Nectar secretion and honey production potential of *Schefflera abyssinica* (Hochst. ex A. Rich.) Harms, Araliaceae

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This study was conducted to determine the nectar secretion dynamics, honey production potential, and the number of bee colonies required to be placed in a hectare of *Schefflera abyssinica* forest. One day prior to nectar removal, five inflorescences were covered with fine mesh bags on different parts of the tree one day before measuring. Fifty flowers per tree were randomly selected from the five covered inflorescences and nectar volume was measured. Nectar volume and concentration were measured with a 1 hour interval. The average nectar volume (µl) per flower in 24h, average nectar concentration and amount of sugar per flower/season, sugar amount per tree, honey per tree, and honey potential per hectare for *S. abyssinica* were 11.6, 25.6%, 17.78 kg, 8.85 kg, 10.79 kg, and 17.91 kg respectively. The actual harvestable amount of honey was half of the potential (895.5 kg/ha). Total financial return was estimated to be $6268.50 based on a value of $7/kg of *S. abyssinica* honey. Mean nectar volume and concentration varied significantly with time of day. Nectar volume and concentration were positively correlated with temperature. One hectare of productive trees of *S. abyssinica* holds 56, 36, or 20 honeybee colonies for traditional, transitional, and frame hive, respectively. Due to its high potentiality, monofloral honey can be produced from this species wherever it is found abundantly. Therefore, propagation and *in-situ* conservation of this species is also recommended for sustainable honey production and environmental conservation.

Keywords: Nectar, honey, sugar, nectar concentration

Honeybee plants are those plant species that provide nectar and/or pollen for honeybees (Addi and Bareke 2019; Addi et al. 2014). The contribution of a bee plant species to honey production depends on the plant's nectar secretion potential, which is mainly affected by biotic and abiotic factors (Adgaba et al. 2017). Additionally, not all bee plants are equally important to bees, and honey production. In every geographical region, there are a few important honey source plants that dominate the honey production (Crane 1990).

Several authors have determined honey production potential for few honeybee plants, based on their nectar secretion potential including Crane et al. (1984), for *Tilia* (lime); Kim et al. (2017) for *Crataegus pinnatifida* Bunge; Adgaba et al. (2012) for *Ziziphus spina-christi* and Bareke et al. (2020) for *Croton macrostachyus*. Determination of honey production potential of plants is very important to estimate honeybee colony carrying capacity for a given site (Al-Ghamdi et al. 2016). Estimation of honeybee colony carrying capacity is also essential to ensure efficient resource utilization in each honey harvesting season without negatively affecting honey production potential of individual colonies (Bareke and Addi 2018).

In Ethiopia, the determination of nectar secretion, and honey production potential of flowering plants is relatively novel. For many important bee plant species, nectar secretion potential and its contribution to honey production have not yet been documented. These plants include one of the most important melliferous species, *Schefflera abyssinica* (Hochst. ex A. Rich.) Harms. *S. abyssinica* is an indigenous tree belonging to the family of Araliaceae and is branched and small to medium in height, reaching up to 30 m (Addi et al. 2014). *S. abyssinica* is an epiphyte that grows on other trees. The seeds are lodged in tree forks and other places that are rich in plant detritus and where water can

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easily reach the seeds (Mulugeta et al. 2015). However, it can be propagated by seeds using aqueous smoke solution for pretreatment of seeds (Bareke et al. 2014). This species grows in upland forest, secondary forest, woodland, wet montane forest, often along streams and in riverine forests with *Celtis africana*, *Polyscias fulva*, *Podocarpus falcatus*, *Syzygium guineense*, *Olea capensis subsp. macrocarpa*, *Mimusops kummel*, *Albizia schimperiana* and *Apodytes dimidiata*, at altitudes between 1400 and 2800 m in most floristic regions of Ethiopia and also in Cameroun, Sudan, Uganda, Burundi, Tanzania, Zambia and Malawi (Fichtl and Adi 1994).

Finally, *S. abyssinica* is considered as the most important tree for producing honey in Ethiopia where it grows, particularly in the south and south western parts of Ethiopia. Honey from this tree is highly prized and is the most expensive honey. Flowering is from March to May with ample nectar, but little pollen (Bareke and Addi 2018).

The flower produces light to pure white honey, with finely granulated particles which fetches the best prices in the local and international markets. The tree is widely used to produce furniture and boxes as well as used for farm tools (Addi et al. 2014). Monofloral honey of this plant species is produced in south western Ethiopia (Gera) (Bareke and Addi 2019) and Guji Zone Uraga District of Ethiopia (Bareke and Addi 2018). However, nectar secretion and honey production potential of this species have not been documented. Therefore, the main objective of this study was to determine the nectar secretion dynamics, honey production potential per tree and also per hectare, as well as the number of bee colonies required to be placed in one hectare of *S. abyssinica* forest.

Materials and methods

The study was conducted in Arsi Zone (Munessa District), West Shoa Zone (Chelia District) and Jimma Zone (Gera District) in Oromia region, Ethiopia (Figure 1).

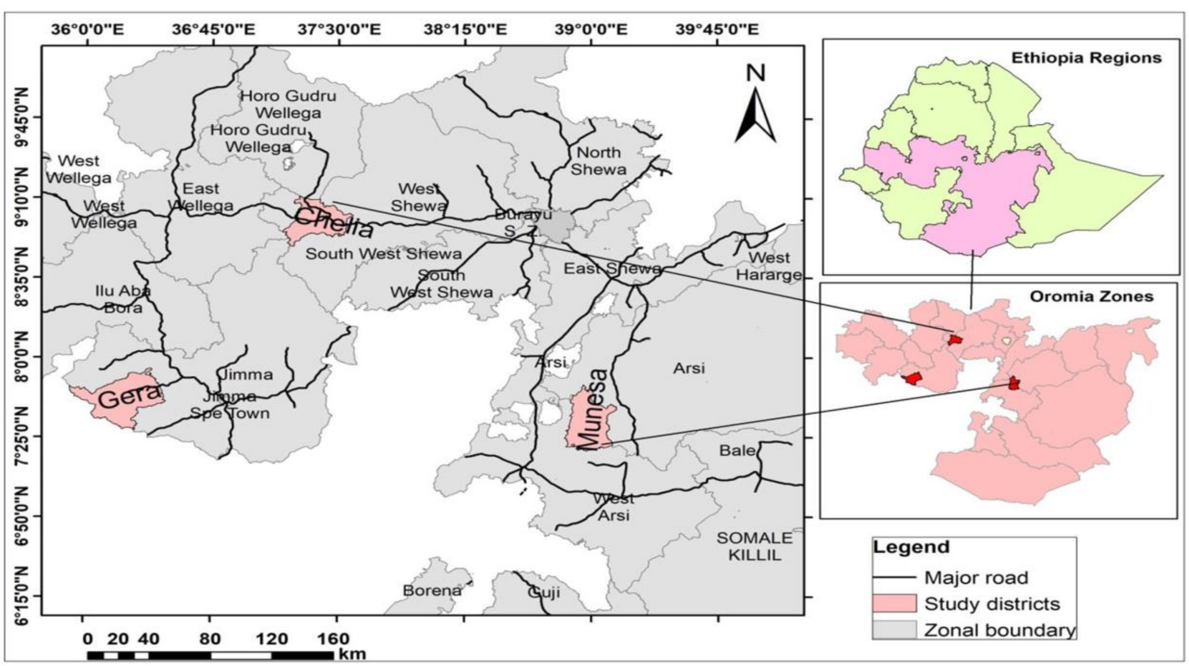

Figure 1: Map of Ethiopia showing the Oromia Region, zones and districts of the study area Source:

This species was selected based on its volume of nectar for honey production and the accessibility of nectar. From each district, the sites were selected based on the abundance of the species.

Phenology

Observations were made on three *S. abyssinica* plants to identify the timing of anther dehiscence and nectar secretion. From each plant, five flower buds (a total of 15) were labeled using string and observed (Bareke et al. 2020).

Determining the number of flower heads per tree

Twenty four productive trees (small (<5 m), medium (5-10 m), and large (>10 m) with massive flowers were selected randomly to get the average number of flower heads per plant. The main branches of the tree were counted. Three branches were selected purposively to count the number of inflorescences per branch (Bareke et al. 2020). After this, ten inflorescences per branch were taken and the number of flower heads per inflorescence was counted. Finally, the number of flower heads per tree = (Total tree branches) x (average number of inflorescences per branch) x (average number of flower heads per inflorescence) was determined (Adgaba et al. 2017).

Determination of nectar volume and concentration

For nectar removal, five inflorescences were covered with fine mesh bags (40 x 40 cm) on different parts of the tree one day before nectar volume measuring (Wyatt et al. 1992; Farkas and Orosz-Kovacs 2003). Six plants were taken per district for nectar measurement. Fifty flower heads per tree were randomly selected and nectar volume measurements were done at the start of nectar secretion up to the end at different times of the days. A total of 900 flower heads were used to determine the average nectar yield per flower head. The volume of nectar produced in 24 hours was determined directly upon sampling the flowers with micropipettes (Bareke et al. 2020).

Determination of nectar secretion dynamics

The nectar volume and concentration, as well as temperature data, were measured at 1 hour intervals from three flower heads at each time (12:00-17:00 hours). Nectar was collected from three flowers at each sampling time for seven consecutive days (3 Flowers*6 times*7 days =126 flowers). Moreover, to determine nectar productivity, the nectar quantity (mg) secreted throughout the lifetime of an individual, five isolated flowers were measured daily from the beginning of nectar secretion to the end of nectar secretion (Bareke et al. 2020). This was done to determine the duration of the nectar secretion period for the species.

Determination of sugar amount in nectar per flower

The mean sugar content in nectar was calculated from the nectar volume, concentration, and sucrose density. The readings in most refractometers are in sucrose equivalents expressed as milligrams of sugar per 100 mg of the solution and can be converted to milligrams of sugar per flower by converting the measured sucrose equivalent to g/liter and multiplying this value by the nectar volume (Bolten et al. 1979). The conversion of sucrose concentration to density was done using the Prys-Jones and Corbet (1987) equation, while the sugar content was calculated using the Dafni (1992) equation.

The amount of sugar per tree was calculated by multiplying the mean number of flower heads per plant with the mean amount of nectar sugar per flower (Bareke et al. 2020). At the international market the acceptable moisture content of honey in one kg is 18% moisture and 82% sugar. Hence, the average amount of honey that can be obtained from a single tree was estimated by multiplying the average number of flowers per tree with the average sugar per flower (Dafni 1992; Masierowska 2003; Kim et al. 2017; Bareke et al. 2020).

The number of plants per hectare was estimated based on the land area covered by the plant species. Accordingly,

$$A = \pi r^2$$

Where, A is a tree canopy area, π=3.14, and r is the radius of the tree canopy (Adgaba et al. 2012). The expected honey yield per hectare was calculated by multiplying the amount of sugar per tree with the number of individual plants per hectare (Bareke et al. 2020).

Estimating optimum honeybee colony carrying capacity

The optimum numbers of traditional (TH), intermediate (IH), and modern hives (MH) for the given area were estimated as follows:

TH = [Expected honey yield per area/ (honey yield of well managed traditional hive) *2]

IH == [Expected honey yield per area/ (honey yield of well managed intermediate hive) *2]

MH= [Expected honey yield per area/ (honey yield of well managed modern hive) *2]

Honeybee colonies consumed 1 kg of honey to store 1 kg of surplus honey for dearth period use and that is why honey productivity potential is divided by two (Chaudhary 2009).

Data analysis

Data were analyzed using one-way ANOVA and prior to analysis, homogeneity of the variances of the data was checked using Levene tests. Tukey test was used for mean separation among the treatments. In addition to this, the linear regression model was computed using R-software to determine the relationship between temperature and nectar volume and concentration.

Results

Mean number of inflorescences per branch of *S. abyssinica* was significantly different ($F_{2,717}$ =3.722, $p \leq 0.05$) among study districts. The highest and lowest mean numbers of inflorescence/branch were recorded at Gera and Munessa District respectively. The mean number of flower heads per inflorescence did not vary significantly among study districts ($F_{2,717}$=1.027, p=0.382). On the other hand, the mean number of flower heads per tree was significantly different ($F_{2,21}$=4.848, $p \leq 0.05$) among the study districts. The highest mean number of flower heads per tree was recorded at Gera Districts and it was significantly different ($F_{2,21}$=4.848, p=0.024) at Munessa and Chelia districts (Table 1). *S. abyssinica* is highly conserved in the Gera forest for white monofloral honey production. As a result, the size of this plant is much larger than in Chelia and Munessa. It is also less abundant in Chelia and Munessa, consequently, monofloral honey is not expected at these two districts.

Nectar volume and concentration of S. abyssinica per flower head

The mean nectar volume secreted in 24 hours per flower head and concentration of nectar per flower head were not significantly different ($F_{2,897}$= 0.395, p=0.674) among the study districts (Table 2). This plant flowered during small rainy season in all data collection sites. As a result, the weather conditions were similar for all districts during data collection and statistically, the values of nectar volume and concentration were not significantly different ($F_{2,897}$=0.395, p=0.674 and $F_{2,123}$=0.404, p=0.675) among the districts.

Effect of temperature on nectar volume and concentration of S. abyssinica

The temperature range during the nectar collection period was between 18^{0}C and 28^{0}C. Nectar volume of *S. abyssinica* was positively correlated with temperature. However, the effect of temperature on nectar volume of *S. abyssinica* was insignificant. On the other hand, nectar concentration has strong and direct relationship with temperature. Temperature was affected the nectar concentration by 63.4% (Figure 2). Thus when temperature increased, the nectar concentration also increased. *S. abyssinica* starts nectar secretion in the afternoon at which time the temperature of the area is high. Due to this, temperature has less effect on nectar volume of this plant species. On the other hand, nectar concentration increased with temperature increment because humidity of the area decreased as temperature increased and the highest concentration value was recorded.

Nectar secretion dynamics

The mean nectar concentration and volume were significantly different across times of days ($F_{5,12}$=12.080, p=0.000 and $F_{5,12}$=7.292, p=0.002 respectively). The lowest mean nectar concentration was recorded at 12:00 and the highest nectar concentration recorded at 16:00 but it was not significantly higher than those obtained at 14:00, 15:00 or 17:00 hours. This nectar concentration value varied due to temperature variation. At the start of nectar secretion time the volume became higher due to humidity of the area and decreased as temperature increased and vice versa for nectar concentration. This indicates that peak nectar volume and concentration secretion time are different due to environmental factors. On the other hand, the highest mean of nectar volume was recorded at 14:00 and 15:00 while the lowest was at 12:00 and 17:00. The mean amount of sugar present in nectar was also significantly different across times of the day ($p \leq 0.05$). The highest mean amount of sugar in nectar was recorded at 15:00, whereas the lowest was recorded at 12:00 (Table 3).

Table 1: Mean number of inflorescence per branch (N=72 main branches; N=720 inflorescences), flower heads per inflorescences, and flower heads per tree (N=24 trees) ± SE for *S. abyssinica*

District	Mean no of inflorescences per branch ± SE	Mean no of flower heads per inflorescence ± SE	Mean no of flower heads per tree ± SE
Gera	294 ^{a} ± 26	164 ^{a} ± 5.4	676541^a ± 87918
Munessa	215 ^{b} ± 13	160 ^{a} ± 11.7	399652 ^{b} ± 67213
Chelia	237 ^{ab} ± 22	185 ^{a} ± 19.5	417686 ^{b} ± 51031

Note: Means with the same letter along a column are not significantly different from each other (p>0.05) based on Tukey tests.

Table 2: Mean nectar volume (µl) (N=900 flower heads) in 24 hours per flower head, nectar concentration (%) per flower head (N=126 flowers) with ± SE of the mean of *S. abyssinica*

District	Mean nectar volume (µl)	Mean nectar concentration (%)
Gera	11.80a ± 2.00	26.10a ± 1.00
Munessa	10.70a ± 2.60	25.50a ± 0.80
Chelia	12.40a ± 3.70	25.00a ± 0.97

Note: Means with the same letter along a column are not significantly different from each other (p>0.05) based on Tukey tests.

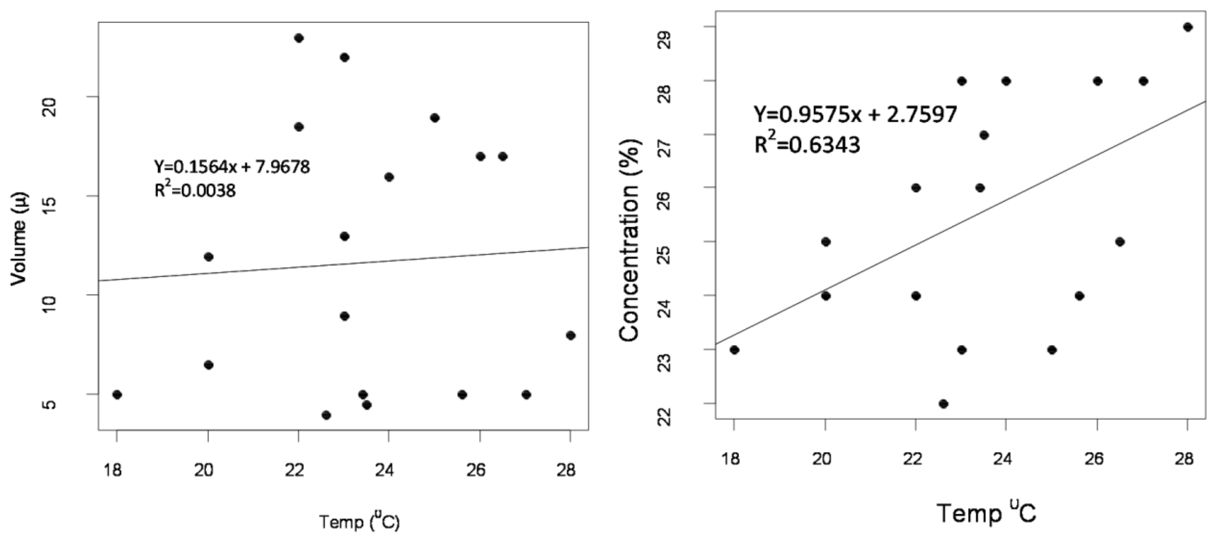

Figure 2: Effect of temperature on nectar volume and concentrations of *S. abyssinica*

Table 3: Mean nectar concentration (%), nectar volume (µl) and amount sugar (mg) in nectar per flower at 1 hour intervals per flower with ± (SE) of *S.abyssinica* in 12:00 to 17:00 hours in Munessa, Chelia and Gera districts

Time (hour)	Average nectar concentration (%) ± SE	Average nectar volume (µl) ± SE	Average sugar amount per flower/1hr intervals
12:00	22.70[c] ± 0.30	4.70[c] ± 0.33	1.00[c] ± 0.09
13:00	23.70[bc] ± 0.30	10.30[ab] ± 3.52	2.40[bc] ± 0.80
14:00	25.70[ab] ± 0.30	18.00[a] ± 3.21	4.65[ab] ± 0.84
15:00	27.70[a] ± 0.33	19.20[a] ± 1.48	5.20[a] ± 0.42
16:00	28.00[a] ± 0.60	12.30[ab] ± 2.33	3.20[abc] ± 0.65
17:00	25.70[ab] ± 1.20	5.30[c] ± 0.60	1.30[c] ± 0.14

Note: Means with the same letter along a column are not significantly different from each other ($p>0.05$) based on Tukey tests.

Honey production potential of S. abyssinica

S. abyssinica has large crowns that hold numerous numbers of flowers per tree. The average number of flowers per tree was 497,960. The mean amount of sugar found in nectar was calculated from the nectar volume, concentration, and sucrose density. Then, the mean amount of sugar produced per flower in 24 hours was multiplied by the nectar secretion length to determine the amount of sugar secreted through the life cycle of a flower. Accordingly, the mean amount of sugar per flower was estimated using 126 flower heads. Hence, the mean amount of sugar found in the nectar of *S. abyssinica* per flower in its life cycle was 17.78 ± 2.6 mg (range 4.8-36 mg). This result is obtained, after nectar volume, concentration, and sucrose density were calculated and converted to sugar amount. In addition to this, the mean amount of sugar produced per tree was about 8.85 kg (range 2.39 kg -17.9 kg).

Given that 1 kg of honey with 18% moisture content (wt/wt) contains 820 g of total dissolved sugar, the mean mass of sugar produced by a single tree of *S. abyssinica* (8.85 kg) per season is estimated to be 10.79 kg of honey (range 2.9 – 21.8 kg). Based on the canopy coverage, the mean land area required per *S. abyssinica* tree is about 60 m^2

considering the required spacing between trees, the total number of *S. abyssinica* trees per hectare of land is 166. Therefore, under ideal conditions, the average honey production potential per hectare of *S. abyssinica* forest area per flowering season would be about 1791 kg (range 481 kg – 3618.8 kg). The actual harvestable amount of honey is half of the potential of *S. abyssinica* (895.5 kg/ha). Half of the expected honey yield is used for the consumption of honeybees. The potential of *S. abyssinica* for a high sugar or honey production is mainly attributed to the richly branched and spreading nature of the crown, with a large canopy surface area. The potential for high nectar secretion could also be due to the flowering pattern of *S. abyssinica*.

Determining honeybee colony carrying capacity based on honey production potential

Honey yield of well-managed honeybee colonies in traditional, transitional and frame hive in southwestern Ethiopia was reported to be 16 kg, 25 kg and 45 kg, respectively (Shenkute et al. 2012; Tullu 2014).

Using this maximum current honey yield of the three hive types, the expected number of bee colonies required for 1 ha of *S. abyssinica* was estimated. Accordingly, the expected optimum number of bee colonies required to be placed in a hectare of *S. abyssinica* forest were 56 honeybee colonies for traditional hives, 36 honeybee colonies for transitional hives or 20 honeybee colonies for frame hives. The optimum expected numbers of honeybee colonies vary from place to place depending on the current yield of specific locations.

Discussion

Flower heads per plant and nectar secretion dynamics

The variation in the mean number of flower heads per tree could be attributed to the variations in their ecological distribution and the climatic factors (temperature, rainfall and wind). In this plant, nectar secretion starts on the day of the opening of the flower (12:00) and continues up to 17:00. *S. abyssinica* provides nectar for approximately 8 days. Nectar secretion reaches a peak between 14:00-15:00. Nectar volumes were higher during the start of secretion than at the end. A similar study conducted by Adjaloo et al. (2015) on *Antigonon leptopus* and *Thevetia peruviana* also indicated that nectar volume was high in the early hours of the day. The variation of nectar secretion rate of *S. abyssinica* at different times of the day could be due to ecological and microclimate variation. The study conducted by Adgaba et al. (2012) on *Ziziphus spina-christi* and by Bareke et al. (2020) on *C. macrostachyus* was also reported that there was the difference in the nectar secretion rate among trees. The causes of nectar secretion variability between flowers on the same plant may be due to position on the flowering stem and/or exposure to ambient microclimate (Macukanovic et al. 2004; Jakobsen and Kristjansson 1994; Petanidou et al. 1996). In addition to this, day to day variation in weather may cause shifts in the pattern of nectar characteristics; morphological and phenological characteristics have effect on nectar secretion. Large flowers may secrete more nectar than smaller ones at intra and interspecific levels as well as the flower phenological stage (protandry, protogyny, ageing) also influences nectar production (Wyatt et al. 1992; Bolten et al. 1979). In addition to this, nectar secretion potential of plants is affected by physical and chemical soil properties, light and altitude (Wyatt et al. 1992). The method by which the nectar is extracted and measured is primarily dictated by the flower size, nectar volume and concentration. Micropipettes are used to measure nectar volumes above 0.5 µl and concentration below 70% (Dafni 1992).

The rapid crystallization of the nectar sugar is largely attributable to the flower morphology and environmental factors (Adgaba et al. 2012). Humidity and dry conditions have effect on the amount nectar concentration (Mačukanović et al. 2004). Petanidou and Smets (1996) also reported that nectar volume and concentration in *Thymus capitatus* increased with temperature, but not over the whole range of the applied temperatures. Study conducted by Kim et al. (2017) on *Crataegus pinnatifida* in Korea and China also indicated that nectar volume was positively correlated with both temperature and relative humidity. Generally, peak nectar yield occurs at a particular temperature that differs from species to species. However, temperature had no significant effect on nectar secretion rate of *S. abyssinica.* There was high nectar secretion during the period of high temperatures (14:00 and 15:00). On the other hand, temperature highly affected the nectar concentration of *S. abyssinica*. As temperature increased the nectar concentration increased and vice versa. Crystallization of the nectar on the surface of the flower may negatively affect the efficient collection of nectar by legitimate pollinators including honeybees. Accordingly, at high temperatures and low humidity, the amount of nectar available to bees and also the amount of honey that can be obtained would be below the estimated potential of the plant (Adgaba et al. 2012). Similarly, the study conducted by Al-Ghamdi et al. (2016) also indicated that the variations in the amount and patterns of nectar secretion by the different bee forage species is due to the variations in biotic and abiotic factors.

Honey production potential

The average mass of sugar secreted per tree (8.85 kg), and the potential amount of honey that can be obtained from a *S. abyssinica* tree (10.79 kg honey) were relatively high. These values indicate the high potential of the *S. abyssinica* for honey production and attraction of pollinators. The actual amount of honey that can be obtained in the hive is expected to be below the estimated amount because when bees collect and transport the nectar to hives they definitely consume a certain amount of sugar for their flight energy. In addition to this, due to rapid crystallization, all the nectar secreted may not be available to honeybees.

The potential of the *S. abyssinica* for such a high sugar/honey production is mainly attributed to the richly branched and thick nature of the crown with a large canopy surface area. The estimated honey production potential (1791 kg) that can be obtained per hectare of *S. abyssinica* forest is better than many other bee plants. These results are comparable to the reports made for different annual plants and trees such as *C. macrostachyus* in range of 234 – 1770 kg/ hectare (Bareke et al. 2020), Lime species (*Tilia* spp.) (90 to 1200 kg honey/ha) (Crane et al. 1984), and *Ziziphus spina-christi* (550-1300 kg of honey/ha) (Adgaba et al. 2012), *Brassica juncea* and *Sinapis alba* crops 65.5 and 71.2 kg/hectare, respectively (Masierowska 2003). Monofloral honey of *S. abyssinica* is produced in many parts of Ethiopia. From southern Ethiopia where it is produced in Bore and Uraga districts (Bareke and Addi 2018) to western Ethiopia in Gera Districts (Bareke and Addi 2019).

Financial implication from a hectare of S. abyssinica through honey production potential

The expected harvestable honey yield from a hectare of productive trees of *S. abyssinica* with massive flowers was 895.5 kg. If a kilogram of *S. abyssinica* honey is valued at \$7, the total expected income is 895.5 * 7 ETB= \$6268.5. This indicates the degree to which this plant is economically valuable, without considering its ecosystem services. This plant is threatened due to human pressure and low regeneration capacity in the forest.

Determining honeybee colony carrying capacity based on honey production potential

Knowledge of bee colony carrying capacity is very important to utilize the flora resource of a given site. Some beekeepers stated that the apiary site is nearby the forest area where the diversity of bee forage species is high and the strength of honeybee colony is good throughout the year, but honey obtained from the area is very low (Bareke and Addi 2018). This is because only a few bee forage plants were flowering at the same time. In such areas, estimation of honeybee colony carrying capacity is very important in order to use the resource effectively. Balancing a number of honeybee colonies with the available resource is used to increase the productivities of honeybee colonies by overcoming the problem of colony overstocking (Adgaba et al. 2017).

The expected optimum number of bee colonies required to be placed in a hectare of *S. abyssinica* productive trees were the highest number for traditional hive, while the lowest for frame hive. Even though the bee forage resources are similar for all bee hive types, the population size of honey bee colony and way of management of the hive types vary. For instance, the size and number of honeybee populations of traditional hives are small compared to transitional and frame hives, which result in variation in honey yield. In addition to this, the traditional hive is not suitable for internal honey bee colony inspection (Bareke et al. 2020). The internal honeybee colony inspection is used to manage honey bee colony for honey production and colony maintenance.

Conclusion

From this study, *S. abyssinica* is a high producer of nectar and significantly contributed to honey production. Temperature had no significant effect on nectar volume of *S.abyssinica*. Amount of nectar volume and concentration is varied at different times of the day. One hectare of *S. abyssinica* forest has a potential to produce 1791 kg of honey. The honey production potential of *S. abyssinica* with maximum colony carrying capacity was the highest for traditional hive (56) followed by intermediate (36) and frame hive (20) honeybee colonies. Due to its high potential, monofloral honey can be produced from this species wherever it is abundantly found. Therefore, propagation and in-situ conservation of this species is also recommended for sustainable honey production and environmental conservation. Honey production potentiality determination should also be done for other major bee forage plants to boost the honey production without negatively affecting the production potential of individual colonies.

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