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Research Article

Quantifying Nectar Secretion Potential of *Hygrophila auriculata* (*Schum.*), *Heine* (Acanthaceae), and *Salvia leucantha Cav.* (Lamiaceae) for Honey Production

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The study was conducted to quantify the nectar secretion dynamics, and honey production capacity of *Hygrophila auriculata* and *Salvia leucantha*. One day before nectar collection, a group of flowers was enclosed with mesh bags to measure accumulated nectar volume. Moreover, nectar volume, concentration, temperature, and humidity were measured at intervals of 3 hours. The collected data was analysed using One-way ANOVA and linear regression. Nectar secretion dynamics of the two species were significantly varied (at $p < 0.05$) at different times of the day. The nectar volume that became available between the two consecutive measurements (three-h intervals) varied from 1.5 to 2.5 μl/flower, and 4.1 to 5.5 μl/flower for *H. auriculata* and *S. leucantha*, respectively. The temperature was positively correlated with the nectar concentration for both species. However, the temperature was negatively correlated with the nectar volume of *H. auriculata* whereas almost at equilibrium for *S. leucantha*. Humidity was negatively correlated with nectar concentration for both species whereas it is positively correlated with nectar volume for *H. auriculata*. However, the relationships between humidity and nectar volume were almost found at equilibrium for *S. leucantha*. Based on the mean amount of nectar sugar secreted by the plants, the mean honey production potentials of the species were estimated to be 29.88 kg and 60.2 kg/ha depending on the size of the plants for *H. auriculata* and *S. leucantha*, respectively. Therefore, propagation and *in-situ* conservation of these species are also recommended for sustainable honey production.

1. Introduction

Ethiopia has diversified flowering plant resources in which most of them are honeybee plants [1]. Bee plants are those plant species that provide only pollen or both pollen and nectar [2] for honeybees. The contribution of bee plant species to honey production depends on the floral morphology, anatomical structure of flowers [3], flowering phenology, and quality and quantity of nectar secreted [4]. The quality and quantity of nectar is affected by environmental variables [5]. Since nectar is exposed to evaporation under the influence of temperature, humidity [6], wind speed, and solar irradiation [7], it is necessary at least to convoy every nectar measurement with the measurements of temperature and humidity [7].

Nectar secretion dynamics and honey production capacity of different bee forage plants have been carried out by different authors. Accordingly, the honey production potential was known for *Acacia gerrardii* [4]; for *Otostegia fruticosa* and *Ziziphus spina-christi* [5]; for *Croton macrostachyus* and *Schefflera abyssinica* [8, 9]; and for *Coffea arabica* [10].

Determination of the honey production capacity of bee forage plants is very essential to estimate the honey bee colony carrying capacity of a given vegetation type without negatively affecting honey production capacity of the single colony [6]. The honey production capacity of bee plants is varied from plant species to species [10]. In every geographical region, there are very few important honey source plants that provide honey to the world [5]. Hence, it has supreme importance to characterize them according to their degree of honey production capacity.

In Ethiopia, the knowledge of nectar secretion dynamics and potential for honey production is relatively at an infant stage. For many important bee forage plant species, nectar secretion capacity and its contribution to honey production have not been documented yet. These plants include one of the important melliferous species, *Hygrophila auriculata (Schum.), Heine*, and *Salvia leucantha* Cav.

Hygrophila auriculata is an erect sparingly branched perennial or annual herb with square stems and elliptic leaves that belongs to Acanthaceae family [11]. It grows at altitudes as low as 500 m above sea level in areas waterlogged for most part of the year and up to 2800 m in grassland and along paths of forest edges. It is eaten by cattle and the seeds can produce semidrying oil. The fleshy root has a cooling, slimy taste, and a marshy smell. *H. auriculata* gives flower from August to February; honeybees collect pollen and nectar from the flowers frequently [11].

Salvia leucantha is a perennial ornamental herb, growing up to 40–100 cm and much branched, densely pubescent with white hairs. Its flowers are whitish pink or pale violet. It is cultivated as an ornamental and often naturalized in the wetter regions of the flora area, at altitudes between 1800 and 2800 m and also in upland Eritrea and elsewhere but native in Mexico. *Salvia leucantha* gives flowers after the rainy season and it is an excellent source of bee forage during the dry period [1].

However, nectar secretion dynamics and honey production prospective of these plant species have not been known. Therefore, the main objective of this study was to identify the nectar secretion dynamics and estimate honey production potential of *Hygrophila auriculata and Salvia leucantha*.

2. Materials and Methods

Micropipettes and micropipettes' tips were used for the nectar collection. A digital refractometer was used to measure nectar concentration, whereas a hygrometer measured temperature and humidity at the same time.

2.1. Study Area. The experiment was carried out in southwest Shoa Zone, Ethiopia for three years (2018–2020). The two species were selected based on their ecological adaptation range, foraging intensity of honeybees, and accessibility of the flower for nectar measurement.

2.2. Estimating the Number of Flowers Per Plant and Plant Per Area. Ten plots were randomly taken to determine the number of plants per area from each site. Plot size was 2 m $*$ 2 m for *Salvia leucantha* and 1 m $*$ 1 m for *Hygrophila auriculata*. Plants per plot were taken to count the number of flowers per plant. Accordingly, the average number of flowers per hectare = average number of plants/ha $*$ average flowers/plant.

2.3. Nectar Volume and Concentration Measurement. Prior to nectar removal, the inflorescences were covered with fine mesh for 24 hours to prevent visitors. Flowers were marked at random from different inflorescence parts [12]. Accumulated nectar for 24 hours was taken from 20 flowers at random per day for three days [13].

2.4. Identifying the Nectar Secretion Duration. Time of opening of flowers, pollen release, and nectar secretion were taken. Fifteen (15) individual flowers were measured daily from the start to the end of nectar secretion to determine the nectar secretion duration [8].

2.5. Determining Nectar Secretion Dynamics. Data of nectar volume, nectar concentration, temperature, and humidity were taken at three hours intervals from 6:00 to18:00 hours simultaneously [12] depending on the nectar secretion durations of plant species. For each plant and sampling time, the nectar volume was measured from an average of 5 individual flowers at a time [13].

2.6. Calculation of Sugar Amount in Nectar Per Flower. The amount of sugar found in nectar was calculated from the nectar volume, concentration, and sucrose density. Nectar concentration was converted to sucrose density using Pryjones and Corbet's [14] equation. The amount of sugar was calculated using the [7] equation.

2.7. Estimation of Honey Production Potential (HPP). Honey production potential of plants was estimated as the following: Average amount of sugar per hectare = Average number of flowers per ha $*$ average amount of sugar per flower $*$ nectar secretion days. Average amount of sugar per m^2 was converted to hectares [3, 7, 15]. The mean amount of sugar per hectare was converted to honey.

In the international market, the average moisture content of the honey is 18% from 1 kg while 82% is sugar. This was used to convert the mean amount of sugar produced per hectare per flowering season to honey. The honey estimated from the sugar was the honey production potential of the plants [8].

2.8. Data Analysis. The collected data was analysed using descriptive statistics and one-way ANOVA. Tukey was used for mean separation among the treatments. In addition to this, a linear regression model was computed using R-software to see the effect of temperature and humidity on nectar volume, concentration, and calculated sugar.

3. Results

The mean nectar secretion lengths of both species are similar which were 8.3 and 8.45 for *S. leucantha* and *H. auriculata, respectively*. The maximum nectar secretion periods were 10 days for both species (Table 1). The mean number of plants per m^2 was 1 for *S. leucantha* and 10 for *H. auriculata*. *S. leucantha,* which has more branches than *H. auriculata*

Table 1: Mean nectar secretion length (day), flowers/plant, flowers/ha, plant/ha, flowers/m^2, and plants/m^2 of *S. leucantha* and *H. auriculata*.

Parameters	*Salvia leucantha*			*Hygrophila auriculata*		
	Mean ± std.error	Minimum	Maximum	Mean ± std.error	Minimum	Maximum
Nectar secretion length (day)	8.3 ± 0.3	7.00	10.00	8.45 ± 0.3	7.00	10.00
Flowers/plant	473 ± 56	80.00	1350	43.5 ± 2.77	9.00	90.00
Flowers/ha	4892000 ± 550847	800000	13500000	4690000 ± 451542	630000	14400000
Plant per ha	10750 ± 421.7	10000	20000	103750 ± 6073	30000	170000
Flowers/m^2	489.2 ± 55	80.00	1350	469 ± 45.2	63.00	1440.00
Plants/m^2	1.1 ± 0.04	1.00	2.00	10.4 ± 0.6	3.00	17.00

and due to this the number of flowers per plant is few. This is due to the nature of plant species. Moreover, the mean flowers per plant were 473 for *S. leucantha* and 44 for *H. auriculata*. The more branched plant species provide the highest number of flowers per plant.

3.1. Nectar Secretion Dynamics. The highest nectar volume of *H. auriculata* was obtained at 18 hours while the lowest was at 9 hours (Table 2). Due to the nature of this plant (Figure 1), the lowest nectar volume was found early in the morning until 9:00 hours. On the other hand, the highest nectar concentration (33%) was recorded at 15 hours while the lowest was at 6 hours (early in the morning).

Nectar volume and concentration of *S. leucantha* were significantly different ($p < 0.05$) at different times of the day. The highest nectar volume (5.5 μl) of *S. leucantha* was found at 15 hours whereas the lowest was early in the morning (at 6 hours) (Table 2). For many plant species, the nectar volume is the highest early in the morning due to the high humidity and low temperature of the local area. However, due to the nature of flower morphology of *S. leucantha* (Figure 2), the utmost nectar volume was obtained at the maximum humidity and temperature values of the study area. On the other hand, the uppermost nectar concentration was obtained from 12–18 hours of the day while the lowest was at 6 hours.

3.2. Nectar Volume and Solute Concentration in Different Years. Nectar concentration and volume had significant differences among the years of data collection. The highest nectar concentration was obtained in 2019 while the volume was the lowest this year (Figure 3(a)). This is because during our data collection, the weather condition was sunny and windy. On the other hand, the nectar volume was significantly higher in 2018 than in 2019 year of data collection (Figure 3(b)). This is due to small rainy weather conditions during field data collection.

Nectar volume and solute concentration had significant variation among the years of data collection. Accordingly, the highest nectar concentration and nectar volume were obtained in 2019 whereas the lowest was in 2020 for both volume and concentration (Figures 4(a) and 4(b)).

3.3. Effect of Temperature and Humidity on Nectar Volume and Concentration. Temperature (°C) was positively correlated with nectar concentration of *H. auriculata*. However,

Table 2: Mean nectar concentration (%) and volume (μl) per flower at 3 hours intervals with ± (SE) of the 2 species at 6:00–18:00 hours in southwest Shewa Zone.

Time (h)	*H. auriculata*		*S. leucantha*	
	Volume ± SE	Conc. ± SE	Volume ± SE	Conc. ± SE
6:00	1.8 ± 0.42^{ab}	11 ± 2.14^{d}	4.1 ± 0.3^{b}	24.8 ± 0.46^{c}
9:00	1.5 ± 0.2^{b}	16.6 ± 2^{c}	4.3 ± 0.4^{b}	28.1 ± 0.45^{b}
12:00	2.2 ± 0.18^{ab}	27 ± 1.5^{b}	4.27 ± 0.4^{b}	$30.98 \pm .51^{a}$
15:00	2.17 ± 0.24^{ab}	33 ± 0.7^{a}	5.5 ± 0.52^{a}	31 ± 0.70^{a}
18:00	2.5 ± 0.3^{a}	30.1 ± 1.86^{ab}	4.81 ± 0.37^{ab}	31.7 ± 1.00^{a}
Mean	**2.0 ± 0.13**	**23.5 ± 1**	**4.59 ± 0.18**	**29.3 ± 0.35**

Note. treatments with the same letter are not significantly different along column.

the effect of temperature on the nectar concentration was insignificant (Figure 5(a)). The highest nectar concentration values were secreted between 20°C and 25°C for *H. auriculata*.

On the other hand, the temperature was negatively correlated with nectar volume. This means as temperature increased the nectar volume decreased and vice versa. However, the temperature had no significant effect on the nectar volume of *H. auriculata* (Figure 5(b)).

Humidity was negatively correlated with the nectar concentration of *H. auriculata* (Figure 6(a)). This indicates that at the lower values of humidity, the highest nectar concentration values were obtained and vice versa. The influence of humidity on the values of nectar concentration was insignificant.

Humidity of the study area has direct relationships with nectar volume (Figure 6(b)). The highest values of the nectar volume were found between 45% and 70% of humidity whereas the lowest values of nectar volume were obtained at <25% of humidity.

The temperature was positively correlated with the nectar concentration of *S. leucantha* (Figure 7(a)). It influences the nectar concentration by 30.67%. The peak nectar concentration was obtained between 25°C and 30°C.

The relationships between nectar volume and temperature of the local area were almost found at equilibrium (Figure 7(b)). This indicates whether the temperature of the local area increased or decreased and it has no effect on the nectar volume of *S. leucantha*.

The humidity of the study area was negatively correlated with the nectar concentration of *S. leucantha* (Figure 8(a)). At the lowest humidity the highest nectar concentration

Figure 1: Flowers of *H. auriculata* and when the honeybees collect nectar.

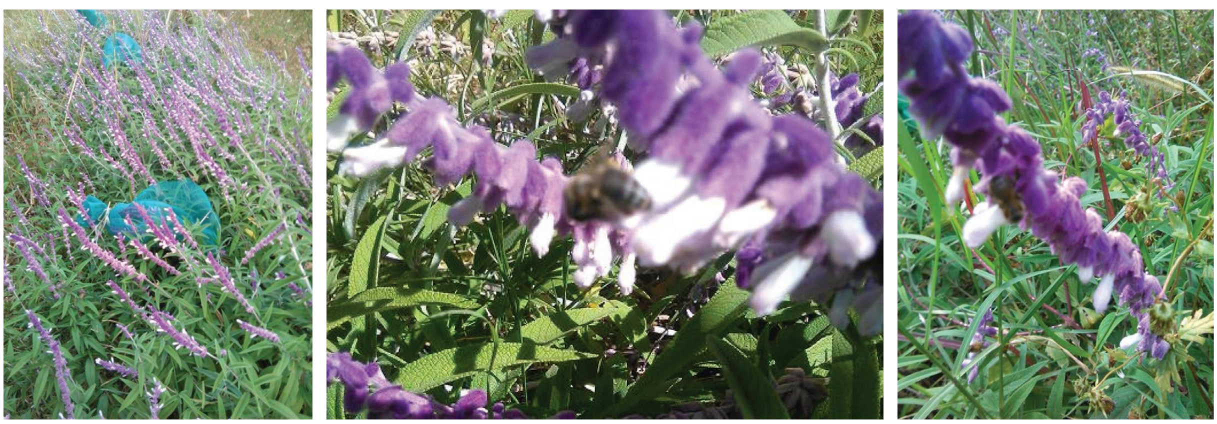


Figure 2: Flowers of *S. leucantha* and when the honeybees collect nectar.

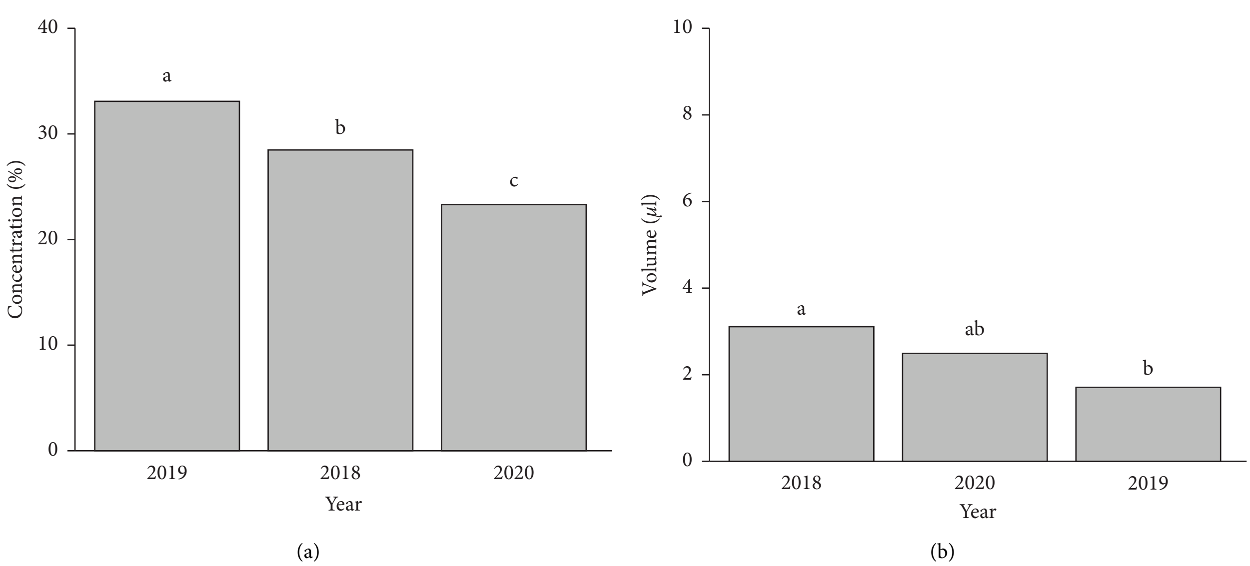
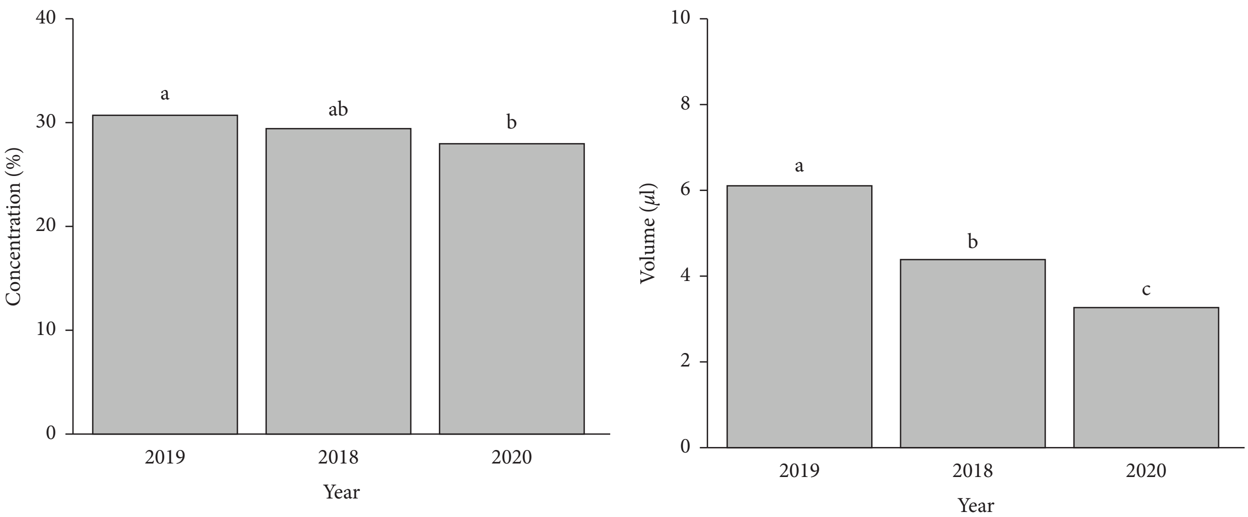
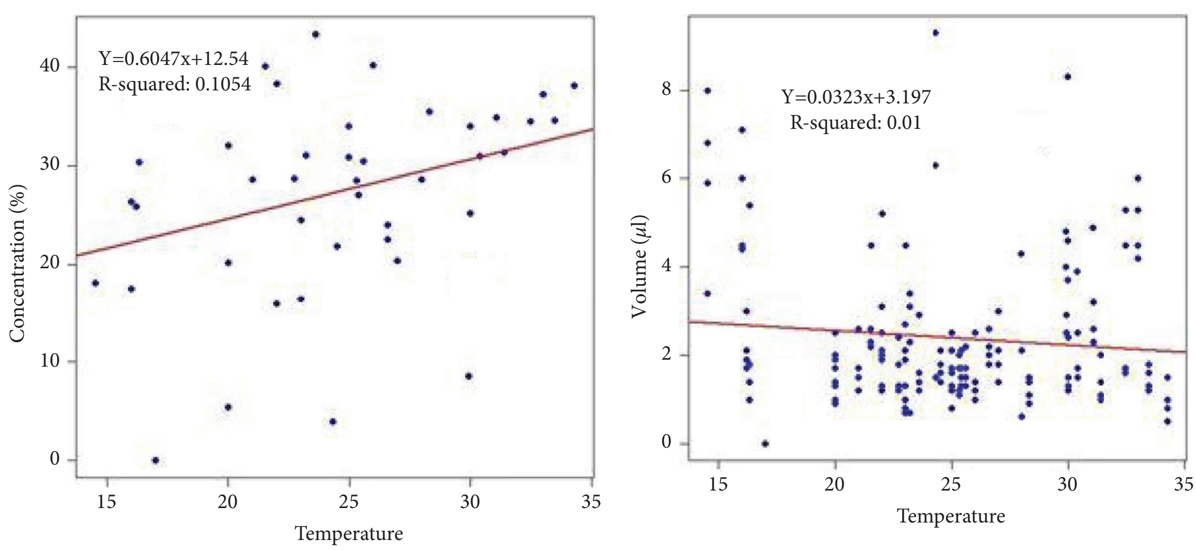


Figure 3: Nectar concentration (a) and volume (b) of *Hygrophila auriculata* from 2018 to 2020 years in southwest Shewa Zone, Ethiopia.



(a) (b)

Figure 4: Nectar concentration (a) and volume (b) of *Salvia* leucantha from 2018 to 2020 years in southwest Shewa Zone, Ethiopia.



(a) (b)

Figure 5: Effects of temperature on nectar concentration (a) and volume (b) of *Hygrophila auriculata*.

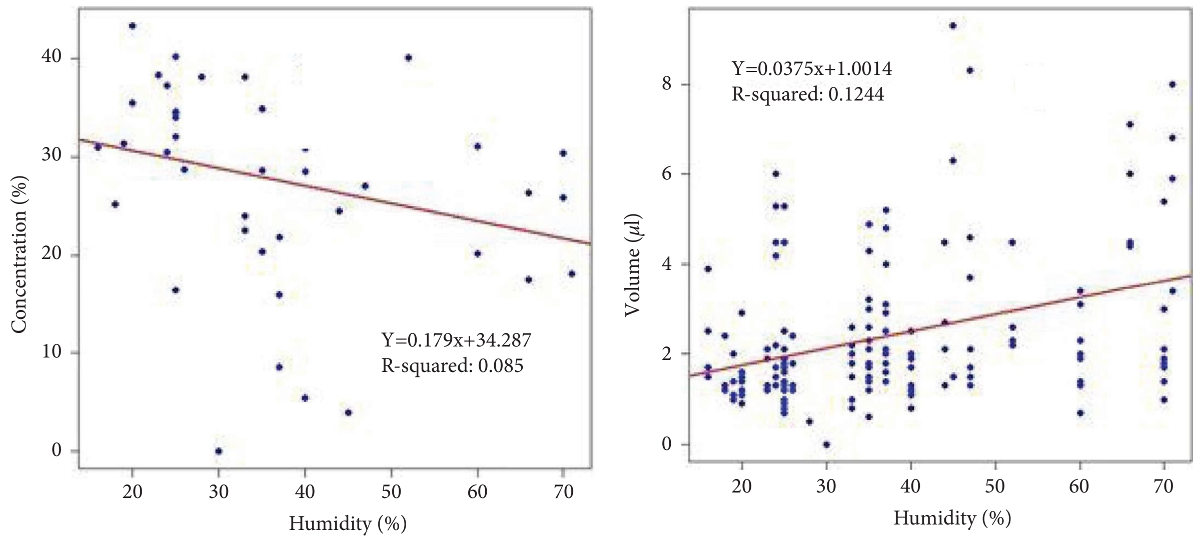
values were obtained. The relationship between humidity and the nectar volume of *S. leucantha* was almost found at equilibrium (Figure 8(b)). Hence, whether the values of humidity increased or decreased, it has no effect on the nectar volume of *S. leucantha*.

3.4. Estimating the Amount of Sugar and Honey Production Capacity. The mean number of flowers/ha of *H. auriculata* was 4690000 (ranging from 630000 to 14400000) (Table 1) and it was used to estimate sugar per ha. The mean sugar per flower was 5.22 mg (ranging from 0.47 to 23.02 mg/flower). Accordingly, the mean sugar per ha was 24.5 kg (ranging from 1.54 to 281.2 kg/ha). When it was converted to honey, the mean amount of honey per ha was 29.88 kg (ranging from 1.88 to 342.9 kg/ha).

The mean number of flowers per ha of *S. leucantha* was 4892000 (ranging from 800,000 to 13500, 000) (Table 1). The mean sugar per flower was 10.09 mg (ranging from 1.83 to 30.45 mg/flower). The amount of sugar per ha was 49.36 kg (ranging from 1.46 to 411 kg/ha depending on the size of the plants). When the above-mentioned amount of sugar was converted to honey, it was 60.2 kg/ha (ranging from 1.78 to 501.2 kg/ha depending on the size of the plants).

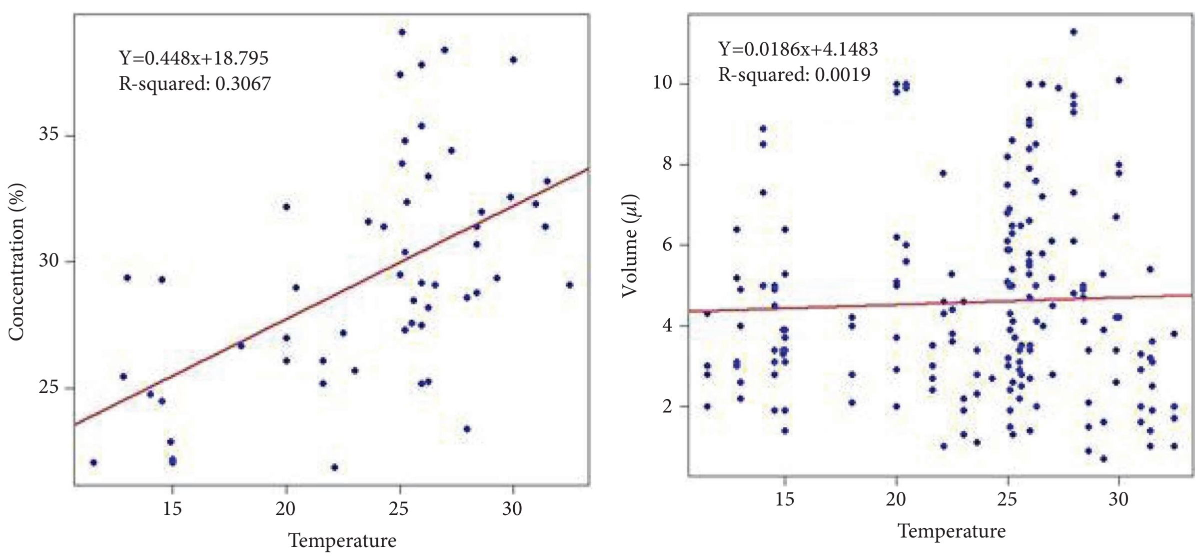
4. Discussions

4.1. Number of Flowers Per Plant. The mean number of flowers per plant varied due to the variation in size and age of the plants. A similar study conducted on *Schefflera abyssinica* and *Croton macrostachyus* also revealed that the



(a) (b)

Figure 6: Effect of air humidity on nectar concentration (a) and volume (b) of *Hygrophila auriculata*.



(a) (b)

Figure 7: Effects of temperature on nectar concentration (a) and volume (b) of *S. leucantha*.

variations in number of flowers per plant could be attributed to the variations in their ecological distribution and climatic factors (temperature, rainfall, and wind) [8, 9].

4.2. Effect of Weather Conditions on Nectar Secretion Dynamics. The nectar secretion duration of *H. auriculata* and *S. leucantha* occurred during the whole day times. However, the nectar secretion of *H. auriculata* varied depending on the weather condition of the area, during the windy periods the secretion was started after 9 hours and during normal weather it started at 6 hours. Microclimate determines the chances of changes in nectar volume and concentration; patterns of daily and or seasonal changes in nectar variables; and pollinator behaviour (frequency, duration of visits, and foraging behavior) [7]. Nectar production is differed between the growing seasons due to environmental variables such as air temperature and humidity which can highly affect the nectar secretion and concentration of sugars [16].

The nectar secretion duration is varied from plant species to species. For example: for *Antigonon leptopus* and *Thevetia peruviana from* 6 h to 19 h [17]; *Lavandula dentata* and *Lavandula pubescens* from 6 h to 18 h [18]; *Ziziphus spina-christi* from 6 h to 18 h [19]; and pear cultivars from 8 h to 19 h [20]. Floral durability plays an important role in reproductive ecology, influencing the total number of visits by honeybees and other pollinators as well as the honey production potential of the plants [18].

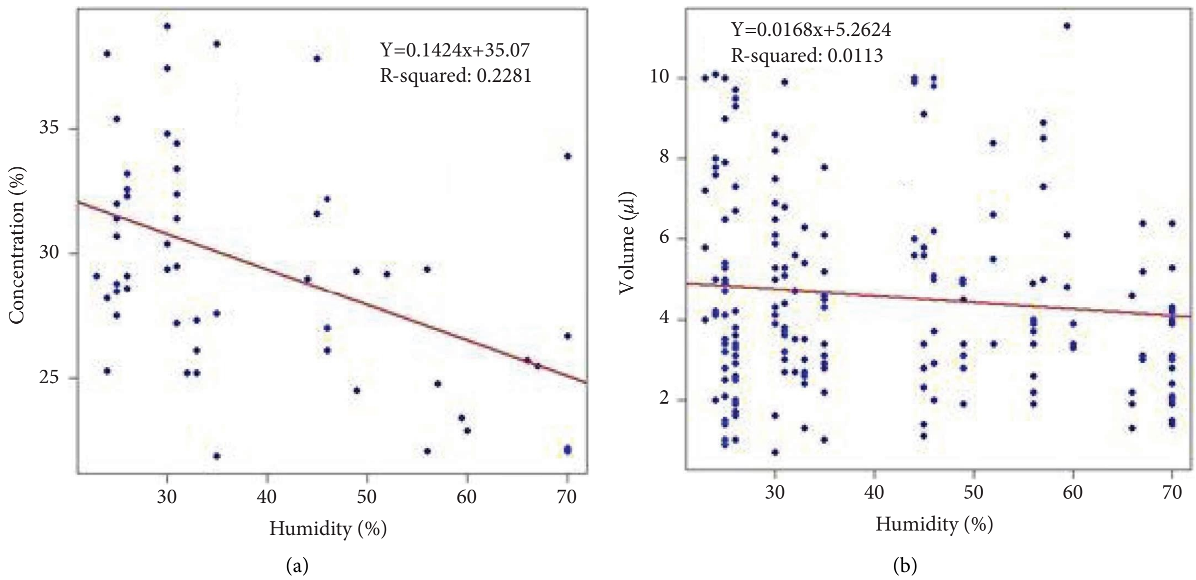


Figure 8: Effect of air humidity on nectar concentration (a) and volume (b) of *S. leucantha*.

Temperature was positively correlated with nectar concentration for both species. However, the temperature was negatively correlated with the nectar volume of *H. auriculata* whereas almost at equilibrium for *S. leucantha*. Humidity was negatively correlated with nectar concentration for both species whereas it positively correlated with nectar volume for *H. auriculata*. However, the relationships between humidity and nectar volume were almost found at equilibrium for *S. leucantha*. This indicates that every plant species has its own optimum humidity and temperature for nectar secretion. A similar study conducted by Nuru et al. [18] on *Lavandula dentata* and *Lavandula pubescens* also showed that the two species have different optimum humidity and temperature levels for the secretion of maximum nectar.

4.3. Honey Production Potential. Under natural conditions, the amount of honey obtained per hectare of land was 29.88 kg (ranging from 1.88 to 342.9 kg/ha) and 60.2 kg/ha (ranging from 1.78 to 501.2 kg/ha) depending on the size of the plants for *H. auriculata* and *S. leucantha*, respectively. This variation shows the honey production potential of bee plants is varied from plant species to species. This variation occurred due to the nature of the plant, the habit of the plants as well as weather condition of the study area. For example: *Lavandula dentata and Lavandula pubescens* provide honey of 51 kg/ha and 24.1 kg/ha, respectively Nuru et al. [18], *Coffea arabica* 125 kg of honey/ha [10] and *Schefflera abyssinica* 1791 kg honey/ha [8].

The honey production potential of the bee plant species is very important to determine the number of honeybee colonies required to be placed in the selected area. This can be carried out with an effective foraging range (2 km radius or 4 km^2 area or 400 hectares) of honeybee colonies. Balancing several honeybee colonies with the available floral resource is used to harvest paramount honey by alleviating the problem of colony overstocking.

5. Conclusions

Based on the dynamics and the amounts of nectar secreted per flower and per plant, both species can be considered a potential honey source plants for the study area. However, the honey production potential of *S. leucantha* is better than that of *H. auriculata*. In general, the importance of the species is significant not only in terms of serving as sources of honey but also in terms of their ecological values. Therefore, further research on how to propagate and *in-situ* conservation of these species are also recommended for sustainable honey production.

Data Availability

Data are found with the corresponding author and available when necessary.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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