Heliyon 10 (2024) e25500

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Honeybee colonies carrying capacity determination in north-east dry land areas of Amhara region, Ethiopia

Agazhe Tsegaye [a,*], Awraris Getachew [b], Amssalu Bezabih [c]

[a] Sekota Dry Land Agricultural Research Center, P.O. Box 62, Sekota, Ethiopia
[b] Bahir Dar University, P.O. Box 79, Bahir Dar, Ethiopia
[c] Holetta Agricultural Research Center, P.O. Box 31, Holetta, Ethiopia

ARTICLE INFO

Keywords:
Carrying capacity
Honey yield
Honeybee colonies
Nectar secretion
Nectar sugar

ABSTRACT

The objective of the study was to examine the dynamics and sugar content of nectar of major bee flora species and to determine an approximate honeybee colony carrying capacity in northeast dry land areas of the Amhara region. Acacia asak, Acacia etbaica, Acacia tortolis, Becium grandiflorum, and Cordia africana honeybee floral species were selected on the basis of relative dominance in the area. Floral nectar was collected through micropipette and washing techniques based on the flower nature of the species and nectar sugar was measured by refractometer. Hence, A.asak, A.etbaica, A.tortolis, B.grandiflorum, and C.africana could have been estimated to produce 10.2 ± 6.4 mg, 5.3 ± 4.6 mg, and 2.6±1 mg. 4, 3.7 ± 2.1 mg, and 5.7 ± 3.2mg/flower head of nectar sugar, respectively. In a single tree of A.etbaica, A.asak, A.tortolis, B.grandiflorum, and C.africana a mean of 0.15 kg, 0.15 kg, 0.06 kg, 0.01 kg, and 0.03 kg of honey yield was expected to produce respectively. Similarly in a hectare of land, a mean of 49.9 kg, 128.9 kg, 5.6 kg, 5.5 kg, and 2.2 kg of honey was estimated to harvest. In a hectare of land a sum of 57.5 kg, 57.5 kg, and 128.9 kg of honey in highland, midland, and lowland locations, respectively was estimated to produce during the main harvesting season of the area. The mean number of honeybee colonies introduced in the lowland have estimated to be 18 traditional, 6 transitional, and 5 modern hives, and in the highland 12 traditional, 6 transitional, and 5 modern hives whereas in the midland 8 traditional, 5 transitional, 3 modern hives. In summary, even in the study area with limited rainfall and high temperatures, these species secreted a substantial amount of nectar sugar and supporting the enhancement of honey yield.

1. Introduction

Apiculture is a worthwhile endeavor that actively contributes to the income generation of smallholders, in particular, as well as the nation's economy as a whole. Subsistence Ethiopian smallholder farmers, especially small landholders and land, benefit from its significant role in generating and diversifying their income [1]. In Africa, Ethiopia boasts the biggest bee population with more than 10 million honeybee colonies, of which about 6.9 million are believed to be hived while the remaining exist in the wild [2]. Ethiopia has the distinction of being the first honey-producing country in the world with an estimated annual honey production of 129 million kilograms. Traditional hives are the primary source of harvest for a larger proportion of this [2]. Furthermore, Ethiopia's beekeeping

* Corresponding author.
E-mail address: agazhetsegaye@gmail.com (A. Tsegaye).

https://doi.org/10.1016/j.heliyon.2024.e25500
Received 2 August 2023; Received in revised form 28 January 2024; Accepted 29 January 2024
Available online 1 February 2024
2405-8440/

system is characterized as a low-input-low-output system, with a major focus on rural smallholder beekeepers.

The availability of natural resources in an area is more important for beekeeping than for any other livestock activity. Improved management skills and advanced technologies alone cannot guarantee the success of beekeeping in areas where it is not appropriate. One of the most important aspects of the beekeeping industry is the availability of adequate bee forage, which is why this is considered one of the most important elements [3]. Obtaining information about plants used in an area is usually achieved through direct field observations of honeybees foraging on flowers.

It's crucial to have a beekeeping area that has abundant nectar and pollen plants and a relatively long blooming season. It's not always easy to locate or find such potential areas. Not all bee floras are equally important for honeybees rather it is better to think about the food source they contain either in pollen and nectar production potential or the blooming duration of the plant. Pollen or nectar production is influenced by differences in flowering dates and duration between regions and seasons. It is important for beekeepers to know the timing and duration of the blooming season for every major honeybee flora species including the environmental factors affecting them and the carrying capacity of the area, which encompasses the maximum number of colonies that can be employed for production [3]. Apiary establishment requires understanding the ideal carrying capacity of an area and estimating the amount of nectar for each species, which is a very crucial step.

Considering the above realities, it was crucial to provide information on the amount of nectar amount and honey production potential of important honeybee floras, and determining the optimum honeybee colonies carrying capacity of beekeeping sites to have effective and sustainable honey production practice in the study area. Therefore, this study was mainly conducted to prepare the nectar sugar amount, honey yield and to suggest the number of honeybee colonies to be introduced in a hectare of specific beekeeping areas in the north-east dry land areas of Amhara region, Ethiopia.

1.1. Objectives

- To examine the patterns of nectar production and nectar sugar of significant bee flora species in the research area.
- To estimate the expected honey yield of major honeybee flora species
- To determine the optimal carrying capacity of honeybee colonies, taking into account the honey yield potential and the distribution of major bee plant species.

2. Material and methods

2.1. Description of the study area

The Waghimra zone (Fig. 1) is the dry land area that can be found in northern Ethiopia in the Amhara region, which is located at 12°

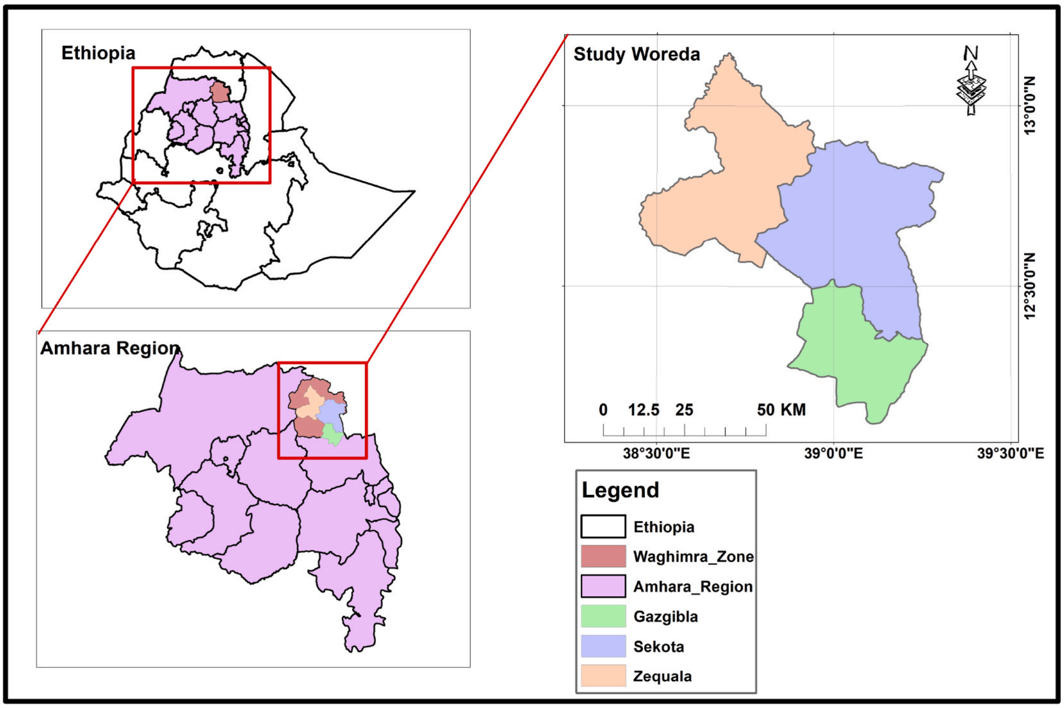

Fig. 1. A map that depicts the study area.

N latitude and 38° E longitude, and has an altitude of 500–3500 mean above sea level with an annual rainfall of 150–700 mm, a type of rainfall that is not regular. Temperatures during the year range from 15 °C to 40 °C on average.

This zone is home to the primary livestock species, which include cattle, small ruminants, Honeybees, poultry, and equines. About 408,352 cattle, 595,054 goats, 222,089 sheep, 11,038 equines (Donkey and Mule), 40,687 poultry, and, 130,771 honeybee colonies in the study area [2]. In this corridor, beekeeping is a predominated farming system in which local beekeepers benefited from honey in local use and as a cash source of economic return.

Among the honey bee plant species that honeybees utilized for nectar and pollen source include *Guizotia abyssinica*, *Bidens* spp., *Echinops Spp*., *Vicia faba*, *Cynodon dactylon*, *Acacia seyal*, *Hypoestes trifolia*, *Becium grandiflorum*, *Acacia tortolis* and *Ocimum bacilicum* were the top 10 (more frequent) plants in highland representative area where *Acacia asak*, *Sorghum bicolor*, *Sesamum indicum*, *Acacia mellifera*, *Acacia tortolis*, *Acacia seyal*, *Acacia brevispica*, *Bidens* spp., *grass spp*. and *Grewia bicolor* were more common in the lowland while *Hypoestes trifolia*, *Ocimum bacilicum*, *Acacia tortolis*, *Becium grandiflorum*, *Bidens* spp., *Acacia seyal*, *Sorghum bicolor*, *Echinops* spp., *Vicia faba* and *Guizotia abyssinica* were their presence in the midland altitude representation was dominant [4].

2.2. Sampling procedures

The selection of a simple village from the vast geography of the area was achieved through the use of stratified and purposive sampling techniques in this study. Three stratified districts were selected from the total seven districts in the Waghimra Zone because they have potential to beekeeping and have agro-ecology.

2.3. Data collection methods

2.3.1. Methods of nectar collection and evaluation of nectar sugar

The five most important bee plant species selected in the region (*Acacia asak*, *Acacia etbaica*, *Acacia tortolis*, *Becium grandiflorum* and *Cordia africana*) were taken into account when collecting nectar, evaluating the mass and determining the carrying capacity of bee colonies. This species among other locally available bee flora species were selected for nectar collection based on relative dominance and technical suitability. In addition, these five bee plants were considered a source of honey production in the area and bees were very attracted to them.

2.3.2. Nectar collection methods

Bee flora species suitable for their flower morphology or large flowers (Fig. 2) for direct extraction and measurement of nectar volume; nectar volume was determined by withdrawing nectar directly from the flower using micropipette [5]. There fore the nectar amount of *B.grandiflorum* and *C.africana* changed into measured at once from the micropipette in μl.

Micropipette extraction is not an effective method for extracting flowers with nectar that is insignificant or viscous. For species with

Fig. 2. Flower morphology *Becium grandiflorum (a) and Cordia africana species (b)* and nectar collection in *B.grandiflorum* species (c).

a small flower, washing the sticky nectar is an alternative method (Fig. 3) and low amounts of nectar [6]. Hence, two washes with a known volume of distilled water removed 95 % of total floral sugar and it provided information on nectar production in this species that could not have been obtained using a standard micropipette extraction method [6]. Hence in the present study, the nectar of *Acacia* species was measured by soaking the flower with 1 ml of distilled water waiting for 5 min. After this sieving the solution and measured the volume. Hence the volume of final solution minus 1 ml added distilled water given the volume of washed nectar. The nectar collection, as well as sugar concentration measurement, was performed in 5 h intervals of a day at 6:00, 9:00, 12:00, 15: 00, and 18: 00. The volume of nectar was measured using an average of five flowers, and it was reproduced in three consecutive days on each plant.

2.3.3. Nectar sugar estimation

A digital refractometer was employed to measure the nectar sugar concentration [7] and, the mass of sugar in the nectar secreted by each flower head was calculated from the volume and concentration of the measured solution. The sucrose mass/volume was calculated using the [8] conversion table using the sucrose concentration values (mass/total mass, g of sugar/100 g of solution). Total soluble solid in nectar was calculated per plant type or hectare.

2.3.4. Expected honey yield estimation

By multiplying the average quantity of flowers in 1 m^3 by the average surface area or volume of the species' canopy, the average number of flowers per tree was calculated. A quadrant method was employed to get the number of trees of a species in a hectare of land using 20mx20 m and 5mx5m for trees and shrub-type species.

The average mass of the nectar sugar per flower and the average number of blossoms per plant are used to estimate how much honey may be produced from a single plant. Assuming all other variables stay the same, 1 kg of honey with 18 % moisture content has 820 g of total dissolved sugar. Therefore, in order to collect 1 kg of excess honey, the colony must consume an additional 1 kg of honey for survival, brood rearing, and as fuel energy for foragers [9]. Therefore, expected honey yield/plant species = nectar sugar per tree/2/0.82 and expected honey yield/hectare = Nectar sugar/hectare/2/0.82.

Fig. 3. Photos of *Acacia etbaica* species (a), *Acacia tortolis* species (b) and *Acacia asak* species (c) in flowering time.

2.3.5. Determination of approximate honeybee colonies carrying capacity

Honeybee colonies carrying capacity was determined based on the existing honey productivity in the three hive types and the expected honey yield from the present species in a hectare of land. Data on current honey productivity in each hive type was obtained through key informant interview in the study area. The approximate honeybee colonies caring capacity was estimated as per a hectare of beekeeping, Hence approximate honeybee colonies carrying capacity = honey yield expected (kg/colony/year/hectare/average honey productivity of the area (kg/colony/year/hectare) by hive types.

2.4. Statistical analysis

The mean nectar volume and sugar quantity per flower were compared to location, time, and weather-related fixed factor variables using SPSS software. The results were displayed in a table and a line graph. Analysis of variance (ANOVA) and T-test were also employed. The volume of nectar and mass of sugar secreted per flower were compared to the environmental parameters (temperature and relative humidity of the area) using a pairwise correlation analysis and non-linear regression model analysis.

3. Results

3.1. Phenology of selected honeybee floras

The location of the honey-source plants' flowering periods differed throughout species (Table 1). Only *A. tortolis* had an autumnal flowering season; the majority of species had a spring flowering season with minimal extension into early summer. As a result, *A. tortilis* was seen to flower during the leafless stage of the dry season; but, in the event of rain, the plant was seen to shed its flower buds and grow new leaves. When there is rainfall, *B. grandiflorum* has been seen to bloom all year round in the midland and lowland agro-ecologies.

3.2. Floral density and flower biomass

The mean number of flowers per tree of *A.etbaica, A.tortolis, A.asak*, *B.grandiflorum, and C.africana was* estimated to be 23810.7, 18786.6, 11489.3, 2692.1, and 4400.1 respectively (Table 2). In a hectare of land, a mean of 325.9 trees of *A.etbaica*, 97.9 trees of *A. tortolis*, 859.4 trees of *A.ask*, 455.5 trees of *B.grandiflorum*, and 69.8 trees of *C.africana* was recorded.

3.3. Nectar secretion potential of selected species

3.3.1. Mass of nectar sugar of Acacia species

In the present study, the nectar amount of *A.etbaica* species was significantly different among study agro ecologies ($P < 0.01$) while the nectar amount of *A.tortolis* had no significant different ($p > 0.05$) among agro ecologies. Daily average nectar sugar of 10.2 ± 6.4 mg, 5.3 ± 4.6 mg, and 2.6 ± 1.4 mg/flower head was recorded for *A.asak, A.etbaica, and A. tortolis,* respectively (Table 3). Hence the highest amount of nectar sugar was recorded in the *A.asak* species which is only available in the lowlands of Waghimra zone.

3.4. Nectar volume and sugar amount of B.grandiflorum and C.africana species

The mean volume of nectar per flower, sugar concentration percentage, and total sugar mass per flower of *B.grandiflorum* were 9.8 ± 4.8 μl, 38.0 ± 12.4 %, and 3.7 ± 2.1 mg flower per head, respectively (Table 4) and the mean volume of nectar per flower, sugar concentration percentage, and total sugar mass per flower of *C.africana* were recorded 16.5 ± 6.9 μl, 34.5 ± 14.5 %, and 5.7 ± 3.2mg/flower head, respectively (Table 4).

Nectar sugar secretion starts in the morning at 6:00 with 3.5 ± 3.1, 6.7 ± 4.9, and 6.7 ± 4.9mg/flower head for *A.etbaica*, *A.tortolis*, and *A.asak,* respectively (Fig. 4). The peak nectar sugar amount was observed in the afternoon from 12:00 to 15:00 h with 7.6 ± 4.8, 4.2 ± 1.0, and 15.1 ± 5.8mg/flower head for *A.etbaica*, *A.tortolis*, and *A.asak,* respectively (Fig. 4). Furthermore, the examined species'

Table 1
Flowering period distribution of five major honeybee flora species.

Species	Months of the year											
-	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	July
Acacia etbaica		■	■	■						■	■	
Acacia asak	■	■	■	■								
Acacia tortolis								■	■	■		
Beciumgrandiflorum	■	■										
Cordiaafricana			■	■								

Table 2
Number of flowers per m^3, canopy volume (m^3), number of flowers per tree and number of trees per hectare.

Species name	Number of flowers/m^3	Canopy volume (m^3)	Number of flowers/tree	Number of trees/hectare
A.etbaica	2767.3	8.4	23810.7	325.9
A.tortolis	2358.8	8.2	18786.6	97.9
A.asak	2079.3	5.6	11489.3	859.4
B.grandiflorum	2692.1	–	2692.1	455.5
C.africana	537	8.27	4400.1	69.8

Table 3
Nectar sugar amount (mg/flower) of *Acacia* species in different agro-ecologies.

Location	A.tortolis	A.etbaica	A.asak
Highland	2.4 ± 1.4	4.470 ± 3.9b	–
Midland	2.6 ± 1.5	6.039 ± 5.0a	–
Lowland	2.7 ± 1.3	–	10.2 ± 6.4
Overall mean	2.6 ± 1.4	5.3 ± 4.6	10.2 ± 6.4
Sign.	*ns*	**	

Note: Means with the different letters are significantly different from each other ($p < 0.01$) based on the *t*-test (*A.etbaica*) and Tukey's test (*A.tortolis*).

Table 4
Volume of nectar (μl), nectar concentration (%) and mass of nectar sugar (mg) of *B.grandiflorum* and *C.africana species*.

Agro-ecology	B.grandiflorum species			C.africana species		
	Volume nectar (μl)	Nectar concentration	Nectar Sugar	volume nectar	Nectar concentration	Nectar sugar
Highland	9.7 ± 4.6	37.7 ± 12.2	3.7 ± 2.1	16.5 ± 6.6	33.3 ± 14.0	5.5 ± 3.1
Midland	9.9 ± 4.9	38.3 ± 12.7	3.7 ± 2.1	16.5 ± 7.2	35.8 ± 15.0	5.8 ± 3.4
Mean	9.8 ± 4.8	38 ± 12.4	3.7 ± 2.1	16.5 ± 7.0	34.5 ± 14.5	5.7 ± 3.2
Signifi.	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*

nectar sugar secretion patterns demonstrated a rising trend in the early morning that peaked around midday and then declined. As shown in Figs. 4 and 5, the nectar secretion dynamics of all studied species started lower and peaked immediately and decreased as the day becomes sunny and the temperature increased. This supports the general truth of plants needs a moderate sunrise and temperature for nectar secretion by supporting photosynthesis. Due to local humidity, the volume increased at the beginning of nectar secretion period and decreased as temperature rose, and vice versa for nectar concentration. This suggests that environmental factors cause differences in nectar secretion time of the species.

3.4.1. Influence of temperature and humidity on the nectar sugar of Acacia species

Temperature and humidity revealed a significant positive and negative association ($p < 0.01$), respectively, with the amount of nectar sugar in Acacia species (Table 5). This means that the temperature had a big impact on this plant species' nectar sugar. Because the area's humidity dropped as the temperature rose and the concentration reached its maximum, it is implied that the nectar concentration increased with temperature rise. In advance, the effect of air moisture on nectar sugar amount had a highly significant negative correlation (Table 5). This indicates the air moisture either dilutes or vapors the nectar sugar amount of study plants.

3.4.2. Influence of air humidity and temperature on B.grandiflorum and C.africana species' nectar sugar content

In the refractometer reading, the maximum nectar concentration of *B.grandiflorum* was observed at 29 °C. The non-linear regression model indicated that the nectar concentration of *B.grandiflorum* and *C.africana* species increased as temperature of the day reached at 29 °C ($R^2 = 0.53$) and 30.4 °C ($R^2 = 0.5$), respectively while beyond this temperature range the nectar concentration showed a

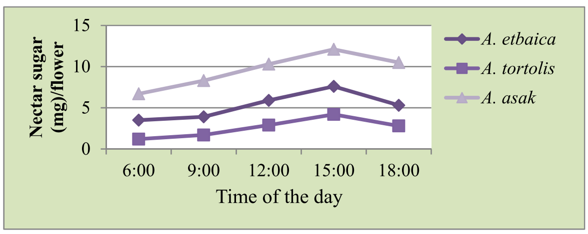

Fig. 4. Nectar sugar amount (mg) of *Acacia* species per flower over the time of the day.

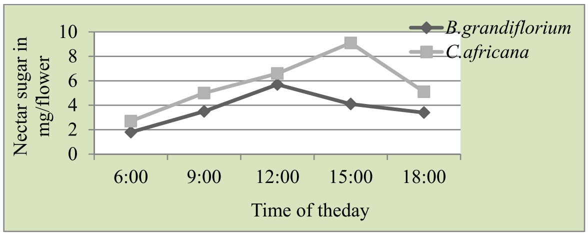

Fig. 5. Nectar sugar amount (mg) of *B.grandiflorum* and *C.africana* species per flower over the time of the day.

Table 5
Correlation (r) between mass of nectar sugar (mg) and different weather condition of three Acacia species.

Species	Temperature (°C)	Humidity (%)
Acacia etbaica	0.32**	−0.32**
Acacia tortolis	0.73**	−0.69**
Acacia asak	0.40**	−0.87**

Note: The value ** denotes the variables were significant at $p < 0.01$.

decreasing trend (Figs.. 6a and 7a). In other ways the nectar concentration increased when air humidity decreased in both species (Figs.. 6a and 7b).

3.5. Honey yield of major honeybee flora species

Among the species, a single tree of *A.etbaica* has produced relatively higher nectar sugar (0.15 kg) followed by *A.asa*k (0.12 kg), *A. tortolis* (0.05 kg), *C.africana* (0.03 kg), and the least *B.grandiflorum* (0.01kg/tree (Table 6). *A.etbaica*, *A.asak*, *A.tortolis*, *B.grandiflorum*, and *C. africana* were found to produce, in descending order, an average of 0.18 kg, 0.15 kg, 0.061 kg, 0.012 kg, and 0.037 kg of honey per single tree (Table 6). Therefore, the plants in the genus *Acacia* produce more honey than that *B.grandiflorum*, and *C.africana* because of their large number of small flowers with a large canopy of a tree. The actual nectar and honey yield of the species in a hectare of land has been calculated based on the abundance of the plants in the area. In this regard, *A.asak* could have produced the highest amount of honey (128.90 kg/ha) than other species while the lowest was recorded for *A.tortolis* could produce (2.16 kg/ha) (Table 6).

3.5.1. Total expected honey yield

In each agro-ecological zone, the quantity of honey produced per hectare of land varied according to the distribution and variability of nectar production among all species. Hence the four plant species (*A.etbaica*, *A.tortolis*, *B.grandiflorum*, and *C.africana* species) in the highland, and midland, and the only *A.asak* species in the lowland were considered in estimating honey production potential during the main honey production season because they had the same blossoming period. Hence the maximum honey (128.91 kg) was

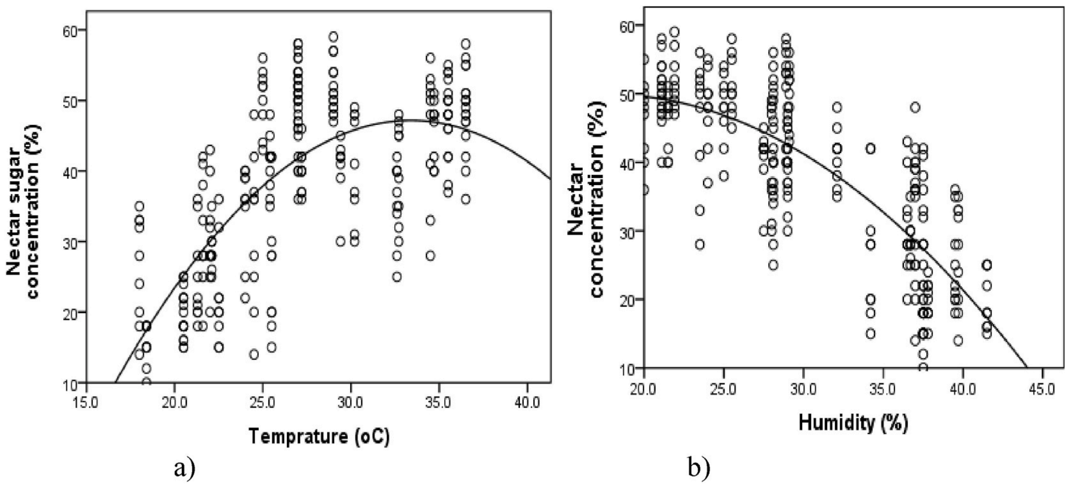

Fig. 6. Influence of temperature (a) and air humidity (b) on the nectar concentration of *B. grandiflorum* species.

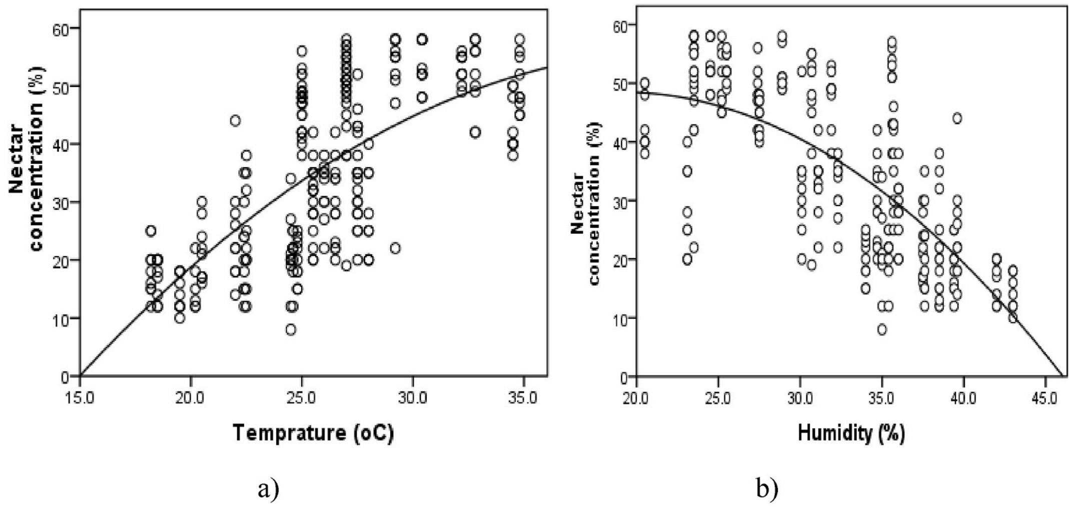

Fig. 7. Influence of temperature (a) and air humidity (b) on the nectar concentration of *C.africana* species.

estimated in the low land agro-ecology while in the mid and high land agro-ecologies, equal amount of honey (57.49) was expected in a hectare of land (Table 7).

3.6. Estimated honeybee colonies carrying capacity

The average productivity of traditional, transitional, and modern frame hives was 9.7 kg, 13.3 kg, and 19.3 kg, respectively, according to the results of our thorough key informant interview conducted in the northeastern dry land areas of the Amhara region and practical observation. Thus, from traditional, transitional, and modern hives in the highlands, an average of 7 kg, 10 kg, and 15 kg of honey was obtained per hive annually; in the midland, 10 kg, 15 kg, and 18 kg of honey were produced in traditional, transitional, and modern hives, respectively. In lowland areas; traditional, transitional, and modern hives have yielded an average of 12 kg, 15 kg, and 25 kg of honey, respectively (Table 8).

The number of honeybee colonies to be placed in a specific beekeeping site depends on the expected honey yield of the area and the types of beehives. A relatively large number of honeybee colonies; 18, 9, and 5 of traditional, transitional, and modern hives respectively could be introduced in the lowland agro ecology (Table 8). This is due to the availability of the dominant *A.ask* honeybee flora species.

4. Discussion

The mass of nectar sugar of *Acacia* species was recorded as 10.2 ± 6.4 mg, 5.3 ± 4.6 mg, and 2.6 ± 1.4 mg/flower head for *A.asak, A.etbaica, and A.tortolis,* respectively. In this regard, in Saudi, a mean of 3.8, 1.6, and 2.0mg/flower head was reported for *A.asak*, *A. etbaica*, and *A.tortolis,* respectively [5]. As a result, the species' nectar sugar amount in the current investigation was greater than in the report in Saudi, this is might due to the agro-ecological difference and the soil characteristics difference that affect the species' nectar properties. Among the studied species the highest and lowest nectar sugar was recorded in A.*asak* and *A.tortolis* species, respectively. Therefore it is indicated that *A.asak* a dominant honeybee flora species in the low land area is responsible for a good crop of honey by producing more nectar for honeybees during its flowering time.

There were not significant variations in the mean nectar volume, concentration, or amount of sugar between the research agro ecologies ($p > 0.05$). The Nectar volume of *B.grandiflorum* and *C.africana* per flower was recorded five times a day from different flowers and the average amount was taken as the estimated nectar potential of the species. By this, a mean of 9.8 ± 4.8 μl and 16.5 ± 6.9 μl per flower head was recorded for *B.grandiflorum* and *C.africana* species respectively. In this regard, the nectar volume per flower of both species is lower than *S.abyssinica* and higher than *C.macrostachyus* with 17.7 μl and 3.6 μl volume per flower head, respectively in Ethiopia condition [10,11]. Actually, nectar production is varying among plant species with a variation of flower morphology, the soil and environmental conditions of an area is mainly contributing factor to this. Using a refractometer, the species' sugar concentration was determined from the measured amount of nectar and it was obtained a mean of 38.0 ± 12.4 % and 34.5 ± 14.5 %, of sugar for *B. grandiflorum* and *C.africana* respectively. Hence the study indicated that *B.grandiflorum* nectar is concentrated more than *C. africana* nectar, this is why because Ethiopian kids sucked the flower of *B.grandiflorum* flower during their thin age. The average sugar content per flower of *B.grandiflorum* and *C.africana* was 3.7 ± 2.1 mg and 5.7 ± 3.2 mg, respectively. Once the sucrose density, concentration, and nectar volume were computed and translated to sugar quantity, this result was produced.

There was a significant difference ($P = 0.001$) in the mean nectar sugar quantity among all the species that were tested. 12:00 a.m. was the time with the lowest mean nectar quantity and 15:00 p.m. was the time with the greatest nectar sugar amount. The nectar

Table 6
Mass of nectar sugar per tree (kg), amount of expected honey yield per tree (kg), expected nectar yield (kg/hectare) and expected honey yield (kg/hectare) of five major honeybee flora species.

Species	Mass of nectar sugar per tree (kg)	Amount of expected honey yield per tree (kg)	Expected nectar sugar yield (kg/hectare)	Expected honey yield (kg/hectare)
A.etbaica	0.125	0.153	40.74	49.86
A.asak	0.120	0.150	103.13	128.90
A.tortolis	0.047	0.057	6.60	5.58
B.grandiflorum	0.010	0.012	4.56	5.47
C.africana	0.025	0.031	1.75	2.16

Table 7
Expected honey yield (kg/hectare) in three different agro-ecologies.

Agro-ecology	Expected honey yield (kg/hectare)
High land	57.49
Midland	57.49
Low land	128.91

Note: Honey yield in the highland and midland was estimated from the sum of *A.etbaica*, *B.grandiflorum*, and *C.africana* species while in the lowland from *A.asak* species only.

Table 8
Average honey yield (kg/hectare), honey yield expected (kg/hectare) and optimum number of honeybee colonies to be introduced in a hectare of land within different agro-ecology.

Agro-ecology	Average honey yield in each hive type (kg/hectare)			Honey yield expected (kg/hectare)	Optimum number of honeybee colonies in each hive type/hectare		
	traditional hive	Transitional hive	Modern hive		Traditional hive	Transitional Hive	Modern hive
Highland	5	10	12	57.49	12	6	5
Midland	7	12	18	57.49	8	5	3
Lowland	7	15	25	128.91	18	9	5

sugar secretion dynamics of the investigated species in the current study revealed a rising trend early in the morning that peaked at midday and then declined. Similarly the amount of sugar over time increased for *A.ehrenbergiana* and *A.tortilis* in Saudi Arabia [12]. This supports the general truth of plants needs a moderate sunrise and temperature for nectar secretion by supporting photosynthesis. Because of the increasing humidity in the area at the beginning of nectar secretion time, the volume increased and decreased with temperature, and the opposite was true for nectar concentration. This suggests that environmental conditions affect peak nectar volume and concentration secretion.

The study area's temperature and humidity range during data collection time was 18–36.50C and 20–43 %, respectively. Sugar concentration and nectar secretion are temperature-dependent plant biological processes. It has been discovered that temperature significantly affects nectar release, with extremely high temperatures having a detrimental effect on all species [13]. On this side, the present study revealed temperature had a significant positive correlation with the nectar sugar amount of studied species. Likely the ambient temperature had a significant positive association with nectar values (volume/flower, sugar content, and concentration in all species of Saudi Arabiya [5], which may point toward the adaptations of the species to higher temperatures. The presence of a positive association between the temperature and nectar secretion was observed for *A.ehrenbergiana* and *A.tortolis* species under Saudi conditions [14]. The current study supported the study carried out on *the Z. spina-Christi* species in Saudi Arabia, which found a positive relationship between temperature and nectar concentration [15]. Similarly, in southern Saudi Arabia reported that the amount of nectar per flower of two lavender species considerably increased as the temperature raised [16].

The total nectar sugar content of all the tree's accessible flowers was used to determine the quantity of nectar sugar present in each tree of the species. Therefore the highest number of flowers per species could have been estimated to have higher nectar sugar. Hence in a single tree of *A.etbaica*, *A.asa*k, *A.tortolis, C.africana,* and *B.grandiflorum* species calculated to have a mean 0.15 kg, 0.12 kg, 0.05 kg, 0.03 kg, and, 0.01 kg nectar sugar, respectively. In this regard, the potential for *A.etbaica* was alike to the amount of 0.15kg/tree but for *A.asak, A. tortolis* was 0.2 kg, and 0.4kg/tree, respectively [5] which higher than the present investigation. Mainly it is because this plant species in the Saudi Arabiya had large canopy volumes of 20 m^3, and 22.8 m^3, respectively [15]. The present finding is also lower than *C.macrostachyus* and *S.abyssinica* plants in Ethiopian that can produce a nectar sugar amount of 3.2 kg, and 8.85 kg per tree, respectively that is because these trees have massive crowns that are home to a vast quantity of tiny blooms of 483,840 and 676541floweres/tree, respectively [10,11]. The studied species secrete a substantial amount of nectar sugar and have a great deal of promise for beekeeping, despite the research area's high temperatures and little rainfall.

Considering that 820 g of total dissolved sugar are present in 1 kg of honey with 18 % moisture content (wt/wt). Therefore, it was anticipated that a single tree of *A.etbaica*, *A.asak*, *A.tortolis*, *B.grandiflorum*, and *C.africana* would produce, on average, 0.18 kg, 0.15 kg, 0.061 kg, 0.012 kg, and 0.037 kg of honey, in progressive order. Therefore, the plants in the genus *Acacia* produce more honey than that *B.grandiflorum*, and *C.africana* because of their large number of small flowers with a large canopy of a tree.

For *A.etbaica*, *A.asak*, *A.tortolis*, *B.grandiflorum*, and *C.africana*, the estimated amounts of honey in a hectare of land were 49.86, 128.90, 5.58, 5.47, and 2.16, respectively. The projected average output of honey that can be collected from the studied plants per hectare under ideal environmental conditions is less than the yield of honey reported per hectare for several annual crops and trees, such as milkweed (500–600 kg/ha) [17]; red clover with an estimated sugar yield of 883 kg/ha/flowering period [18], and various lime species (90–1200 kg/ha) [19]. Since honey production potential also depends on the number of flowers per unit area or volume and the plant canopy, some species have high nectar sugar content per flower but low honey production potential per tree or hectare of land.

The study showd that the flowering time of the species matters the total harvestable honey of a specific area in the specific period in each study location. Plants with the same flowering period help to harvest maximum honey in specific beekeeping areas. Based on this 57.49 kg/hectare of honey was expected in the highland and midland agro-ecologies while 128.91 kg/ha in the lowland locations during the main harvesting season of each respective agro-ecology. Therefore, in the lowland localities has been expected high honey productivity due to the highest honey production potential and abundance of *A.asak* species.

By dividing the expected honey production capacity of the species in a hectare of land by the maximum honey productivity of honeybee colonies in each hive type under the current conditions of the location, the number of honeybee colonies introduced in a hectare of land was estimated. Depending on this, a relatively large number of honeybee colonies could be introduced in the lowland agro ecology that 18, 9, and 5 of traditional, transitional, and modern hives honeybee colonies. Relatively minimum honeybee colonies (8, 5, and 3 of traditional, transitional, and modern hives) could have been estimated to be introduced in the midland agro ecology. In an investigation conducted on *S.abyssinica*, and *C.macrostachyus* forests in Arsi, Jimma, and Southwest zones of the Oromiya regional state, a maximum of 24 traditional, 16 intermediate, and 9 movable hives, and 56 traditional, 36 intermediate, and 20 modern hives were estimated to be introduced in a hectare of forest area, respectively [10,11]. In this regard, the variation with the present finding is due to the nectar production potential of the species.

5. Conclusion

The study revealed that the examined species had a great potential for beekeeping since they emit a substantial amount of nectar sugar, even in spite of the study area's high temperatures and little rainfall. A hectare of beekeeping site, in the lowland of the Waghimra zone, could be produced relatively higher honey yield than highland and midland agro-ecologies due to the more abundance and higher nectar secretion potential of *A.ask honeybee flora species*. In conclusion, in lowland areas during the flowering time of *A.asak*, a higher number of honeybee colonies could be introduced in a hectare of land than the midland and highland agro ecologies due to the higher honey production potential of the species.

Since the study honeybee flora species has considerable promise to yield honey, multiplication and conservation are advised for sustained honey production in the study area. Other than these studied species in the study area, there are some honey plants to be estimated for honey production, therefor such investigations shall be done in the inclusion of the rest of the important bee floras especially shrubs and herbs. Above all, it is anticipated that the findings produced by this study will be helpful in determining the carrying capacity of an area for honey bee colonies and in establishing apiary sites.

Statement of funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Additional information

No additional information is available for this paper.

Data availability statement

Instead of being uploaded to a website, the data is stored on my desktop computer so that I am able to send you the data up on your request.

CRediT authorship contribution statement

Agazhe Tsegaye: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Awraris Getachew:** Methodology. **Amssalu Bezabih:** Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We are grateful to the Amhara Agricultural Research Institute (ARARI), Sekota Dry Land Agricultural Research Center for delivering research materials and supporting for the whole study.

References

[1] T. Gezahegne, Marketing of honey and beeswax in Ethiopia: past, present and perspective features, in: Proceedings of the Third National Annual Conference of the Ethiopian Beekeepers Association (EBA), Addis Ababa, Ethiopia, 2001, pp. 78–88. September 3-4, 2001.

[2] 2020 CSA, Central Statistical Authority of Ethiopia: Report on Livestock and Livestock Characteristics (Private Peasant Holdings), vol. II, 2020 no. March.

[3] A. Al-ghamdi, N. Adgaba, A. Getachew, Y. Tadesse, New Approach for Determination of an Optimum Honeybee Colony ' S Carrying Capacity Based on Productivity and Nectar Secretion Potential of Bee Forage Species, 2016, pp. 92–100.
[4] A.J. Wubie, A. Bezabeh, K. Kebede, Floral Phenology and Pollen Potential of Honey Bee Plants in NorthEast Dry Land Areas of Amhara Region , Ethiopia Floral Phenology and Pollen Potential of Honey Bee Plants in North- East Dry Land Areas of Amhara Region , Ethiopia, 2014, https://doi.org/10.9790/2380-07513649 no. May 2017.
[5] A. Nuru, et al., Nectar secretion dynamics and honey production potentials of some major honey plants in Saudi Arabia, Saudi J. Biol. Sci. 24 (1) (2017) 180–191, https://doi.org/10.1016/j.sjbs.2016.05.002.
[6] S.A. Mallick, "Technique for washing nectar from the flowers of Tasmanian leatherwood (Eucryphia lucida Eucryphiaceae),", Austral Ecol. 25 (2) (2000) 210–212, https://doi.org/10.1046/j.1442-9993.2000.01010.x.
[7] A.B. Bolten, P. Feinsinger, H.G. Baker, I. Baker, On the calculation of sugar concentration in flower nectar, Oecologia 304 (1979) 301–304.
[8] R. Weast, CRC Handbook of Chemistry and Physics, 67th ed., CRC Press, Inc., Boca Raton, Florida, 1986.
[9] M. Kim, J. Han, M. Kang, Y.K. Park, Honeybee visit and nectar secretion characteristics of the Chinese Hawthorn Crataegus pinnatifida Bunge, J. Apic. 26 (1) (2011) 11–14. The Apicultural Society of Korea.
[10] B. Tura, K. Tolera, R. Kasim, A. Admassu, Nectar secretion dynamics and honey production potential of Croton nectar secretion dynamics and honey production potential of Croton macrostachyus L ., Euphorbiaceae, Bee World (2020) 1–5, https://doi.org/10.1080/0005772X.2020.1763086, vol. 0, no. 0.
[11] T. Bareke, T. Kumsa, A. Addi, Nectar Secretion and Honey Production Potential of Schefflera Abyssinica, Hochst . ex A . Rich .) Harms, Araliaceae, 2020.
[12] A. Nuru, et al., Pollination Ecology , Nectar Secretion Dynamics , and Honey Production Potentials of Acacia Ehrenbergiana (Hayne) and Acacia Tortilis (Forsk .) Hayne , Leguminosae (Mimosoideae), in an Arid Region of Saudi Arabia, vol. 57, 2016, pp. 429–444, no. 3.
[13] H.B. Jakobsen, K. Kristjánssonf, Influence of temperature and floret age on nectar secretion in Trifolium repens, Oxford Unive 74 (4) (1994) 327–334.
[14] A. Nuru, et al., Nectar Secretion Dynamics and Honey Production Potentials of Some Major Honey Plants in Saudi Arabia, 2016, https://doi.org/10.1016/j.sjbs.2016.05.002 no. May.
[15] A. Nuru, A.M. Awad, A.A. Al-Ghamdi, S.E. R, Abdulaziz S. Alqarni, 2, Nectar of Ziziphus Spina Christi (L.) Willd (Rhamnaceae): Dynamics of Secretion and Potential for Honey Production, vol. 56, 2012, pp. 49–59, https://doi.org/10.2478/v10289-012-0023-9. no. 2.
[16] A. Nuru, A.A. Al-ghamdi, A.G. Shenkut, Floral phenology, nectar secretion dynamics, and honey den production potential, of two lavender species (v t a t a la, and) in southwestern Saudi Arabia 59 (2) (2015) 135–144, https://doi.org/10.1515/JAS-2015-0028.
[17] A. Farkas, E. Zajacz, Nectar production for the Hungarian honey industry, Eur. J. Plant Sci. Biotechnol. 1 (2) (2007) 125–151.
[18] H. N, T. Szabo, Flowering, nectar secretion and pollen production of some legumes in the Peace River Region of Alberta, Canada, Apic. Res 24 (2) (1985) 102–106.
[19] E. Crane, P. Walker, R. Day, Directory of Important World Honey Sources, International Bee Research Association, London, 1984, p. 384.