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Floral nectar secretion dynamics of *Pavonia urens* (Malvaceae) and honey production potential

TURA BAREKE♥, ADMASSU ADDI
Oromia Agricultural Research Institute, Holeta Bee Research Center. P. O. Box 22 Holeta, Ethiopia.
Tel.: +251-112370023/0371, Fax.: +251-112372115, ♥email: tura_berake@iqqo.org

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Abstract. *Bareke T, Addi A. 2024. Floral nectar secretion dynamics of* Pavonia urens *(Malvaceae) and honey production potential. Nusantara Bioscience 16: 89-95.* The honey production potential of honey plant is estimated using the total floral nectar secretion potential of the plant foraged by honeybees within a given location. The current study aimed to determine the floral nectar secretion dynamics of *Pavonia urens* Cav. in addition to estimating the potential amount of honey that can be produced thereof. Nectar volume (using micropipette), nectar concentration (using digital refractometer), temperature, and humidity (using thermo hygrometer) were measured at 3 h intervals. Nectar volume and concentration differed significantly at different time points throughout the day. Also, nectar volume and concentration differed annually. There was a positive correlation between nectar volume and humidity as well as between temperature and nectar concentration. The mean nectar volume per 24 hours of *P. urens* was 7.23±0.43 µL. Individual flowers continuously secreted nectar for about 10 days throughout flower life. During each flowering season, an average of 823.5 mg g^{-1} of honey was generated per plant. Additionally, the average honey production capacity of *P. urens* was 35 kg ha^{-1}. This suggests that *P. urens* has the capacity to produce honey; therefore, for sustainable honey production, planting and in-situ conservation of this plant are recommended.

Keywords: Concentration, humidity, sugar, temperature, volume

INTRODUCTION

Ethiopia has favourable climatic conditions that encourage wide flora biodiversity which in turn favours beekeeping activities (Fichtl and Adi 1994). According to Addi et al. (2014), most of Ethiopia's flowering plants are foraged by bees for their flora nectar and pollen to satisfy their energy and protein requirement (Obeng-Darko et al. 2022, 2023). However, different plants produce varying nectar amounts hence, impacting the resultant honey obtained from different plants. Beekeeping promotes planting of trees, which indirectly addresses climate change by creating favourable microclimate (Bareke et al. 2022). The value chain of beekeeping is huge, thus it creates direct employment for the many unemployed in Ethiopia (Abro et al. 2022). According to Bareke and Addi (2019), bee plants are those plant species that produce floral nectar and/or pollen for honeybees. Nectar volume and concentration are indices used to evaluate the amount of honey that can be obtained from a potential bee plant species (Bareke et al. 2020a). Nectar is basically plant syrup produced by nectaries, specialized secreting structures beneath the flower surface (Galetto and Bernardello 2004). Nectar is chiefly composed of sucrose and hexoses with trace amounts of other constituents like amino acid, flavonoids, vitamins and other several organic compounds which may affect foraging ecology and the behaviour of foragers (Bertazzini and Forlani 2016).

Honeybee plant species' contributions to honey production are influenced by floral shape, flower anatomy, flowering phenology, and the quality and quantity of secreted nectar (Alqarni et al. 2015). The quality and quantity of nectar is affected by environmental variables (Adgaba et al. 2017). Since nectar is exposed to evaporation, temperature, humidity (Bareke et al. 2021a), wind speed, and sunlight (Dafni 1992), it is necessary to perform nectar measurement relative to these climatic variables (Dafni 1992).

Therefore, it is imperative to evaluate the honey production potential of flowering plant species to understand the relationship between the nectar production of flowering plants, and the carrying capacity of beehives per honeybee colony. Ultimately, such studies help to improve our understanding of forest and watershed management strategies within the environments (Bareke et al. 2022). Different plant species have different capacities for producing honey (Bareke et al. 2021b). There are only few major honey source plants in any region that provide high amount of nectar for honey production (Adgaba et al. 2017) to the world. Therefore, it is crucial to categorize them in accordance with their level of honey production capacity.

Different studies have investigated the nectar exudation and accumulation dynamics in some flowering plants (Búrquez and Corbet 1991; Obeng-Darko et al. 2022) and the capacity of various bee foraging plants to produce honey (Adgaba et al. 2017). Accordingly, the honey production capacity of *Acacia gerrardii* Benth. (Alqarni et al. 2015), *Otostegia fruticosa* (Forssk.) Schweinf. ex Penzig, *Ziziphus spina-christi* (L.) Desf. (Adgaba et al.

2017), *Schefflera abyssinica* (Hochst. ex A.Rich.) Harms (Bareke et al. 2020a), *Croton macrostachyus* Hochst. ex Delile (Bareke et al. 2020b), and *Coffea arabica* L. (Bareke et al. 2021b) were recognized.

The dynamics of nectar secretion and the potential for honey production in flowering plants remain mostly unknown to Ethiopians. Nectar secretion capability and its impact on honey production for significant numbers of bee forage plant species are not yet known. Among these plants, *Pavonia urens* Cav. (Inchinni) is one of the most significant melliferous species (Addi et al. 2014). It is a perennial herb that can reach a height of 2 m and is a member of the Malvaceae family. In addition to being common in Madagascar and tropical Africa, it also grows along edges, trails, and clearings in upland and riverine forests, secondary forest, scrub, abandoned cultivations, and up to 3000 m above sea level in the Ethiopian Highlands and Eritrea (Fichtl and Adi 1994). According to de Boer et al. (2005), *P. urens* is a medicinal plant that is used to cure stomachaches and pneumonia in addition to giving honeybees' nectar and pollen (Addi et al. 2014). However, studies to quantify the amount of honey that could be obtained from the flora nectar of *P. urens* are non-existent. The current work focused on determining the nectar secretion patterns and the potential amount of honey that can be sourced from the nectar of *P. urens.*

MATERIALS AND METHODS

Nectar volume was measured using micropipette. Nectar concentration was measured using a digital refractometer, while temperature and humidity were measured simultaneously using a thermo hygrometer.

Study area

Based on the accessibility and abundance of *P. urens*, study locations were chosen. *P. urens* was chosen because of its ecological adaption range, honeybee foraging intensity, and its honey production potential. The three-year experiment took place in Ethiopia's southwest Shewa Zone from 2018 to 2020.

Calculating the proportion of plants and flowers in a given region

To estimate the number of plants per area at each site, ten plots were randomly selected. Three plants per plot, each measuring 2 m by 2 m, were selected at random. The quantity of flowers on each plant was counted individually (Bareke and Addi 2022). Sixty plots were identified for the study and a total of 180 plants were selected. It is used to estimate the number of flowers per plant as well as flowers per area.

Determining the length of the nectar secretion

Nectar secretion and flower opening and ending times were recorded. To identify the length of the nectar secretion, five distinct flowers were measured every day from the starting to ending of nectar secretion repeatedly (Bareke et al. 2020a).

Measurement of the nectar's volume and nectar concentration

Insect nectar robbers were precluded by covering the inflorescences with fine mesh for 24 h before nectar harvest from each flower. Wyatt et al. (1992) labeled flowers from various inflorescence portions at random and nectar secretions within 24 h from 20 random flowers were harvested each day for three consecutive days at three hour interval (Esteves et al. 2014).

Determining dynamics of nectar secretion

Nectar volume, nectar concentration, temperature, and humidity were measured four times per day at intervals of 3 hours concurrently (Wyatt et al. 1992). The nectar volume was measured from an average of five separate flowers per plant and sampling period, which equates to 20 blooms per day (Esteves et al. 2014).

Calculating the amount of sugar in each flower's nectar

The amount of sugar present in the nectar was determined based on nectar volume, concentration, and sucrose density. The sucrose density was estimated from the nectar concentration using the Prys-Jones and Corbet (1991) equation as follows:

$$\rho = 0.003729/C + 0.0000178\ C^2 + 0.9988603$$

Where:
ρ: The estimate of sucrose density for a given value of C,
C: Nectar concentration (%) (Refractometer reading)

The equation from Dafni (1992) was used to determine the amount of sugar per flower as follows:

$$\text{Amount of sugar (A)} = \frac{\text{\% of sugar reading in the refractometer}}{100} \times \text{A volume }(\mu l) \times \text{Density of sucrose at the observed concentration}$$

Estimation of sugar and Honey Production Potential (HPP)

The plants' potential for producing honey was assessed to be as follows: Average sugar content per ha = average number of flowers per ha (Minimum to maximum number of flowers per ha) * average sugar content per flower/flowering season (Dafni 1992; Masierowska 2003; Kim et al. 2017).

One kg of ripe honey is expected to have an average moisture content of 18% while the sugar content is 82%. Therefore, the honey per ha of *P. urens* plants= sugar content per ha of *P. urens* plants divided by 0.82 kg of sugar (Bareke et al. 2020a).

Data analysis

One-way ANOVA was used to evaluate the gathered data. For mean separation between the treatments, Tukey Test was utilized. Additionally, a linear regression model was generated using the R programming language to examine how temperature and humidity affect the volume and sugar concentration of nectar.

RESULTS AND DISCUSSION

Flowers per plant and hectare

The highest level of flowers per m^2 and flowers per plant were found in 2018, while the lowest was obtained in 2019 (Figure 1). This demonstrates that plant bloom counts fluctuated annually and was somewhat influenced by climatic factors. Due to differences in plant size and age as well as changes in environmental factors throughout time, the mean quantity of blooms per plant and per hectare of land fluctuated. Similar research on *C. macrostachyus* and *S. abyssinica* suggested that changes in the ecological distribution of these plants as well as environmental conditions like temperature, rainfall, and wind as well as habitat could explain variations in the number of flowers per plant (Bareke et al. 2020a,b).

Early in the morning, *P. urens* flowers opened, supplying nectar to honeybees. It was immediately visited by honeybees after being opened. Depending on the weather, it begins to close after 12:00, but areas with shade remain open until 15:00 (Figure 2). This is due to the nature of plants and might be physiological constraints that the plant performs to conserve water loss through evaporation. Depending on the local weather, the honeybees begin visiting the flower between 6:30 and 7:00 hours in the morning and continue until the flower closed. The length of time that nectar and pollen are released varies from plant species to plant species. For instance: For *Z. spina-christi* 6 h to 18 h (Adgaba et al. 2012); *Antigonon leptopus* Hook. & Arn. 6 h to 19 h (Adjaloo et al. 2015); *Lavandula dentata* L. and *Lavandula pubescens* Decne. 6 h to 18 h (Adgaba et al. 2015); and Pear cultivars 8 h to 19 h (Farkas and Orosz-Kovacs 2003). The entire plant's blossoms could remain in bloom for up to a month. The length of the floral period has a significant impact on reproductive ecology, affecting both the potential of the plants to produce honey and the total number of visits by bees and other pollinators (Adgaba et al. 2015).

Dynamic of nectar secretion

The nectar volume varied greatly during the day (p= 0.01), reaching its highest value at 6:00 h and its lowest at 15:00 h (Table 1). The highest volume of nectar was collected at 6^{th} hour in the morning when the humidity was at its peak. The nectar concentration was varied significantly (p=0.000) during the day depending on the time of day. The highest concentration was measured at 15:00 h whereas, the lowest concentration was detected 6:00 h (Table 1).

The amount of sugar varied significantly during the day (p=0.03), with the highest amount recorded at 6:00 and 15:00 h (Table 1). In general, the plants studied had their main nectar production occurring between 6:00 and 12:00, and in the open, the flower petals will be furled after this period (at where no shade plant). However, in the shade, the flower stayed opened to continuously offer nectar to the honeybees until 15:00 h. This is due to the physiological constraints. Microclimate influences pollinator behavior (time of activity, frequency, and duration of visits, as well as foraging behavior), patterns of daily and/or seasonal fluctuations, and the likelihood of changes in nectar volume and concentration (Dafni 1992). Due to climatic factors like air temperature and humidity, which can significantly affect the nectar secretion and concentration of sugars, nectar secretion varies throughout the flowering seasons (Denisow et al. 2018).

The amount of daily secreted nectar varies from plant species to plant species. For instance, *L. pubescens* and *L. dentata* both supply nectar every day for 12 hours each, as well as *A. leptopus* and *Thevetia peruviana* Thevetia peruviana for 14:00 h (Adgaba et al. 2015). For *P. urens*, the largest nectar volume was measured after 6:00 h, whereas the highest concentration was observed at 15:00 h. At the lowest temperature and maximum humidity, nectar volume and concentration were at their highest and lowest, respectively. This implies that temperature and humidity may have some relationships with nectar secretion. The highest sugar amount, however, was recorded during 15:00 h of the day. The weather was quite hot and dry during this time. This demonstrates that both temperature and humidity have an impact on the plant's ability to secrete nectar. In addition to environmental factors, nectar concentration can change based on the floral sexual stages and flower position (Antoń and Denisow 2014; Lu et al. 2015). Honeybee foraging can be significantly impacted by the concentration and quality of nectar (Bertazzini and Forlani 2016).

Among the different years of data collection, there are considerable variations in nectar volume and concentration. The value of nectar volume was the highest in 2020 whilst nectar concentration was lowest for the same year. This indicates that nectar concentration decreases with increasing nectar volume. The nectar volume was the lowest in 2019 while the greatest nectar concentration was recorded in this year (Figure 3.A). This is due to the windy and sunny weather that prevailed during the data collecting. However, compared to the other data collection years, nectar volume was substantially higher in 2020, and this year's concentration was at its lowest (Figure 3.B). This is a result of a brief period of rain during field data gathering.

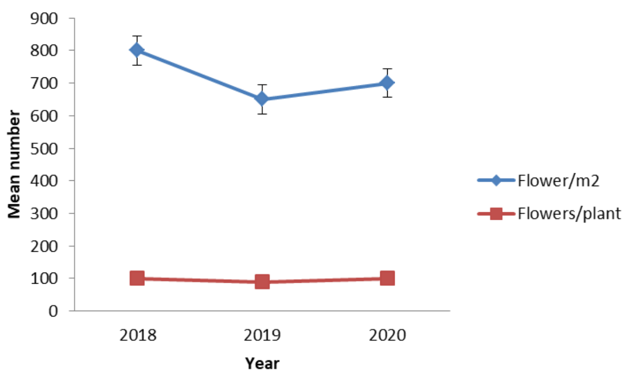

Figure 1. The average number of *Pavonia urens* flowers per plant and flowers per square meter from 2018 to 2020

Table 1. Mean nectar concentration (%), nectar volume (µl) and sugar amount (mg) /flower with ± (SE) in nectar per flower at 3 hours intervals of *Pavonia urens* with mean temperature (°C) and humidity (%) at 6:00 to 15:00 hours (h) in South west Shewa Zone, Ethiopia

Time (h)	Temp (°C)	Humidity (%)	Volume ± SE (µl)	Concentration (%) ± SE	Sugar (mg)/flower ± SE
6:00	14.3	60.6	5.79±0.39[a]	16.89±1.1[d]	8.33±0.60[ab]
9:00	21.4	43.3	4.49±0.42[ab]	22.28±1.14[c]	7.12±0.5[ab]
12:00	27.1	28.6	3.18±0.21[bc]	29.38±1.16[b]	6.66±0.26[b]
15:00	27.7	22.7	2.24±0.21[c]	38.63±0.94[a]	8.93±0.83[a]
Mean	22.6	38.8	4.3±0.2	24.43±0.85	7.5±0.3
Significance level			**	***	*
P-value			0.01	0.000	0.03

Note: Treatments with the same letter are not significantly different along column

Figure 2. A *Pavonia urens* flower with nectar and closed flowers in the late afternoon. A. Accumulated nectar, B. Nectar collection, C. Closed after 12:00 hour, D. Opened early in the morning

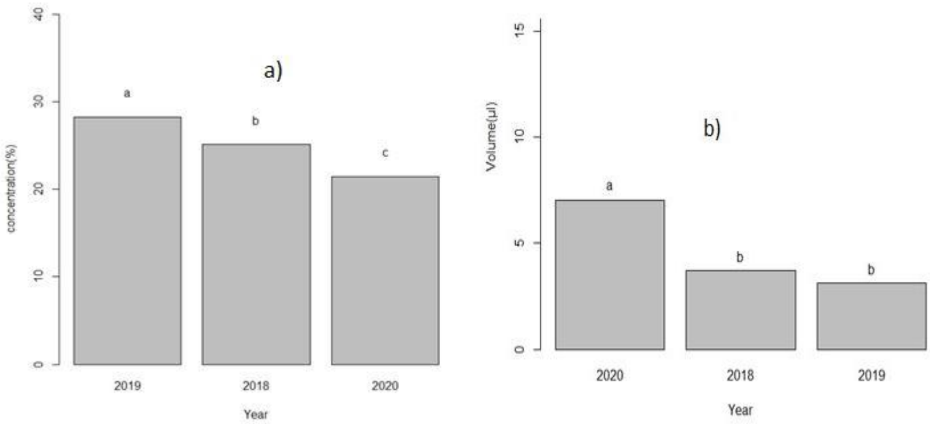

Figure 3. A. Nectar concentration and B. Volume of *Pavonia urens* from 2018-2020 years in South West Shewa Zone, Ethiopia

The nectar concentration of *P. urens* was directly correlated with temperature (°C). This indicates that the values of nectar concentration increased as the temperature rose. However, the concentration of nectar was less affected by temperature (Figure 4.A). The maximum nectar concentrations were obtained between 20 and 30°C. On the other hand, the volume of nectar was indirectly related to temperature. This suggests that the volume of nectar decreased with rising temperature. However, the amount of nectar secreted was not highly influenced (R^2= 32.84) by temperature. The highest amount of nectar was produced between 15 and 25°C (Figure 4.B).

Nectar volume and air humidity in the research area are directly correlated (Figure 5.A). Therefore, a rise in air humidity resulted in an increased nectar volume. The volume of nectar was influenced by air humidity by 30.94%. The largest nectar volume values were detected between 40 and 70% air humidity, whereas the lowest nectar volume were detected at less than 40% air humidity.

The nectar concentration produced by *P. urens* was inversely associated with the humidity of the air (Figure 5.B). This shows that the higher nectar concentration values were obtained at the lower air humidity values and vice versa. The parameters of nectar concentration were influenced by air humidity by 50.88%.

The amount of sugar in *P. urens* was not significantly impacted by the research area's temperature or air humidity (Figure 6). Based on the plant's nectar volume and concentration, sugar content was calculated. As shown before, there was a direct correlation between temperature and concentration as well as between humidity and nectar volume. However, there was indirect correlations between nectar volume and nectar concentration. Temperature and humidity had negligible effects on sugar content because their effects on nectar and volume are the reverse of one another.

Number of flower/plants, nectar secretion length, sugar and honey production capacity of *P. urens* per flower

The *P. urens*'s nectar secretion lasted an average of 10 days, ranging from 9 to 12 days (Table 2). However, the flower can stay alive for up to 15 days. In addition to this, the average number of flowers per plant was 90±8.47 with 15 and 217 as the minimum and maximum record per plant, respectively. This range of variation shows that extremely small to large plants with enormous flowers were included in the plants used to estimate the number of flowers per plant. The mean nectar volume per 24 h of *P. urens* was 7.23±0.43 µL (Table 2).

Table 2: Mean no. of plants/m^2 (N= 60 plots), mean no. plants/ha, mean no. of flowers/plant (N= 180 plants), mean no. of flowers/ha, mean nectar secretion length and mean sugar per flower/season for *Pavonia urens*

Parameters	**Mean ± SE**	**Minimum**	**Maximum**
No. of plants/m^2	4±0.37	1.00	10.00
No. of plant/ha	40000±3415.7	10000.00	100000.00
No. flowers/plant	90±8.47	17.00	198.00
No. of flowers/ha	3820250±485856	170000.00	11880000.00
Nectar volume (µl)/24 hours	7.23±0.43	1.30	20.00
Nectar secretion length	10±0.11	9.00	12.00
Sugar (mg)/flower	7.5±0.27	2.45	19.53
Honey (mg)/flower	9.15±0.33	2.99	23.83

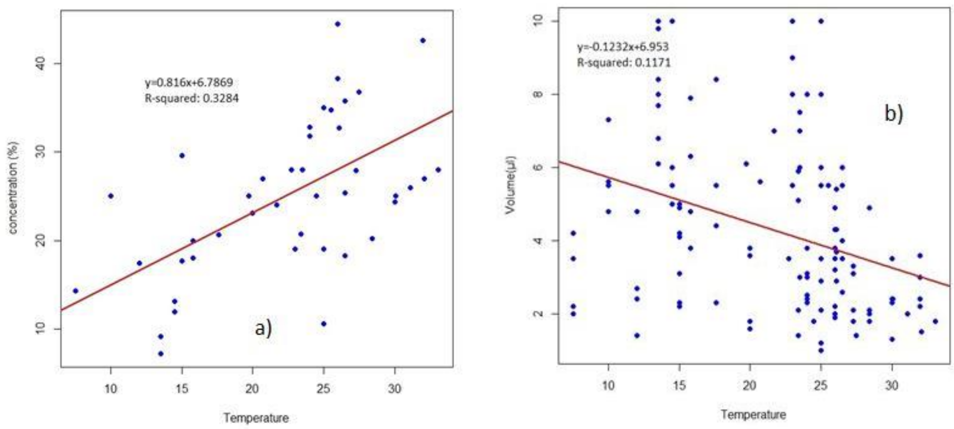

Figure 4. A. Effect of Temperature on nectar concentration and B. Volume of *Pavonia urens*

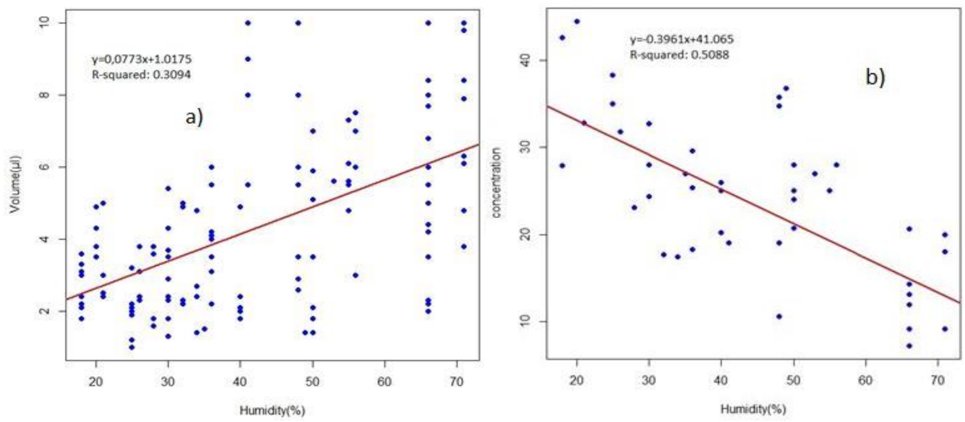

Figure 5. A.Effect of air humidity on nectar volume and B. Concentration of *Pavonia urens*

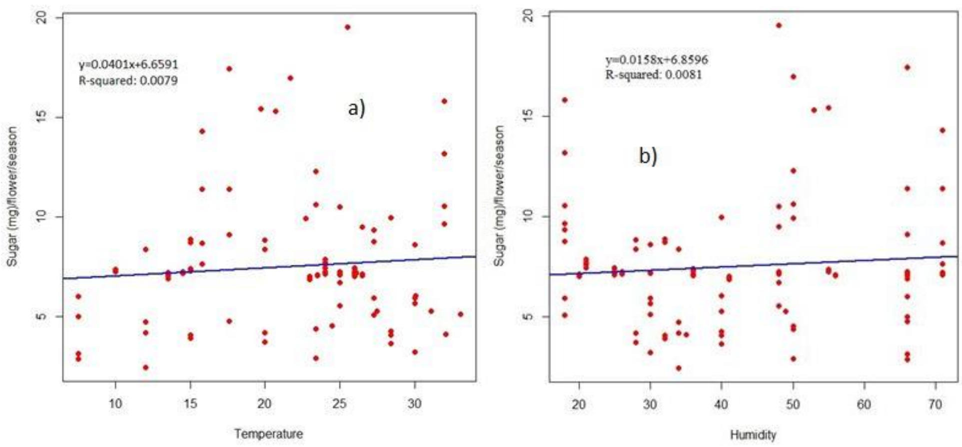

Figure 6. A. Effect of temperature and B. Air humidity on amount of sugar/flowers/season of *Pavonia urens*

There were about 170,000 to 11,880,000 flowers per hectare with a mean value of 3,820,250 flowers (Table 2). This was used to calculate the amount of sugar per hectare by multiplying it by the sugar per flower (Table 2). Accordingly, the average sugar per flower per flowering season was 7.5±0.27 mg (ranges from 2.45 to 19.53 mg) whilst the honey per flower was 9.15±0.33 mg (ranges from 2.99 to 23.83 mg).

Estimated honey production potential of *P. urens* plants per hectare of land

The average sugar per hectare of *P. urens* plants was estimated as follows: average number of flowers per ha (Minimum to maximum number of flowers per ha) * average sugar content per flower/flowering season. Hence, the average sugar content per ha was 3820250 (170,000 to 11,880,000) * 7.5 mg (Table 2) = 28651875 mg (ranges from 416,500 to 232,016,400 mg) or 28.65 kg (ranges from 0.42 kg to 232 kg) of sugar.

On the global market, 1 kg of honey has an average moisture content of 18% while the sugar content is 82%. Hence, Honey (kg) per ha of *P. urens* plants = sugar content per ha of *P. urens* plants divided by 0.82 kg of sugar. When sugar per hectare of *P. urens* plants was converted to honey per ha, it was an average of 35 kg (ranging from 0.5 kg to 283 kg from very small plant to big) per hectare of *P. urens* plants. This finding suggests that a plant's ability to produce honey is influenced by its flower density. The amount of honey that can actually be taken out of the hive is anticipated to be less than its potential. The ability of a plant to secrete nectar that honeybees use to make honey is referred to as the capacity of the plant for producing honey. It is anticipated that half of the potential of the plant will be collected via the bee colonies' honey. Merely 50% of the honey is used for nectar and pollen gathering, with the remaining 50% being stored. Study conducted by Al-Ghamdi et al. (2016) indicated that the honeybees use sugar as an energy source throughout their journey to collect nectar and pollen.

The ability of bee plants to produce honey varies from plant species to plant species. Accordingly, *L. pubescens* and *L. dentata* produce honey at rates of 51 kg per hectare and 24.1 kg per hectare per flowering season, respectively (Adgaba et al. 2015). The *C. arabica* produces 125 kg of honey per hectare (Bareke et al. 2021b); *S. abyssinica* produces 1791 kg per hectare per flowering season (Bareke et al. 2020a). Accordingly, the honey production potential of *Lavandula* species is somewhat similar with *P. urens*; because it is herb. However, the others are trees and shrubs which are bigger in size as compared to *P. urens.*

The amount of honeybee colonies needed to be installed in a chosen region depends heavily on the bee plant species' capacity to produce honey. A honeybee colony's effective foraging range can cover a 2 km radius, a 12.56 km^2 area. By addressing the issue of colony overstocking, supreme honey is produced by balancing several honeybee colonies with the available floral resource.

In conclusion, *P. urens* has a strong chance of producing nectar that greatly aids in the creation of honey. Local temperature and air humidity had an impact on *P. urens* nectar volume and concentration. The volume and concentration of the nectar varied greatly throughout the day. It offers nectar for anywhere between 6 and 15 hours, depending on the habitat. *P. urens* secret nectar only remains open for 12 hours under normal circumstances; in shade, it remains open until 15 hours. 35 kg of honey might be produced per season from a hectare of *P. urens* plants.

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