of *Lavendula pubescens* and *Lavendula dentata* (mean values are given ± SD)

| Species | Plant height (cm) | Crown height (cm) | Crown diameter (cm) | Crown volume ($m^3$) | No. of flowers /plant |
|---|---|---|---|---|---|
| *L. dentata* | 85.7±17.5[a] | 41.4±9.4[a] | 74.7±28.5[a] | 0.09±0.1[a] | 18537 |
| *L. pubescens* | 53.0±20.8[b] | 27.6±10.0[b] | 97.4±23.8[b] | 0.04±0.1[b] | 17750 |
| t-value | 8.701 | 7.383 | -3.324 | 3.975 | - |
| P-value | 0.000 | 0.000 | 0.003 | 0.000 | - |

Means followed by the same letter within columns are not significantly different at $\alpha = 0.05$

*N* = 63 for *lavendula dentata* & *N* = 47 for *L. pubescence*

**Table 2**
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Table 2: Daily dynamics of nectar production in flowers of the two lavender species

| Species | N | Mean nectar volume (µl) accumulated in a flower at different times of the day (local time = GMT+3 h) 06:00 (a) | 09:00 (b) | 12:00 (c) | 15:00 (d) | 18:00 (e) | F-value | P-value |
|---|---|---|---|---|---|---|---|---|
| *L. pubescens* | 90 | 0.28±0.19[a] | 0.41±0.25[ab] | 0.46±0.23[b] | 0.50±0.24[b] | 0.41±0.21[c] | 12.597 | < 0.001 |
| Rate of secretion * | | a = 0.28 | b-a = 0.13 | c-b = 0.05 | d-c = 0.04 | e -d = -0.09 | | |
| *L. dentata* | 90 | 0.35±0.15[a] | 0.40±0.14[a] | 0.53±0.19[b] | 0.64±0.20[c] | 0.68±0.19[c] | 62.645 | < 0.001 |
| Rate of secretion * | | a = 0.35 | b-a = 0.05 | c-b = 0.13 | d-c = 0.11 | e -d = 0.04 | | |

| | N | Mean for species: *L. pubescens* | *L. dentata* | t-value | P-value |
|---|---|---|---|---|---|
| Nectar volume per flower (µl) | 450 | 0.41±0.24[a] | 0.52±0.22[b] | -6.991 | < 0.0001 |

Means followed by the same letter are not significantly different at α = 0.05

**Table 2**



* Rate of nectar secretion is the average volume of nectar secreted during 3 hours which is calculated as the difference between the two consecutive measurements.

Table 3: Correlation of temperature and relative humidity with nectar volume measurements for the two lavender species

| Variable | By variable | Count | Correlation | | P-value | |
|---|---|---|---|---|---|---|
| | | | *L. pubescens* | *L. dentata* | *L. pubescens* | *L. dentata* |
| Temperature (°C) | Nectar in µl | 450 | 0.2360 | 0.2796 | 0.0001 | < 0.0001 |
| Relative humidity | Nectar in µl | 450 | -0.0826 | 0.1373 | = 0.080 | = 0.004 |

Fig. 1. A.

Fig. 1 B.

Fig. 1. A. *Lavandula dentata* and Fig.1, B. *Lavandula pubescens* with their growing habitats

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Fig. 2: Floral morphology of spike (left) and corolla (right) of *L. pubescens*

Fig. 3: Floral morphology of spike (left) and corolla (right) of *L. dentata*

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