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EVALUATION OF *ACACIA GERRARDII* BENTH. (FABACEAE: MIMOSOIDEAE) AS A HONEY PLANT UNDER EXTREMELY HOT-DRY CONDITIONS: FLOWERING PHENOLOGY, NECTAR YIELD AND HONEY POTENTIALITY

Abdulaziz Saad Alqarni[1], Awad Mohamed Awad[1*] and Ayman Ahmad Owayss[1],

[1] Department of Plant Protection, College of Food and Agriculture Sciences, King Saud University, Riyadh 11451, P.O. Box 2460, Saudi Arabia.
[*] Corresponding author's email: awad.univ@gmail.com

ABSTRACT

The nature of both bee-plant interactions and pollination ecology critically depends on flowering phenology and nectar yield. These two factors determine whether the plant has the potential to produce honey by honey bees. Here, we characterized flowering phenology, quantified nectar yield and calculated honey potentiality of Talh (*Acacia gerrardii* Benth.). Talh is a widespread melliferous species distributed in Africa and the Middle East. Field investigations were performed in Rawdhat-Khoraim oasis, Riyadh, Saudi Arabia, from April to August for 3 years (2011-2013). Flowering phenology, nectar yield and tree canopy area data were used to predict the honey production potential of Talh trees. The bloom season of Talh trees began around mid-May and ended in mid-August. Flower density varied significantly ($p<0.001$) among months, while the general mean (±SE) was 148±14 flower heads (FHs) per m^2 per day. The total soluble solids (TSS) secreted were 30.4 mg/ FH/ day. Talh trees may produce potential honey weighing 495 ± 60 g/ tree/ day and 45,032 ± 6,359 g/ tree/ season. In conclusion, Talh trees have a high potential for honey production. Further studies are needed to estimate the actual honey production and to understand other aspects of flowering.

Key words: *Apis mellifera*; *Acacia gerrardii*; flowering; honey; honeybees; nectar; pollination; Saudi Arabia.

INTRODUCTION

Honey bees (*Apis mellifera* Linnaeus) obtain nectar, pollens and resins from plants. Bee flora is the most important factor dictating honey bee activities and honey production (Keasar and Shmida, 2009). Previous studies have quantified and characterized the quality of nectar in numerous plant species. These studies have been primarily restricted to the pollination biology of the studied species (Castellanos *et al*., 2002; Galetto and Bernardello, 2004). Fewer studies have addressed nectar yield or honey potentiality (Masierowska, 2003; Kim *et al*., 2011; Adgaba *et al*., 2012). The nectar of some acacia species has been studied in Africa, Australia and South America (Sedgley *et al*., 1992; Baranelli *et al*., 1995; Stone *et al*., 1998; Kenrick, 2003; Stone *et al*., 2003; Fleming *et al*., 2007). These studies focused on pollination but not honey potential.

Talh trees (*Acacia gerrardii* Benth.) are relatively common throughout Africa and the Middle East in woodlands, wooded grasslands, dry river valleys scrubs, thornveld and bushveld. Talh trees are beneficial to their ecosystems and have multiple uses in traditional medicine (Dharani, 2007).

Talh trees are among the major melliferous plant species of Saudi Arabia (Alqarni *et al*., 2011). Honey bees produce one of the most popular honeys in Saudi Arabia from the flower heads (FHs) of Talh (Al-Khalifa and Al-Arify, 1999). The English name of this acacia is "red thorn", and the common Arabic name is "Talh." Hence, honey produced from Talh FHs is called "Talh" honey (Bahaffi and Al-Lihaibi, 2005). However, data on Talh flowering phenology and nectar yield are not available. To date, no study has estimated the potentiality of Talh honey in Saudi Arabia or elsewhere. Information on several important aspects of Talh trees found in arid regions regarding their flowering behavior, nectar yield, and honey potential in scanty and the present study aims to characterize the flowering phenology, measure the nectar yield and to estimate the honey potentiality of Talh trees.

MATERIALS AND METHODS

Site of study: Field investigations were conducted in Rawdhat-Khoraim, an oasis located 120 km northeast of Riyadh city, Saudi Arabia (between 25°30'- 25" N and 47°46'- 30" E at 1829 ft.). This oasis is approximately 18 km long and 1 to 2.5 km wide. This region is extremely dry (10% RH) and hot (37 ˚C) when Talh blooms. A sizeable Talh population occurs in this region with other plant communities. Talh growth in this region depends on estuaries flowing from the surroundings during autumn, winter and spring.

A pilot study was conducted during 2011 to test and improve sampling procedures. Field investigations were recorded from May to August in 2011, 2012 and 2013.

Flowering phenology: Five Talh trees were randomly selected and labeled in April 2011 in the testing area. The selected trees were investigated weekly from April to August in 2011, 2012 and 2013. A variety of flowering traits were measured, including flower opening phenology, bloom season phenology, and flowerage density.

Flower opening phenology: To characterize flower opening phenology, 20 mature flower buds per tree were randomly selected and labeled with small tags. The mature flower buds were yellow in hue, while the young buds were green. Additionally, the mature flower buds were larger than the young buds. The selected flower buds were observed to record the opening and withering times. Observations began when the flower heads opened and continued every two hours until they senesced. The timing of flower head opening and senescence age were recorded following the procedures of Adgaba *et al*. (2012). This work was performed once during 2011.

Bloom season phenology: To document bloom season phenology, the five selected trees were observed weekly from April to August in 2012 and 2013. The dates of first flower bud and the first and last flower heads (FHs) to bloom were recorded. The length of time between the budding of the first and the last flower heads was calculated and considered to be the duration of the bloom season for Talh trees.

Flowerage density: An area of 1 m^2 was selected on the crown of each tested tree. The number of FHs/1 m^2 was documented weekly for each tree in 2012 and 2013. This procedure has been modified from the methods of Masierowska (2003), Kim *et al*. (2011), and Adgaba *et al*. (2012).

Nectar yield: The washing method recommended by Mallick (2000) and Morrant *et al*. (2009) for studying FHs with minute florets (such as *A. gerrardii*) was used. Water volumes were tested in 2011 to obtain the minimum volume that could cover four FHs and completely dissolve their nectar content. The minimum volume found to perform this task was 4 mL, which was the volume used in the nectar measurements conducted in 2012 and 2013.

Every week, 20 mature flower buds per tested tree were randomly selected and bagged in the evening one day before nectar measurement. The following day, four bagged FHs were cut and placed in a 10 mL vial with 4 mL deionized water. The vial was shaken for two minutes. A hand-held refractometer was used to estimate TSS in the solution (Corbet, 2003). This procedure was repeated five times weekly at five fixed times during the day: sunrise, forenoon, noon, afternoon and sunset (approximately 530 h, 830 h, 1130 h, 1430 h and 1730 h, respectively).

A bridal-veil netting was used to bag the selected FHs. The netting was carefully fixed around the selected FHs to prevent bees and other flower visitors from removing nectar (Wyatt *et al*., 1992).

A digital hand-held refractometer (Reichert®, model 13950000, USA) was used to estimate TSS. The Brix-TC reading mode, which is a temperature-corrected mode, was used (Adgaba *et al*., 2012).

The nectar yield was calculated as TSS weight (in g/4 FHs) depending on the fixed water volume used (4 mL) and the measured TSS concentration (%), according to the formula:

$$TSS_{Weight}\ (g/\ 4\ FHs) = TSS_{\%} \times 100 / 4$$

where TSS_{Weight} is the absolute weight of the nectar yield estimated in total soluble solids, $TSS_{\%}$ is the percentage of nectar yield estimated in total soluble solids, g is gram, ***FHs*** is the Flower Heads, ***100*** is the percentage constant, and ***4*** is the fixed volume of deionized water (mL). Formulas similar to ours have been used previously (Mallick, 2000; Adgaba *et al*., 2012).

The nectar yield at each time of day was calculated in the following manner: forenoon nectar yield = calculated forenoon TSS – sunrise nectar yield. Likewise, noon nectar yield = calculated noon TSS – forenoon nectar yield. Nectar yield at other times of day was calculated in the same way.

Honey potentiality: The crown (hemispheric in shape) radius of each selected tree was measured using a steel tape measure. The surface area of the selected trees' crowns was calculated with the following equation:

$$A = 2 \times \pi \times r^2$$

where A is the surface area of the tree crown, π is the pi constant (3.14), and r is the radius of the tree crown.

Talh honey contains on average 80% TSS (Alqarni *et al*., 2014a). Consequently, potential Talh honey was calculated using the following equation:

$$PH = TSS_{Weight} \times 100 / 80$$

where PH is the weight of the potential honey, TSS_{Weight} is the weight of nectar yield estimated as (TSS), and ***100/80*** is the inverse percentage of Talh honey content of TSS. This model has been modified after Adgaba *et al*. (2012).

Data processing and statistical analyses: Data were processed using Excel 2013®. The aforementioned formulas were used to calculate nectar yield, canopy surface area, and honey potentiality. The charts of the results were designed using the same software. The results are presented in "mean±SE". The data were checked for normality and homogeneity of variances using the Kolmogorov-Smirnov and Levene tests, respectively. The data were analyzed using SPSS 21®. The differences among the means were tested using Duncan's new multiple range test after ANOVA showed a significant overall effect.

RESULTS

Flowering phenology:

Flower opening phenology: Flower buds appeared on the sides of 1-year-old twigs. Every node produced flower buds and opened in a consecutive fashion. The flower bud had a green color and increased in size. The color then changed to yellow 1 day before opening. The FH opened a little after dawn and remained opened during the day until it withered by the evening of the same day (i.e., the FH lasted for a single day). Every FH was composed of many minute florets. The FH was globose in shape and creamy yellow in color. The florets inside a FH opened gradually and took about one hour to open totally.

Bloom season phenology: Flower buds of Talh trees appeared in late April. The bloom phenophase began in May, while the mean photoperiod was approximately 12 hours and 50 minutes. The bloom extended from May to August.

Talh trees flowered later in 2013 compared to 2012. During 2012, flower buds appeared in late April and started opening in mid-May, while the bloom season ended during the first week of August. In 2013, the flower buds of Talh trees came out around the last week of April, began opening during the last third of May and finished opening during the third week of August. These findings mean that the bloom season is approximately 90 days.

Flower density: The general mean of the flower density was 148±14 FHs/m^2/day. The flowerage density was significantly ($P < 0.05$) greater in 2013 (150 ±18 FHs/m^2/day) than in 2012 (146 ±21 FHs/m^2/day). The flower density of Talh significantly varied ($P < 0.001$) throughout the months of bloom phenophase (Figure 1). July was the peak month of Talh flower density, with a general mean of 272 ±23 FHs/m^2/day.

The bloom phenophase can be classified into three sub-phenophases: kickoff (May), main flow (June-July) and fading (August), with flowerage density means of 6, 217 and 18 FHs/m^2/day, respectively. This classification was built from the flowerage density data (Figure 1). The main flow sub-phenophase lasts approximately 2 months, while each of the kickoff and fading periods lasts approximately 2 weeks.

The mean surface area of Talh trees was 79 ± 19 m^2/tree. The mean of the total flowerage of a tree was 11,759 ± 595 FHs/tree/day, while the means of each month were 456 ± 45, 12,899 ± 883, 21,615 ± 1,174 and 1,429 ± 152 FHs/tree/day during May, June, July and August, respectively. These means were significantly ($P < 0.001$) different. The flowerage density values were 11601 ± 905 and 11894 ± 789 FHs/tree/day during 2012 and 2013, respectively. Additionally, the flowerage density varied significantly ($P<0.001$) among individual trees.

Nectar yield: The Talh FH secreted a mean of 24.4 ± 0.9 mg TSS / 4 FHs/ 3 hrs, while the secretion averaged 21.9 ± 0.8 and 26.4 ± 1.5 mg/ 4 FHs/ 3 hours in 2012 and 2013, respectively. The nectar secretion behavior of Talh FHs varied hourly and seasonally (Figures 2 and 3).

The daily percentage yield of Talh nectar was 19%, 21%, 27%, 22% and 12% at sunrise, forenoon, noon, afternoon and sunset, respectively (Figure 2). These means differed significantly ($P<0.001$). Nectar secretion rate increased until it reached a peak at noon and then decreased, falling to a minimum value at sunset, which coincided with the withering of the FHs. Generally, the total daily nectar yield of Talh trees reached 122 mg/ 4 FHs/day, and a single FH was expected to yield approximately 30 mg TSS/day.

Nectar secretion increased from May until the bloom ended around mid-August (Figure 3). The mean values of secreted nectar differed significantly ($P<0.001$) among months of the flowering season in 2012 as well as in 2013. Additionally, the nectar secretion rate was significantly ($P<0.05$) greater in 2013 than in 2012.

The maximum nectar yield was secreted during August (34.6 ± 2.8 mg/ 4 FHs/ 3 hrs.). This value was about three-fold greater than that of May (11.7 ± 0.7 mg/ 4 FHs/ 3 hrs.).

Because the general mean of nectar yield was 24.4 mg/ 4 FHs/ 3 hrs, the mean nectar yield of a single FH might be approximately 6.1 mg/ 1 FH/ 3 hrs. Assuming a Talh nectar concentration of 50%, a single FH might secrete approximately 12.2 µL nectar/ 3 hrs. Whereas at a nectar concentration of 75%, a single FH is expected to secrete approximately 9.15 µL nectar/ 3 hrs.

Honey potentiality: The seasonal potential honey of Talh was 45,032 ± 6,359 g/tree/season. In 2012 and 2013, the seasonal potential honey of Talh was 32,406 ± 8,366 and 57,654 ± 5,685 g/tree/season, respectively. The quantities of Talh potential honey varied on a yearly, monthly and tree-by-tree scale.

Months of the flowering season differed significantly ($P < 0.001$) in their potential honey quantities, with a general mean of 11258 ± 2492 g/tree/month (Figure 4). The highest potential honey value was recorded in July (31,888 ± 5549 g/tree/month), while the monthly potential honey values were 8102 ± 2283 and 14414 ± 4385 g/tree/month, in 2012 and 2013, respectively. The four flowering months were significantly different in 2012 ($P < 0.001$) as well as in 2013 ($P < 0.001$).

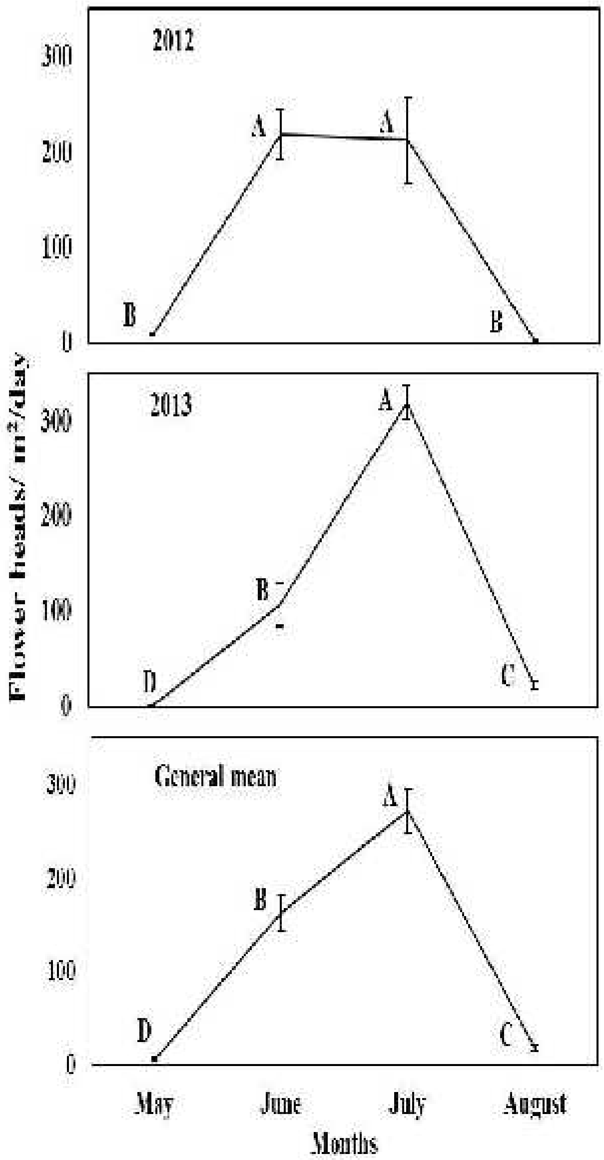

Figure 1. Flowerage density (mean±SE) of Talh trees, *Acacia gerrardii* Benth. (Fabaceae: Mimosoideae), in number of flower heads (FHs) per 1 m^2 of the canopy surface with its own depth per day.

* Means with the same letter in the same chart are not significantly different (P >0.05).

The peak value of potential honey (total mean) was recorded in July of the two study years (Figure 4). This month contributed 70.8% of the total seasonal potential Talh honey. June came second with 26.6%, while the months of May and August contributed only 0.3% and 2.2% of the total sum, respectively. This trend was quite similar during the two years of the study (Figure 4).

The main flow sub-phenophase period of Talh trees was estimated to contribute 97.4% (43871 g/tree) to Talh potential honey. This period contributed 98.9% and 96.6% (32054 and 55687 g/tree) in 2012 and 2013, respectively. May and August together contributed 2.6% (1161 g/tree). The same months contributed 1.1% and 3.4% (355 and 1968 g/tree) in 2012 and 2013, respectively (Figure 4).

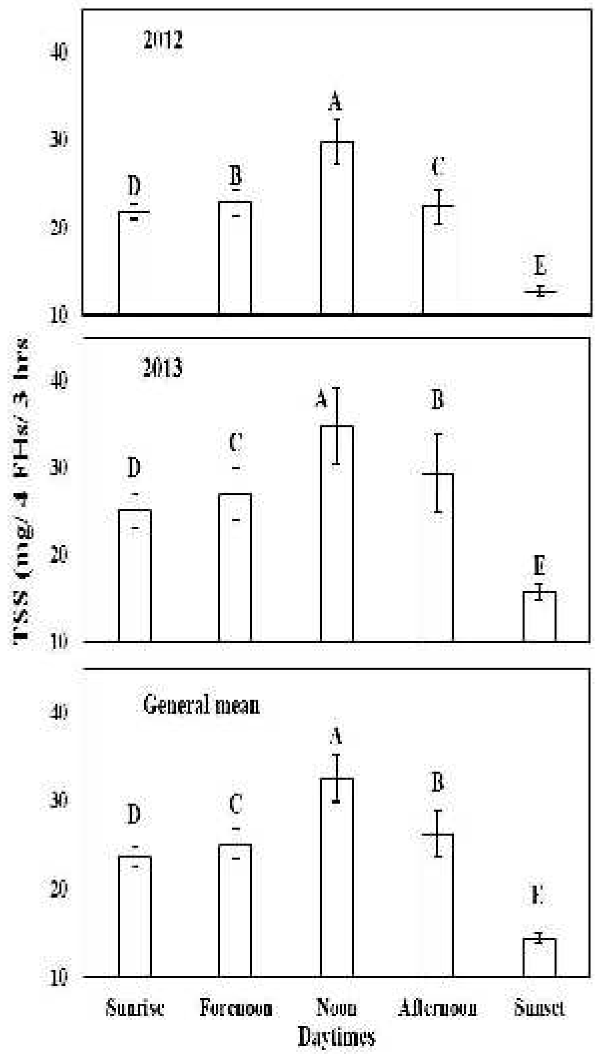

Figure 2. Nectar yield (mean±SE) of Talh trees, *Acacia gerrardii* Benth. (Fabaceae: Mimosoideae), at different times of the day. TSS: total soluble solids, mg: milligram, FHs: flower heads, hrs: hours

* Means with the same letter in the same bar chart are not significantly ($P > 0.05$) different.

One Talh tree could produce an amount of nectar that was sufficient to make a mean of 495 ± 60 g honey/tree/day. The daily potential honey was 386 ± 66 and 588 ± 96 g/tree in 2012 and 2013, respectively. The four flowering months of Talh differed significantly ($P < 0.001$) in their daily average honey potential, either depending on the general mean or during every tested year. However, the daily mean of potential honey was highest in July (1012 ± 127 g/tree/day). The lowest daily mean of Talh potential honey was in May, at 9 ± 2 g/tree/day (Figure 5).

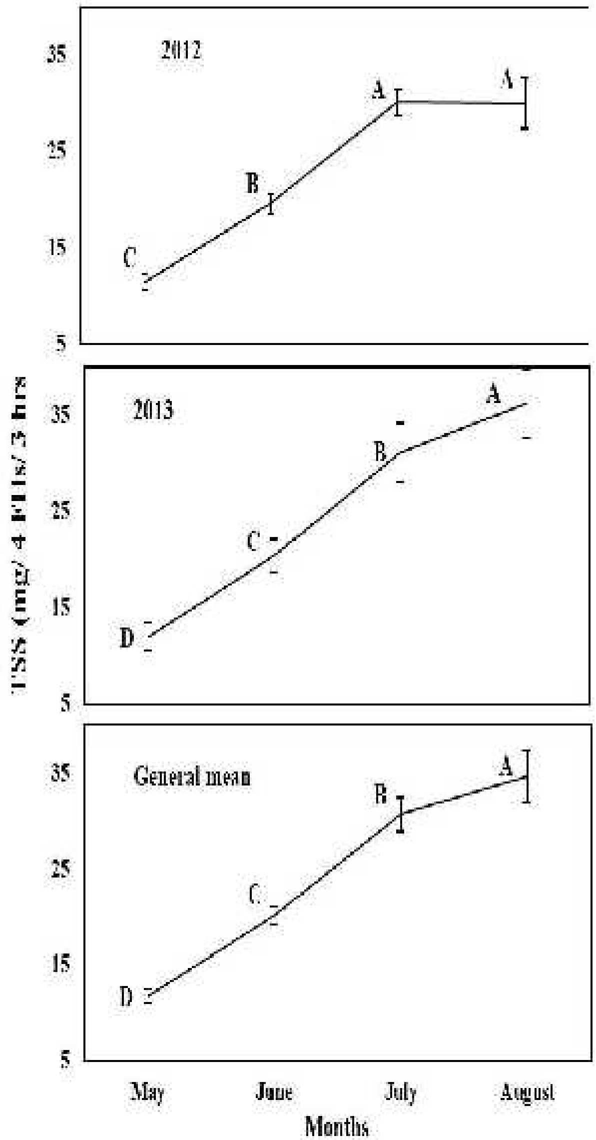

Figure 3. Nectar yield (mean±SE) of Talh trees, *Acacia gerrardii* Benth. (Fabaceae: Mimosoideae), during different months of the flowering season. TSS: total soluble solids, mg: milligram, FHs: flower heads, hrs: hours

* Means with the same letter in the same line chart are not significantly ($P > 0.05$) different.

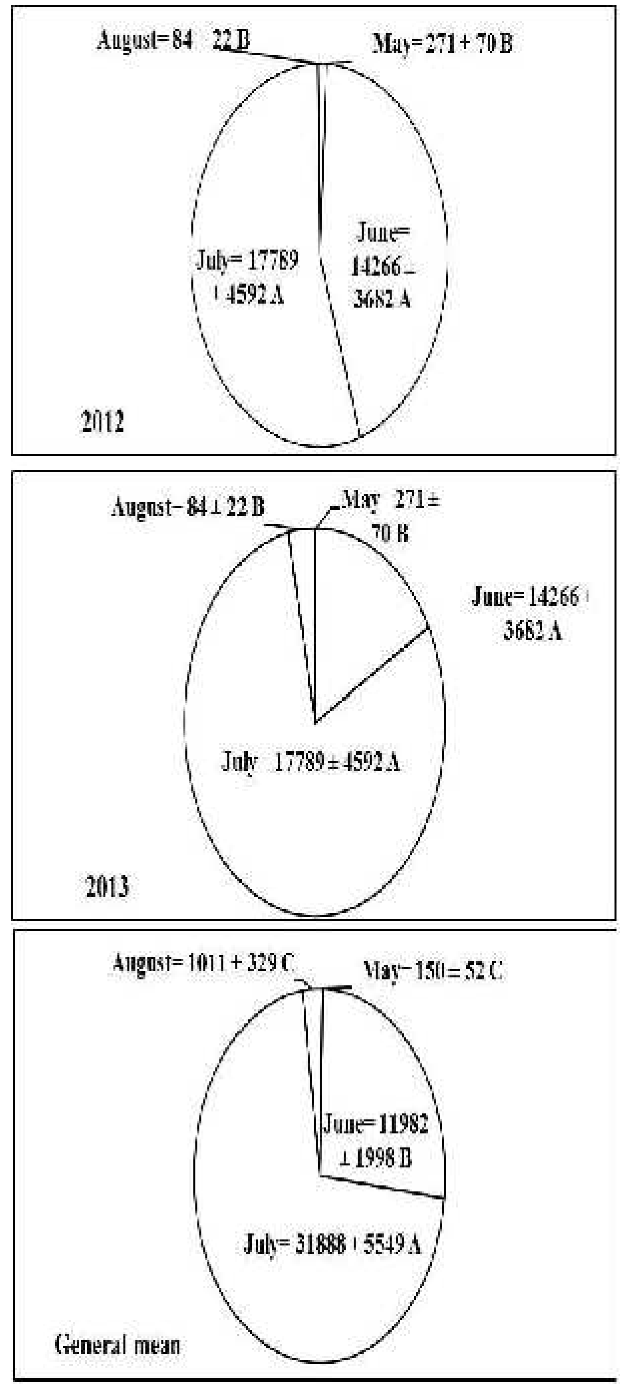

Figure 4: Monthly values (mean±SE) of potential honey (g/tree/month) that could be produced from Talh trees, *Acacia gerrardii* Benth. (Fabaceae: Mimosoideae).

* Means with the same letter in the same pie chart are not significantly ($P > 0.05$) different.

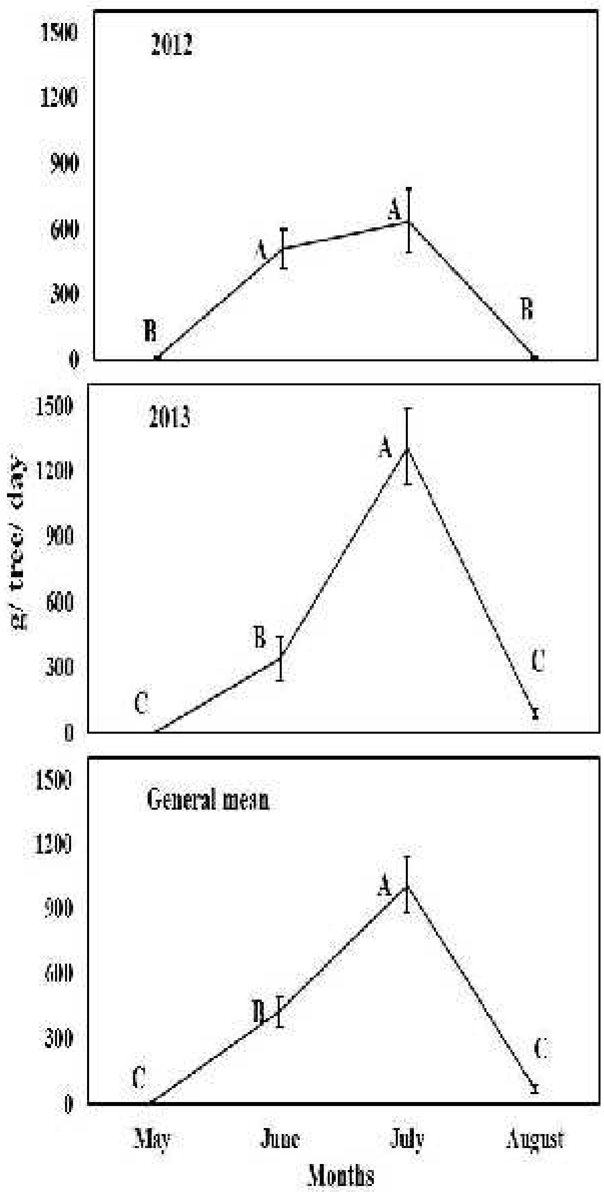

Figure 5. Daily values (mean±SE) of potential honey (g/tree/day) of Talh trees, *Acacia gerrardii* Benth. (Fabaceae: Mimosoideae).

* Means with the same letter in the same bar chart are not significantly ($P > 0.05$) different.

DISCUSSION

We found that Talh FHs open at dawn and last for a single day. The bloom season takes place from May to August over a period of approximately 90 days. The main flow comes in June and July, when the flower density reaches 217 FHs/m^2/day. The Talh yields 30 mg (TSS)/FH/day and is thus expected to yield 45032 ± 6359 gm (honey)/tree/season.

Talh trees are long-day plants, as they bloom in the summer from May to August. This pattern is similar to other acacia species reviewed by Stone *et al*. (2003). In contrast to our results, Dharani (2007) stated that Talh bloomed twice a year, in May and October, using observations made in Kenya, Tanzania and Uganda. The FHs of our studied species open shortly after dawn like many acacias that have been studied previously, e.g., *A. mangium* and *A. auriculiformis* (Sedgley *et al*., 1992), *A. caven* (Baranelli *et al.*, 1995), *A. sinuate* (Raju and Rao, 2002), *A. nigrescens* (Fleming *et al*., 2007) and *A. whibleyana* (Jusaitis *et al*., 2009).

Our data showed a mass flowering behavior in Talh (especially during the main flow sub-phenophase). Fleming *et al*. (2007) reported similar behavior in *A. nigrescens*, but they did not quantify the flowerage. Ten acacia species have a mass flowering behavior at least one point during their bloom seasons (Stone *et al*., 1998). We observed many insects, birds and mammals feeding on the flower buds and FHs. Talh seeds can be seriously damaged by bruchid beetles, *Bruchidius buettikeri* (Aldawood, 2009). Talh trees have most likely evolved the mass flowerage character in response to this damage to their flower buds, FHs and seeds.

During the bloom season, Talh trees copiously secrete nectar throughout the day. They fruit 61 µL/FH/day (assuming a concentration of 50%), while *A. nigrescens* secreted 0.011 µL/floret/day (Fleming *et al*., 2007). Furthermore, high levels of insect visitation were observed on Talh FHs. This observation supports our finding that Talh secretes copious amounts of nectar. Our results contradict those of Stone *et al*. (2003), who reported that floral nectar is uncommon in acacia species. They reviewed published data of nectar secretion in many acacias in Africa, Australia and South America. However, *A. gerrardii* was not considered in their review. This inconsistency is likely due to the differences among species.

The nectar secretion rate of Talh FHs varies hourly and monthly. These variations have been argued to be due to variations in temperature and relative humidity. Nicolson *et al*. (2006) confirmed that the weather can affect nectar volume and nectar concentration. They found a positive correlation between nectar secretion rate and temperature and a negative correlation between nectar secretion rate and relative humidity.

In nature, it is impossible to ensure that the entire nectar yield totally is converted to the honey crop because the possible fates of nectar are manifold: 1) some nectar is taken and stored by honeybees and may be harvested by humans for the honey crop; 2) some nectar is consumed by honeybees or given to their larvae; 3) some nectar is taken by insects or animals other than honeybees; 4) some nectar is reabsorbed by the FH itself; and 5) some nectar remains in the FH until it wilts and falls off. Only the first fate in the list above can be applied to the honey crop; however, this exact amount is unclear. Only one study has evaluated the actual honey yield of a *Ziziphus spina-christi* tree from a survey of the honey yielded from a particular area (Khanbash, 2003). Another study (Adgaba *et al*., 2012) evaluated the potential honey of the same species by estimating the nectar yield as we did in this study.

More studies are needed to assess the actual honey crop of Talh trees from field investigations on honeybee colonies during Talh flow. Additionally, modeling procedures may be followed to mathematically assess the Talh honey that can actually be produced from a Talh tree. Some ecological notes were observed during this study, such as the high rates of bee- and insect-visitation on FHs and the extrafloral nectar on the leaves. We are planning to study these ecological interactions in more detail and the pollination ecology of Talh trees. The Yemeni (*Apis mellifera jementica*) and Carniolan (*A. m. carnica*) honey bees differ greatly in their activities in the Arabian Peninsula (e.g. Alqarni *et al*., 2014b). Therefore their performance on Talh forage need to be evaluated.

The study demonstrates the potential of the melliferous Talh trees as a honey-producing plant, and the results are of great value, not only for the studied species but also for a wide range of species. The results will allow beekeepers to roughly predict the Talh honey crop they may obtain from a particular Talh prairie during a particular period. Additionally, the results assist agricultural authorities in managing the beekeeping sector during Talh flow.

The Arabic name has been chosen in this context for three reasons. First, the honey produced from Talh trees is called “Talh” honey (Bahaffi and Al-Lihaibi, 2005). Second, this species is restricted to Africa and Middle East, where the Arabic language is the most widespread. Finally, it would be confusing to name Talh honey “acacia honey,” as this name is similar to that of the common acacia honey that is produced from *Robinia pseudoacacia***.**

Talh trees bloom during the summer and open their FHs shortly after dawn. Talh trees produce 217 FHs/ m^2/ day, yielding 30 mg TSS/ 1 FH/ day, and are expected to yield approximately 45 kilograms of Talh honey seasonally. This large quantity of potential honey should encourage the conservation of Talh prairies and the planting of others.

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