



RESEARCH ARTICLE

Foraging behavior of honey bees (*Apis mellifera*) on cassava grits

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ABSTRACT

A study was conducted to assess honey bees' foraging activity on cassava grits (*Apis mellifera* L.) to identify times of day and parts of the processing season more favourable for sun-drying grits outdoors. Experiments were conducted in the Mtwara region, Tanzania, namely, Mbawala, Mtendachi, and Narunga villages—experiments involved two uncovered racks containing 10kg of cassava grits each. Population abundances of honey bees were estimated by counting all honey bees' foragers hourly using automated digital imaging cameras. The number of honey bees was recorded for sixteen weeks by manually counting the bee individuals visible in each image. The results indicated that higher honey bee population abundances were recorded at 15:00 and 16:00 hours. The lowest number of honey bee abundance was recorded at 10:00, 11:00, and 12:00 hours in all locations. It indicates that the village of Narunga should optimally select to sun-dry their cassava grits between 11:00 and 13:00 hrs, Mbawala between 10:00 and 12:00 hours, and Mtendachi between 11:00 and 14:00. The honey bees were monitored from May to November, and the lowest population abundances of honey bees were recorded during October in all locations, suggesting it is the most favorable month for outdoor drying

Keywords: *Apis mellifera*; cassava grits; forage behavior; pollinators; Tanzania

INTRODUCTION

The honey bee, *Apis mellifera* (Linnaeus) (Hymenoptera: Apidae), is a species of social insect living in a colony with an atypical size ranging from 50 to 80,000 individuals (Menzel, 2012; Stalidzans et al., 2017). In Africa, more than 25 countries, including Tanzania, keep bees (Hussein, 2000; Nair et al., 2013). Honey bees play significant roles in human lives, which include: pollination that ensures food security and environmental biodiversity (Whitfield et al., 2006; Wubie et al., 2013), and direct income through selling hive products, for example, honey, apropolis, pollen, royal jelly, wax, and bee venom (Ahmad et al., 2007) while requiring minimum resources such as land and labour (Kanniainen, 2013). Despite the economic benefits, honey bees feed on cassava grits, resulting in substantial losses to farmers or cassava processors (Ndibanya et al., 2017).

Prasannakumar et al. (2015) indicated that honey bees feed on plant nectar, and their feeding is associated with one food source over another and the specific position of the flower over another. Honey bees prefer to forage on nectar, pollen, and resin (Abou-Shaara, 2014). The bees prefer continuous water sources to stable ones, and large containers prefer small ones (Abou-shaara, 2013; Karlström et al., 2016; Nwoko et al., 2016; Staveley et al., 2014).

Cassava growers and processors in the Mtwara region, Tanzania, reported cassava grits losses caused by honey bees. During sun-drying of cassava grits, honey bees have been observed feeding on cassava grits as their alternative source of food (Wheeler & Robinson, 2014). The bees collect the grits on their leg combs (corbicular hairs) in the same manner as they collect pollen, before leaving the site. A similar problem was confirmed by Ndibanya et al. (2017). Smallholder cassava growers in Tanzanian villages generate income from marketing cassava products, including cassava flour (Alene et al., 2013). Cassava flour is also used as a staple food and in making bread (Montagnac et al., 2009; Salvador et al., 2014).

Feeding by honey bees causes significant losses of cassava grit (Ndibanya et al., 2017), which may result in reducing the income of smallholder farmers, but also causes hunger. Losses of cassava grits have also been reported by other African countries such as Malawi and Madagascar (Mhlanga et al., 2010; Ranaivoson et al., 2010). Developing an appropriate strategy to reduce cassava grits losses caused by honey bees is essential. This can be achieved through understanding the foraging activity of honey bees. Studies indicate that foraging activity by honey bees differs with time in terms of hours during the day (Honchel & Krishna, 2016; Abou-Shaara, 2014; Couvillon et al., 2015) and months (Sagili & Burgett, 2011). Limited information exists about the foraging activity of honey bee workers on cassava grits in the study areas. Thus, this study aimed to assess the foraging activity of honey bee workers to get information that can help advise cassava growers and processors on the time during the day or months when cassava grits are to be sun-dried, with an average loss in cassava grit weight of about 31.28 % caused by honey bees (Ndibanya et al., 2017).

MATERIALS AND METHODS

Description of the study sites

The study was conducted in the Mtwara region, Tanzania (10° 18' S, 40° 10' E) in 2021/2022 and 2022/2023 seasons and the region is characterized by a unimodal type of rainfall ranging between 810 mm and 1090 mm, with a mean temperature of 27°C (Nene et al., 2015). The experiments were carried out at Mbawala, Narunga and Mtendachi villages in Mtwara rural district. Villages and sites were selected based on the current active cassava processing industry and reports of intensive honey bee problems. Mbawala and Narunga have small-scale processing on one or two sites in each village, respectively. Mtendachi is a medium-sized semi-industrial processing site with the capacity to dry up to 64 racks simultaneously indoors, but small-scale outdoor drying also takes place.

Experimental design

Estimation of bee visitation rates throughout the drying season

Field experiments were conducted in all three south-eastern villages. Randomized complete block design was used in this experiment, with two racks selected from those being used on a given day. Racks consisted of black polythene sheets (available at a local market in sections of 20 m x 5m) that were stretched over a wooden frame, with dimensions varying slightly between villages but typical dimensions being 1 m by 5 m. The drying surface was around 1 m above ground level, and a village may have between 1 and 16 racks in use at any given time. The selected racks were prepared for sun-drying and provided with 10kgs per each of freshly pressed cassava grits (processed from cassava roots by the aid of a grinder and presser machine). Drying progressed for 6h (10:00 - 16:00) during which time each rack was left uncovered and grits occasionally turned by the processors. This allowed honey bees to land and access the cassava grits.

Bees were counted by estimation of seasonal patterns in the number of honey bees visiting the uncovered racks per site. Measurements were carried out using digital imaging, with either a Canon IXUS 125 (Argos, UK) or a Trail and Game automated camera (CCBetter Trail Camera, supplied by Amazon, UK) used for capturing the photos of honey bees when they were landing on the cassava grits during the drying time.

The arrangements were a single rack with one camera held at a distance of 1.5m from the rack so as to capture half the rack per photograph, or the Trail and Game cameras were clipped to a gooseneck arm on an adjacent rack so as to capture the entire observation rack (Figure 1). The digital photographs were then taken from each observation rack hourly from 10:00 to 16:00 hours. Moreover, the numbers of honey bees were recorded in all three sites for sixteen weeks. Photographs were then downloaded from the cameras to a computer, and the number of bees present on the rack was counted manually. Experiments were repeated three times per site over sixteen weeks, during the drying season (July to November) when the honey bee problem is most severe.

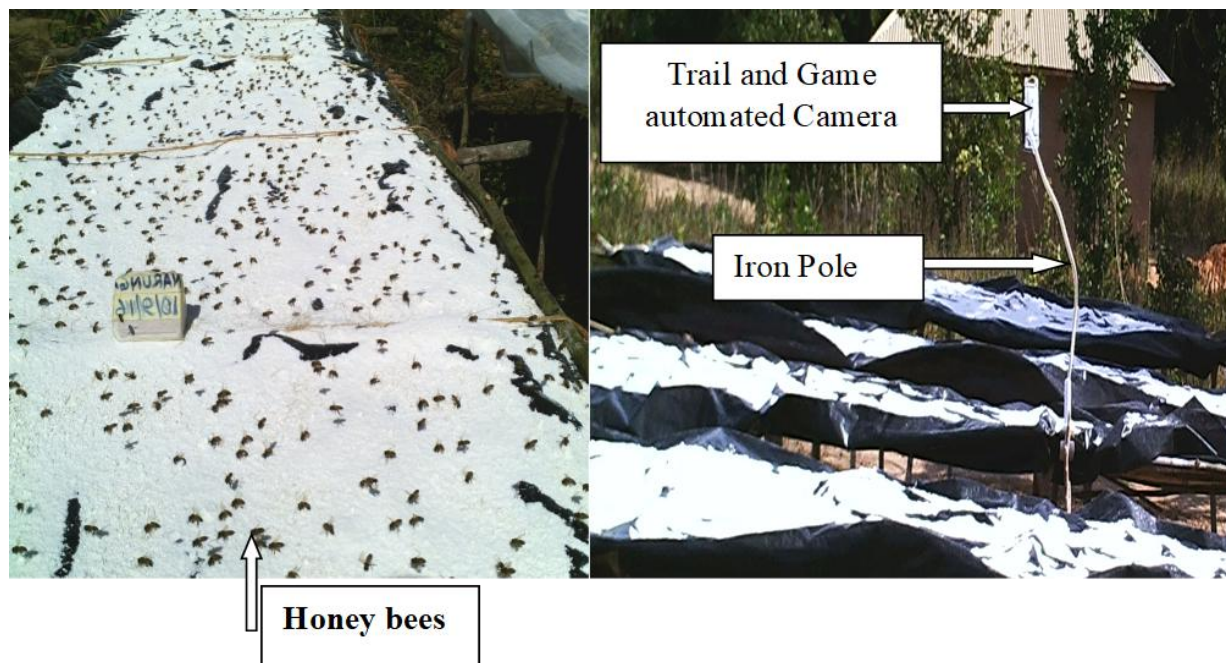


Figure 1. Honey bee foraging on cassava grits and a trail and game automated camera set used for taking bees' image

Data collection

The data collected in the above experiment was the number of honey bees visited on cassava grits during the drying time, based on daily, weekly, monthly and seasonally record.

Data analysis

The Poisson regression analysis was used to determine the association between time during the day, months and locations with honey bees' abundances. Population abundances of honey bees were also determined by the Kruskal-Wallis one-way ANOVA because residuals were not normally distributed. Data were analysed using Genstat (VSN International, UK).

RESULTS

The Poisson regression results showed significant associations between time during the day and honey bee abundance ($df = 6$, $Chi Pr < 0.001$). Time at 11 and 12 hours negatively affected the number of honey bees, in contrast to time at 13, 14, 15 and 16 hours (Table 1). The Honey bees' abundances decreased by 9.6 % and 11.8% at 11 and 12 hours, respectively. In all locations, time at 15 hours recorded the highest number of honey bees, which was 1.5 times higher than was the case in 10 hours ($e = 0.4300$, $p < .001$, $Exp[\beta] = 1.537$).

Table 1. The association between time during the day and number of honey bees across all locations

Parameter	estimate	s.e.	t (*)	t pr.	Exp [β]
Constant	4.0352	0.0313	128.91	<0.001	56.56
Time 11hrs	-0.1012	0.0455	-2.23	0.026	0.9037
Time 12hrs	-0.1254	0.0457	-2.74	0.006	0.8821

Time 13hrs	0.2085	0.0422	4.95	<0.001	1.232
Time 14hrs	0.3286	0.0411	8.00	<0.001	1.389
Time 15hrs	0.4300	0.0402	10.69	<0.001	1.537
Time 16hrs	0.3956	0.0405	9.77	<0.001	1.485

Note: estimate = estimate or coefficient of parameters, s.e. = standard error of estimates, t (*) = estimate/standard error, tpr. = probability, Exp [β] = exponent of estimate

The associations of time and honey bees' abundances for each of the studied areas are presented in Table 2a, 2b and 2c below. The highest honey bees were recorded at 16 hours in Narunga village compared to the rest of the hours. However, the honey bees' abundances were lower at 11:00, 12:00 and 13:00 hours than at 10 hours (Table 2a). Results in Table 2b indicated that honey bees' abundance at 14 hours was 8.7 times higher than at 10 hours in Mbawala village. At Mtendachi village (Table 2c), the highest honey bees was recorded at 15 hours. However, honey bee abundances decreased by 3.1, 14.9 and 9.3% at 11, 12 and 14 hours, respectively, in comparison to 10 hours.

Table 2a. Honey bees' abundance at different hours during the day at Narunga village in Mtwara, Tanzania.

Parameter	estimate	s.e.	t (*)	t pr.	Exp [β]
Constant	4.1564	0.0508	81.86	<0.001	63.84
Time 11hrs	-0.4029	0.0805	-5.01	<0.001	0.6684
Time 12hrs	-0.3571	0.0793	-4.50	<0.001	0.6997
Time 13hrs	-0.2148	0.0761	-2.82	0.005	0.8067
Time 14hrs	0.2524	0.0678	3.72	<0.001	1.287
Time 15hrs	0.5165	0.0643	8.03	<0.001	1.676
Time 16hrs	0.6157	0.0632	9.75	<0.001	1.851

(df = 6, Chi Pr < 0.001).

Table 2b. Honey bees' abundance at different hours during the day at Mbawala village in Mtwara, Tanzania.

Parameter	estimate	s.e.	t (*)	t pr.	Exp [β]
Constant	1.992	0.151	13.22	<0.001	7.333
Time 11hrs	0.727	0.184	3.96	<0.001	2.068
Time 12hrs	1.060	0.175	6.06	<0.001	2.886
Time 13hrs	1.836	0.162	11.32	<0.001	6.273
Time 14hrs	2.169	0.159	13.63	<0.001	8.750
Time 15hrs	1.836	0.162	11.32	<0.001	6.273
Time 16hrs	1.436	0.168	8.57	<0.001	4.205

(df = 6, Chi Pr < 0.001).

Table 2c. The Honey bees' abundance at different hours during the day at Mtendachi village in Mtwara, Tanzania.

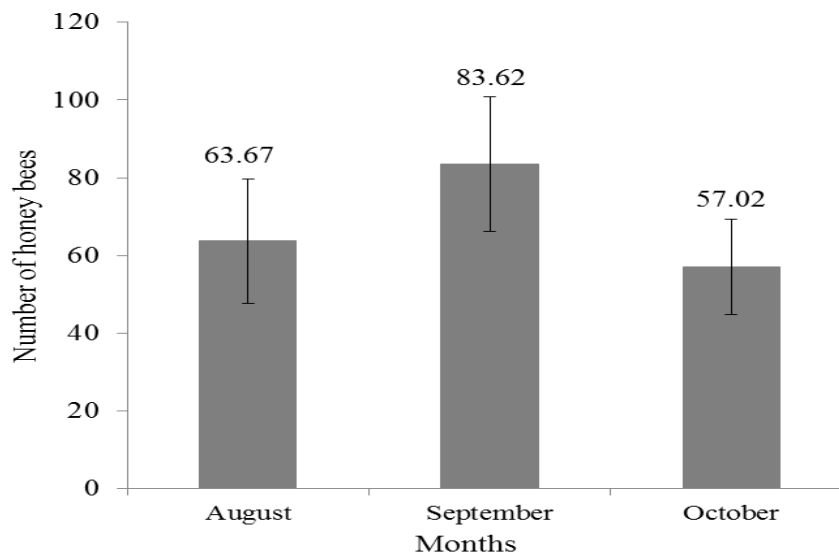
Parameter	estimate	s.e.	t (*)	t pr.	Exp [β]
Constant	4.5901	0.0411	111.59	<.001	98.50
Time 11hrs	-0.0309	0.0586	-0.53	0.598	0.9695
Time 12hrs	-0.1612	0.0607	-2.66	0.008	0.8511
Time 13hrs	0.1240	0.0565	2.20	0.028	1.132
Time 14hrs	-0.0977	0.0596	-1.64	0.101	0.9069
Time 15hrs	0.0905	0.0569	1.59	0.112	1.095
Time 16hrs	0.0447	0.0575	0.78	0.437	1.046

(df = 6, Chi Pr < 0.001).

Table 3 below shows the result of honey bees' abundance in relation to months during the year. There was a 31.3 % increase in Honey bee abundance during September compared to August (e = 0.2726, p <0.001, Exp[β] = 1.313). However, the abundance of honey bees decreased by 10.4 % in October compared to August. Their average means are presented in Figure 2.

Table 3. The honey bees' abundances in different months in all locations

Parameter	estimate	s.e.	t (*)	t pr.	Exp [β]
Constant	4.1537	0.0193	214.97	<0.001	63.67
Months September	0.2726	0.0256	10.63	<0.001	1.313
Months October	-0.1102	0.0281	-3.92	<0.001	0.8957

**Figure 2.** Average number of honey bees recorded during August, September and October in Mtendachi, Narunga and Mbawala areas in Mtwara region, Tanzania.

The results in Table 4 show the association between locations and time (months) in honey bee abundances. During September, Narunga village experienced 41.9 times more honey bees compared to Mbawala ($e = 3.735$, $p < 0.001$, $\text{Exp}[\beta] = 41.91$). This was followed by Mtendachi in the same month of September ($e = 3.042$, $p < 0.001$, $\text{Exp}[\beta] = 20.95$). The lowest number of honey bees recorded was associated with Narunga village in August. The results in Table 5 indicated that the honey bee abundance differed significantly ($p = 0.006$, $df = 2$, Kruskal-Wallis H value=9.794) in relation to locations.

Table 4. Association between different months and location on honey bees' abundances

Parameter (Months. Sites)	estimate	s.e.	t (*)	t pr.	Exp [β]
Constant	4.2247	0.0323	130.71	<0.001	68.36
August. Mtendachi	0.5220	0.0408	12.80	<0.001	1.685
August. Narunga	-2.2168	0.0999	-22.19	<0.001	0.109
September. Mtendachi	3.042	0.138	22.08	<0.001	20.95
September. Narunga	3.735	0.136	27.43	<0.001	41.91
October. Mtendachi	1.3051	0.0584	22.35	<0.001	3.688
October. Narunga	0.5596	0.0649	8.62	<0.001	1.750

Table 5. The population abundance of honey bees in different locations

Locations	Mean rank	Size (n)
Narunga	54.40	42
Mbawala	58.38	42
Mtendachi	77.71	42

Chi square probability = 0.006, $df = 2$, $H = 9.794$

Kruskal-Wallis one-way analysis of variance

DISCUSSION

The Poisson regression analysis of bee abundance recordings demonstrates that, among the hours, foraging behavior of honey bees depends on the spatio-temporal availability of resources, which were not homogeneous across the experimental sites. The results indicate that during the drying periods, honey bee foraging ranges increased with extended drying time from 11:00 to 16:00 hours, while the least recorded was in the morning from 10:00 to 12:00 hours, although the population varied with time and locations. This observation agreed with the studies done by Jaganmohan et al. (2013) and Amaya-Márquez et al. (2014), who observed the variation of honey bees with time and site.

The overall abundance at the three sites was in the order Mtendachi>Nangawanga>Narunga. Temporal and spatial fluctuations in insect population abundances vary with time and locations (Rader et al., 2012). These results agreed with the studies conducted by Honchel and Krishna (2016). Kreider et al. (2020) indicated that the highest foraging activity of bees was observed in the afternoon, from 12:40 to 15:00 hrs, followed by evenings, from 18:00 to 19:00 hours, while the least was recorded in the morning, from 07:00 to 10:00 hours. Honey bees foraging specifically adapt their foraging behavior to exploit more cassava grit resources during the drying event. At the sites, the foraging behaviour of honey bees was not affected by the presence of cashew tree flowers. Instead, many foraging flights landed on cassava grits, just as fewer honey bees land on other tree flowers. This is because during the drying, most of the surrounding trees were observed to have fewer flowers and nectar. This conceptualization is similar to the results observed by Steffan-Dewenter and Kuhn (2003); Danner et al. (2016); Danner et al. (2017); Bänsch et al. (2020), who found that honey bees did not extend their foraging range in response to floral resource scarcity but extended their foraging range to exploit a highly rewarding resource.

Furthermore, this optimization of foraging behavior in response to the availability of highly rewarding resources implies that the off-availability of some important nectars and flowers during the drying of these cassava grits. This rare availability of resources for honey bees foraging at different sites forces the honey bees to use more energy and spend time searching for food. Thus, during this experiment, the number of honey bees was not constantly observed at the sites and times. This concept of honey bees travelling searching for food is similar to the research conducted by Cresswell et al. (2000); Lihoreau et al. (2011), which revealed that honey bees travel searching for rewarding resources. Hence, the cassava farmers in Mtwara, Tanzania, could effectively contribute to providing a constant food supply for honey bees during the dry season, which can benefit them as a substitute for flowers in flower-poor agro-ecosystems, such as sugar solution. Honey bees can adapt their foraging behaviour to spatial and temporal variation across the sites. In different foraging habitats, they tend to optimize the exploitation of highly available resources. In addition, this study shows that honey bees exploit different foraging times during dry periods.

CONCLUSION

The study concludes that honey bee population abundance fluctuates both diurnally and seasonally, and is unevenly distributed across the region. Specifically, during the drying period between 10:00 and 16:00 hours, bee activity and population density vary significantly by time and location, which may lead to reduced cassava grit collection. These findings highlight the importance of strategic management practices. Farmers and stakeholders are encouraged to conserve diverse wild bee populations and ensure the availability of adequate floral resources for managed honey bee colonies, particularly during critical drying periods, to sustain pollination efficiency and agricultural productivity.

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AUTHORS CONTRIBUTIONS

KNN performed the conception or design of the work, data collection, data analysis, interpretation and was a major contributor in writing the manuscript (drafting the article). EM and WN performed a critical revision of the article, providing critical comments concerning the discussion of results, conclusions, and recommendations. All authors read and approved the final manuscript.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

ETHICAL APPROVAL

Not applicable.

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AVAILABILITY OF DATA AND MATERIALS

All datasets analyzed and described during the present study are available from the corresponding author upon reasonable request.

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