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Research Article

The Combined Effects of Beehive Shade and Feed Supplementation on Honeybee (*Apis mellifera*) Productivity

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Abstract

Ethiopia is known as one of the world's most important beekeeping areas due to its favorable environmental conditions for growing diverse natural vegetation and cultivated crops. However, the country faces several challenges, including the need for standardized management practices, a lack of technical skills, and bee colonies absconding for unknown reasons. These challenges have hindered the sector's production and productivity. The study aimed to investigate the effects of beehive shade and feed supplementation on honeybee colony productivity in two different Ethiopian agroecologies: the midland region of Bako and the highland area of Gedo. Bako is located at 9° 10' 148" N, 37° 04' 374" E, and Gedo is situated at 9° 01' 504" N, 37° 26' 109" E. This study used 80 honeybee colonies at both locations. These colonies were divided into four groups with varying techniques of management at each site: Group A provided both a hive shed and dearth period feed, Group B provided a hive shed but no dearth period feed, Group C provided dearth period feed but no hive shed, and Group D provided neither a hive shed nor dearth period feeding. The findings revealed that colonies under treatment A showed significantly more brood and pollen combs compared to treatments B, C, and D at both study sites. The difference in brood production ranged from 340.91% for Bako during March-May to 380.95% for Gedo during September-November. Additionally, colonies in treatment A reared 145.78% to 162.03% more brood during dearth periods (December-February and June-August) than colonies in treatment D. The overall differences in pollen Storage between treatment A and D for Bako and Gedo were 239.0% and 272.4%, respectively. The study also found significant differences in absconding rates among the treatment groups, with Group D having the highest rate (80.0%), while Groups B, C, and A had lower rates (62.5%, 57.5%, and 17.5%), respectively. Moreover, the honey yield per year varied significantly among the groups, with Group A having an average yield of 46.80 kg/colony and Group D averaging only 10.3 kg/colony. The study concluded that the provision of durable beehive shading and supplementary feeding during dearth periods is essential to enhance significantly the productivity of honeybees. Further research is recommended to identify other factors that can affect the productivity of local honeybees.

Keywords

Honeybee, Beehive Shade, Supplementary Fed, Brood, Absconding, Pollen

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1. Introduction

Ethiopia is recognized as one of the world's most significant beekeeping hotspots, predominantly due to its favorable environmental conditions for the growth of diverse natural vegetation and cultivated crops [1-3]. The country is estimated to have approximately 7-10 million honeybee colonies [4-10], of which about 6.9 million are believed to be hived while the remaining exist in the wild [11]. This makes Ethiopia one of the world's leading honey producers, with the potential to produce 500,000 tons of honey and 50,000 tons of beeswax per annum [3, 8, 12], but current production is limited to 52,000 tons of honey [13]. This limitation is due to a number of challenges, including insufficient knowledge of honeybee management, lack of access to basic beekeeping training and extension services in most areas of the country, insufficient support services, and the frequent absconding of local honeybee colonies for unknown reasons [14-17]. Combating these issues through training and adversary services can assist beekeepers in learning and adhering to best beekeeping practices [18-20], resulting in increased production and productivity for the sector, as well as significantly improving beekeepers' income and promoting Ethiopian economic development.

The success of beekeeping is closely tied to the availability of honeybee-friendly plants near the apiary, as well as various environmental conditions [23, 24]. The presence of these plants can fluctuate throughout the year depending on the region. A shortage of bee-friendly flora and limited food sources can adversely affect honeybee colonies by restricting brood rearing, lowering honey yields, and slowing overall colony growth and development [25, 26]. During this period, a range of diseases and pests can appear, posing significant threats to the health and stability of bee colonies. Thus, it is essential to address these challenges by developing and implementing a nutritious feeding strategy for honeybee colonies to support their health, productivity, and overall well-being. This approach not only reduces the likelihood of bee colonies absconding, but also greatly enhances their overall strength and productivity. Therefore, providing supplemental food during periods of scarcity is essential for maintaining healthy colonies and ensuring they have adequate resources for future honey production [27]. Furthermore, supplemental feeding for honeybee colonies is extremely important because it confirms that they receive essential nutrients such as proteins, minerals, and carbohydrates, which are essential for their development, including brood rearing, maturity, adult longevity, and overall health and wellness [28-31].

Honeybee colonies that are established in open areas typically produce significantly less honey than those housed in the shelter [32-34]. This is mainly due to the greater exposure of outdoor colonies to various natural forces [32], they also reported that, the population size of the honeybee colonies in the shaded areas could potentially be larger compared to the hives in the open sun. This difference was attributed to the presence of a favorable microclimate in the shaded areas, which was conducive to the growth and expansion of the honeybee colonies. The demand for a large number of house bees to regulate hive temperature and defend against intruders reduces the number of forager bees available to collect nectar and other essential resources [35, 36]. As a result, reduced forager activity has a negative impact on honeybee colonies production and overall productivity. Thus, unshaded bee hives are particularly susceptible to environmental stressors due to their exposure to direct sunlight and fluctuating temperatures [32]. The heat can cause the hive's internal temperature to rise to levels that are uncomfortable or even dangerous for the bees. In these conditions, the wax that holds the honeycomb in place can soften, making the combs more prone to detachment. This not only disrupts the hive's structure but also interferes with the bees' ability to store honey and raise brood effectively. Even in the most extreme situations, entire honeybee colonies may abandon their hive and abscond, leaving behind their brood, honey, and other resources [37]. This drastic behavior typically occurs when the colony faces overwhelming stressors that threaten its survival, forcing the bees to seek a new location. Furthermore, honeybee colonies may abscond due to various factors, such as pesticides, frequent disturbances, poor hive ventilation, presence of diseases and pests, insufficient honeybee flora in the surrounding area and prolonged sunlight [38]. Despite the importance of beehive shade and feed supplementation, there is limited information available in Ethiopia on how these factors interact. Understanding their combined effect is essential for beekeepers and researchers seeking to prevent colony losses, improve beekeeping practices, and increase the productivity of honeybee colonies. Therefore, the aim of this study was to investigate the combined effects of these two factors on the productivity of honeybee colonies in two Ethiopian agroecologies.

2. Material and Methods

2.1. Study Area

The experiment was conducted from September 2015 to June 2017 at two experimental apiary sites located in Bako (midland agroecology) and Gedo (highland agroecology). The geographical coordinates and elevations of the sites were 9°10'148" N, 37°04'374" E at 1639 meters above sea level for Bako, and 9°01'504" N, 37°26'109" E at 2437 meters above sea level for Gedo (Figure 1). These locations were selected based on their distinct agroecological conditions, which influence the flowering patterns and development of honeybee forage plants, thereby affecting colony growth and honey production. Each apiary was established with a diverse array of honeybee plants that bloomed at different times of the year, ensuring a continuous supply of nectar and pollen. This floral diversity was intended to support colony development and enhance productivity in varying ways across the two agroecological zones. Throughout the study period, regular observations were conducted at both sites to monitor the behavior and activities of the experimental bee colonies.

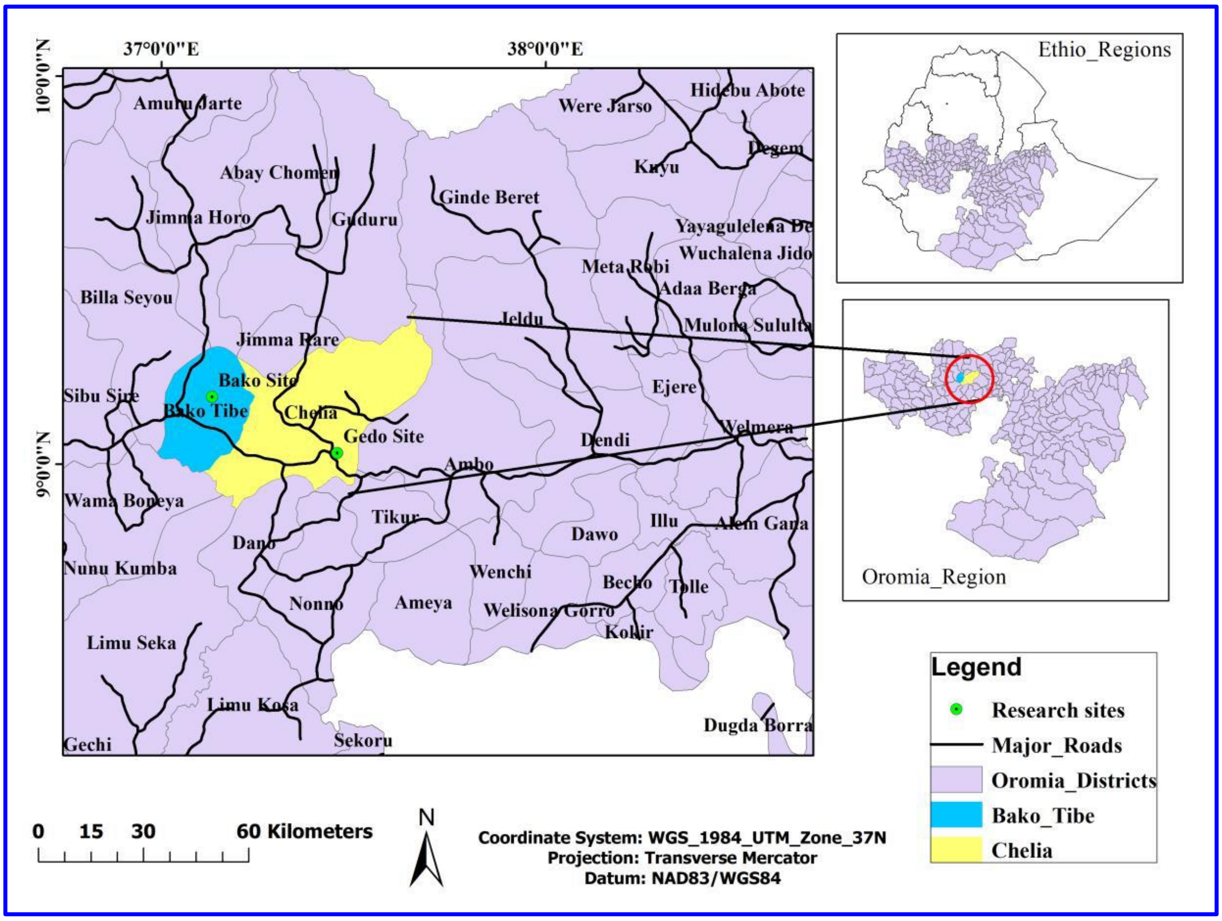

Figure 1. *A map of the study areas.*

2.2. Establishing and Setting up of Experimental Colonies

A total of 80 local honeybee colonies were carefully collected from traditional beekeepers located within a 20-kilometer radius of the two apiaries. These colonies were then transferred to movable Zander-type frame hives at both apiaries at the start of the active season (September). From the third week of December (the beginning of the dearth period) until the first week of June 2016 all transferred colonies were fed one liter of sugar syrup (1: 1 sugar to water ratio) each in order to allow all colonies to properly established. To ensure the uniformity of experimental colonies, all colonies were inspected, and all available resources, such as brood, pollen, nectar, honey, and honeybee populations, were equally distributed for each colony, and they were assigned to four different treatments groups using Complete Randomized Design (CRD) before data collection began in September 2016 at both sites. The experimental colonies were relocated one kilometer from their original location to their designated experimental sites. Each treatment had ten honeybee colonies assigned to it, making a total of 80 colonies used across the two study locations (40 colonies at each location). After being assigned to treatment groups, the colonies were given 42 days to settle before being inspected every 21 days to collect data on brood area, pollen area, absconding events, and colony population changes. The four treatment groups were labeled as follows:

1) Treatment A: Involves providing colonies with a permanent hive shed and regular dearth period feeding
2) Treatment B: Involves providing regular dearth period feeding to colonies without a hive shed
3) Treatment C: Involves providing a permanent hive shed to colonies but no dearth period feeding
4) Treatment D: Does not provide the colonies with both a hive shed and feed during dearth periods

2.3. Beehive Shade Construction

At each site, we carefully constructed two beehive shades for treatments A and C on a 43.4 m^2, with dimensions of 2.0 meters in width and 21.7 meters in length, each designed to accommodate ten honeybee colonies. The shades were constructed with a height of 3.00 meters in the back side and 2.50 meters in the front side from eucalyptus trees. To protect the experimental colonies from sun and rain, the roofs of the shades were covered with dry grass.

2.4. Data Collection on Different Parameters

2.4.1. Brood Area and Pollen Storage

To assess colonies' brood rearing performance, the comb areas occupied by immature worker honeybees (eggs, larvae, sealed brood) in colonies were evaluated every 21 days by overlaying a grid premarked 2.5 cm by 2.5 cm on each side of every brood frame, and the area covered with brood was visually summed [39]. The total brood population was calculated using the total area occupied by the brood and then converted into brood combs. Similarly, the comb areas occupied by pollen stores were also measured in the same way, and the hoarding ability was estimated.

2.4.2. Absconding Rate

Throughout the study period, the colonized hives were inspected internally every 21 days, and the number of absconded colonies for each hive treatment was recorded. The absconding rate was determined by calculating the percentage of absconded colonies in relation to the total number of colonies in each treatment group as follows [40].

$$AR = \frac{\text{Number of absconded hives per treatment}}{\text{Number of colonized hives in the treatment}} \times 100 \quad (1)$$

Where AR=Absconding rate

2.4.3. Honey Yield

Honey was only harvested from supers at the end of the nectar flow season, which typically occurs in November and/or June. Frames containing honey from each super were identified and weighed individually. After extraction, the weight of the frames was measured again to determine the net honey yield (in kg per colony). This was calculated by subtracting the weight of the frame without honey from the weight of the frame filled with honey.

2.5. Data Management and Statistical Analysis

The data collected were entered into Microsoft Excel 2010 and analyzed using SPSS version 20. A Student's T-test was used to compare the effects of different agroecologies on absconding and honey yield. The data on brood rearing, pollen storage, and honey production were analyzed using ANOVA over treatments. Turkey's Honest Significant Difference Test procedures were used to determine whether there were any significant differences between treatments. The 95% Confidence Interval is given in parentheses following the total or an average unless stated otherwise.

3. Results and Discussion

3.1. Brood Rearing Conditions

The results presented in Table 1 examined the impact of four different treatments on the number of brood combs reared by honeybee colonies. Treatment A involved providing colonies with a permanent hive shed and feeding them during the dearth period. Treatment B involved no hive shed but the provision of dearth period feeding. Treatment C involved a permanent hive shed but no dearth period feeding, while treatment D involved no hive shed and no dearth period feed provision. The results of the study indicated that colonies in treatment A had a significantly higher average number of brood combs reared compared to those in treatments B, C, and D at both study sites (Table 1). This difference was statistically significant ($p<0.001$). The study also found that colonies under treatment A demonstrated a significantly larger area of worker-sealed brood during active seasons when compared to colonies under treatment D. The observed difference in brood production ranged from 340.91% for Bako during Mar-May to 380.95% for Gedo during Sept-Nov, indicating that colonies under treatment A were able to rear 3.5 to nearly 4 times more brood than colonies under treatment D, regardless of the agroecology. This highlights the efficacy of treatment A in promoting brood production during active seasons, which is important for colony growth and survival.

Table 1. Effects of different treatments on brood rearing of honeybee colonies across different seasons at the two study locations.

Locations	Seasons	Mean No of Brood combs per treatment			
		A	B	C	D
Gedo	Sept-Nov	4.04 ± 1.02^{aA}	2.69 ± 1.00^{aB}	2.72 ± 0.73^{aB}	0.84 ± 0.41^{aC}
	Dec- Feb	1.98 ± 0.63^{bA}	1.47 ± 0.72^{bB}	1.46 ± 0.56^{bB}	0.78 ± 0.33^{aC}
	Mar-May	3.90 ± 1.01^{aA}	2.61 ± 0.80^{aB}	2.67 ± 0.77^{aB}	0.82 ± 0.42^{aC}

Locations	Seasons	Mean No of Brood combs per treatment			
		A	B	C	D
Bako	June-Aug	1.95±0.86^{bA}	1.52±0.81^{bB}	1.55±0.39^{bB}	0.75±0.36^{aC}
	Sept-Nov	4.07±1.27^{aA}	2.85±0.91^{aB}	2.81±0.67^{aB}	0.85±0.47^{aC}
	Dec- Feb	2.04±0.57^{bA}	1.48±0.74^{bB}	1.49±0.65^{bB}	0.83±0.31^{aC}
	Mar-May	3.88±1.16^{aA}	2.64±0.78^{aB}	2.69±0.86^{aB}	0.88±0.64^{aC}
	June-Aug	2.07±0.77^{bA}	1.44±0.69^{bB}	1.43±0.38^{bB}	0.79±0.27^{aC}

Mean and standard deviation (SD) of brood combs per treatment. Within a column, means followed by different lower case letters indicate significant differences among the seasons, while within a row, means followed by different upper case letters show significant differences among the treatments.

In addition, colonies in treatment A produced 145.78% to 162.03% more brood during dearth periods (December-February and June-August) than colonies in treatment D. This suggests that treatment A is more effective in enabling colonies to rear brood even during periods of reduced nectar flow, which is critical for colony survival. Moreover, the mean number of brood combs reared in colonies under treatments A, B, and C during active seasons was almost double the number of brood combs reared during the two dearth periods. This indicates that colonies under treatments A, B, and C were able to increase their brood production during active seasons, which is essential for colony growth and development. The result emphasizes the importance of seasonal variations in nectar flow and highlights the necessity for beekeepers to adjust their brood management strategies accordingly.

Numerous studies have highlighted the significant influence of temperature on brood development in honeybees [41-43]. Maintaining the optimal temperature for brood rearing is one of the most precisely regulated factors within a honeybee colony, as it directly impacts the growth and survival of larvae [44]. Typically, honeybees keep the brood nest temperature within a narrow range of 33–36°C to create ideal conditions for brood development [45, 46]. This temperature range is crucial for the proper development of honeybee brood, which is the future generation of workers bees that will emerge from the hive. During the pupal stage, this temperature is kept even more precisely at 35±0.5°C to ensure proper growth and maturation [42, 47]. Such precision in temperature regulation supports vital metabolic processes, enzyme activity, and cellular functions in developing bees.

Brood development in honeybees is highly sensitive to temperature, prompting bees to devote substantial energy and time to maintaining optimal brood temperatures, especially under extreme environmental conditions. This increased energy demand can slow brood development and diminish overall colony performance. To regulate brood chamber temperature, honeybees utilize several thermoregulatory strategies, including endothermic heat generation and wing fanning for evaporative cooling [48]. However, these methods become less effective under extreme temperatures above 38°C or below - 6°C when the energy required for temperature regulation surpasses the colony's capacity. As a result, significant losses in worker bees can occur, weakening the colony and reducing its productivity.

Studies by [42, 50], among others, support these findings and highlight the critical influence of external temperature on brood development. Ensuring that brood temperature remains within the optimal range is critical for maintaining the colony's overall performance. Furthermore, colony strength can be influenced by various factors, including environmental conditions and specific treatments. For example, a current study showed that treatment A resulted in stronger colonies compared to other treatments. Previous research by [50-52] has similarly demonstrated that both colony strength and brood-rearing activities are significantly affected by environmental factors.

The successful development of honeybee brood is highly reliant on maintaining stable temperature and humidity levels within the hive [53]. Disruptions to these conditions can significantly compromise colony health and vitality. This study underscores the key factors influencing brood-rearing behavior, revealing that colonies exposed to persistent stress such as extreme temperatures or insufficient nutritional support during dearth periods demonstrated reduced brood-rearing activity. As a result, these colonies were weaker and less efficient in honey production. By recognizing and addressing these challenges, researchers and beekeepers can implement targeted strategies to strengthen colony resilience, enhance survival rates, and support the crucial ecological role of honeybees.

This result aligns with a previous study, which indicates that the overall strength of a colony, as well as its honey production capacity, is closely tied to the effectiveness of brood production [54-56]. The efficiency of this process is crucial because a strong brood population ensures a healthy workforce for tasks such as foraging, hive maintenance, and brood care, all of which contribute to the colony's ability to gather nectar and produce honey. However, brood production is influenced by a variety of biotic and abiotic factors, including food availability, climatic change, pesticides and disease prevalence [57]. Therefore, managing these factors effectively is essential to maintaining optimal brood production and strong colonies. The study revealed that there were no significant seasonal differences for treatment D across both study sites throughout the year. However, colonies under treatments A, B, and C exhibited increased brood rearing at the start of honeybee plant blooming, suggesting that food resource availability is crucial for brood production. Conversely, there was a rapid decline in brood rearing after the end of the active seasons, a trend that was consistent at both sites. In conclusion, the study emphasizes the critical role of proactive management practices in fostering the health and productivity of bee colonies. Ensuring healthy brood production, which is essential for maintaining colony strength, requires constant attention to various environmental and biological factors. By regulating temperature and humisity, beekeepers can prevent extreme conditions that might hinder brood development or weaken the colony. Similarly, a consistent and adequate food supply whether through natural foraging or supplemental feeding supports the nutritional needs of the colony, contributing to overall vitality and growth. Effective disease management, including monitoring for pests and pathogens, is also vital to prevent the spread of infections that could compromise colony health. By focusing on these key areas, beekeepers can create an optimal environment for their colonies to thrive, leading to strong, productive hives that are not only capable of sustaining themselves but also of producing high-quality honey. This integrated approach ensures that colonies are well-equipped to endure seasonal challenges and remain resilient in the face of environmental stressors. Ultimately, such proactive management practices are indispensable for the long-term success of beekeeping operations and the continued health of pollinator populations.

3.2. Pollen Storage Conditions

The results in Table 2 showed that colonies under treatment A stored significantly higher amount of pollen ($P<0.001$) compared to the other treatments at both study locations. The observed overall differences in pollen storing between treatment A and D for Bako and Gedo were 239.0% and 272.4%, respectively indicating that colonies under treatment A store 2.5 to 2.7 times more compared to D. The study also revealed that colonies in treatment A had a significantly higher average number of pollen combs than those in treatments B and C at both study sites (Table 2). This study also clearly indicated that colonies under treatments A stored more pollen during active seasons when compared to the amount stored during the dearth period at both locations (Table 2). But colonies under treatment B, C and D stored similar amount of pollen at Bako during both dearth and active seasons. Whereas colonies under treatment B and C stored significantly lower pollen during dearth season (December-February) compared to active season (September-November and March-May (Table 2).

Table 2. *Effects of different treatments on pollen storage of honeybee colonies across different seasons at the two study locations.*

Locations	seasons	Mean No of pollen combs per treatment			
		A	B	C	D
Gedo	Sept-Nov	1.89 ± 0.25^{aA}	0.88 ± 0.15^{aB}	0.85 ± 0.24^{abB}	0.44 ± 0.16^{aC}
	Dec- Feb	1.01 ± 0.19^{bA}	0.51 ± 0.13^{bB}	0.52 ± 0.16^{bB}	0.37 ± 0.14^{aC}
	Mar-May	1.86 ± 0.23^{aA}	0.85 ± 0.16^{aB}	0.92 ± 0.21^{aB}	0.46 ± 0.22^{aC}
	June-Aug	1.47 ± 0.24^{bA}	0.53 ± 0.18^{abB}	0.56 ± 0.23^{abB}	0.43 ± 0.17^{aC}
Bako	Sept-Nov	1.86 ± 0.22^{aA}	0.94 ± 0.25^{aB}	0.94 ± 0.30^{aB}	0.55 ± 0.23^{aC}
	Dec- Feb	1.19 ± 0.27^{bA}	0.57 ± 0.23^{aB}	0.58 ± 0.23^{aB}	0.38 ± 0.19^{aC}
	Mar-May	1.89 ± 0.21^{aA}	0.92 ± 0.24^{aB}	0.96 ± 0.29^{aB}	0.54 ± 0.21^{aC}
	June-Aug	1.23 ± 0.20^{bA}	0.54 ± 0.17^{aB}	0.55 ± 0.18^{aB}	0.35 ± 0.14^{aC}

Mean and standard error (SE) of pollen combs per treatment. Within a column, means followed by different lower-case letters indicate significant differences among the seasons, while within a row, means followed by different upper-case letters show significant differences among the treatments.

Honeybees, similar to other animals, engaged in foraging activities to obtain their food that provide the necessary nutrients for their growth, development, and reproduction. In the case of social insects like honeybees, foragers not only acquire food for them but also gather nutritional resources such as nectar and pollen for the other members of the hive [58, 59].

Pollen is the most important source of proteins for bees, especially in the larval stage [60, 61]. According to Scofield and Mattila [62] pollen-stressed larvae exhibit earlier, poorer foraging and dancing abilities, as well as lower mass and longevity as adults compared to normally fed larvae. Importantly, pollen is recognized as an essential bee product that is increasingly valued as a functional food due to its significant amount of bioactive ingredients such as proteins, dietary fibers, lipids, carbohydrates, and minerals, all of which are known to have numerous advantages for honeybee's mental and physical well-being [63]. The pollen foraging decision of honeybees are determined by several factors such as genotype, seasonal availability of resources, the amount of brood being reared in the colony and the quantity of pollen currently stored in the hive [64, 65]. In addition, brood pheromone stimulates forager honey bees' pollen-foraging behavior [60]. Several studies have found that pollen storage and quality in bee hives are highly dependent on seasonal resource availability [66, 67]. Indeed, the amount of pollen collected by honey bees varies seasonally, which may be related to different seasonal nutritional requirements in honey bees [66], which is consistent with our findings.

3.3. Absconding Rate

In beekeeping, absconding refers to the sudden departure of bees from their hive. It is a common and unfortunate occurrence for beekeepers as it can disrupt the productivity and profitability of their business. In Ethiopia, this is not only disappointing but also has a significant impact on the viability of the beekeeping industry and the spread of improved beekeeping practices. On the other hand, absconding can be viewed as an important survival strategy in tropical climates where year-round conditions are favorable for flowering and honey bee flight. The current study demonstrates the extent of absconding in colonies under various treatments. The data presented in Table 3 indicates that absconding occurred significantly higher and more frequently in colonies under treatment D as compared to the rest of the treatment groups.

Over the course of two years, it was recorded that the total absconding of 75.0% and 85.0% were recorded for Gedo and Bako, respectively. These figures were only 20.0% and were similar at both sites for treatment A. However, it is important to note that the magnitude of absconding was significantly higher in the first year than in the second year in all treatments, with no differences under both agroecologies. This higher absconding rate in the first year can be attributed to the fact that transferring colonies from place to place for establishment causes disturbance to the colonies. At least there was about 57.7% more absconding in the first year compared to the events of absconding in the second year at Gedo and 53.3% more absconding in the first year than in the second year at Bako. When we compare the magnitude of absconding events between treatments, it is observed that B and C were similar, with overall absconding of 60.00% and 55.00% over the two study years for Gedo, respectively, while this was 65.00% and 60.00% for the Bako study site, respectively. When absconding of colonies from all treatments the two studies combined and assessed, 26.25% of colonies absconded from the highland (Gedo) and 30.0% of colonies absconded from the midland (Bako). This study also found that the frequency of absconding events varied according to season. The absconding of colonies under all four treatments during the periods of forage scarcity, which were from December to February and June to August, was 66.7% higher than during the blooming seasons of the first year. In the second year, 85.2% of the absconding occurred during droughts (Table 3). When the dearth periods were compared, it was discovered that the months of June to August, which were the months of heavy rain in the areas, were when more absconding occurred in the highlands than the months of December to February, whereas the opposite was true in the midland Bako area. This could be explained by the fact that many colonies can abscond if rain drips into their nest, justifying the importance of using a beehive shed. Overall, during the two dearth periods (December to February and June to August) in the first year, 69.2% of Gedo and 80.0% of Bako absconded, with the balance occurring during the blooming seasons. The reason that colonies under treatments B and C were less affected than colonies under treatment D was that providing a beehive shed or feeding can help to limit the level of absconding.

Table 3. *Effects of different treatments on colony absconding rate under highland (Gedo) and midland (Bako) agro ecologies in four seasons.*

Locations	**Years**	**Seasons**	**Mean absconding (%) per Treatment**			
			A	**B**	**C**	**D**
		Sept to Nov	0.00	5.00	5.00	5.00
		Dec to Feb	0.00	10.00	5.00	15.00
Gedo	2016/17	March to May	0.00	5.00	10.00	10.00
		June to Aug	10.00	20.00	15.00	20.00
		Annual Sum	10.00	40.00	35.00	50.00

Locations	Years	Seasons	Mean absconding (%) per Treatment			
			A	B	C	D
		Sept to Nov	0.00	0.00	5.00	0.00
		Dec to Feb	5.00	5.00	5.00	5.00
	2017/18	March to May	0.00	0.00	0.00	5.00
		June to Aug	5.00	15.00	10.00	15.00
		Annual Sum	10.00	20.00	20.00	25.00
		Sept to Nov	0.00	0.00	5.00	10.00
		Dec to Feb	15.00	20.00	25.00	30.00
	2016/17	March to May	0.00	10.00	0.00	5.00
		June to Aug	0.00	10.00	10.00	10.00
		Annual Sum	15.00	40.00	40.00	55.00
Bako		Sept to Nov	0.00	0.00	5.00	10.00
		Dec to Feb	15.00	20.00	25.00	30.00
	2017/18	March to May	0.00	10.00	0.00	5.00
		June to Aug	0.00	10.00	10.00	10.00
		Annual Sum	15.00	40.00	40.00	55.00

The values represent the mean percentage of absconded colonies per treatment during the second and third years (n=20 observation colonies)

Furthermore, the current study discovered that agroecology was not a significant factor in absconding, with only minor differences between the two agroecologies observed. Several reports show that a colony can abscond due to different factors such as invasion of the colony by aggressive pests (small hive beetles, ants, wax moths), poor physical conditions such as entry of water into the hive, and excessively high temperatures due to lack of beehive shed, and none of these factors can be considered as a single major factor for absconding in different regions [37, 54, 68-71]. The study also found that colonies under treatment D were observed to be attacked by different pests, and the situation was worse during the dearth periods. According to some survey reports, pests attack up to 100% of bee colonies in some areas of Ethiopia, with the majority of damage occurring during the rainy season and hot months of the year [72, 73]. This study also indicate that pests typically appear after the colony has absconded and destroyed the combs, but there are some exceptions, particularly in colonies under treatment D, where pest pressure was well recognized before the colonies absconded from the hives. As a result, food availability and pests may limit colony development, eventually leading to absconding.

According to Hepburn et al. [69] and Pokhrel et al. [37], bees in tropical areas may abscond to find better food sources or to avoid predators, parasites, or diseases. Furthermore, honeybees' adaptation to their environment can be conveyed by the colony's annual development pattern, food source balance, and host-parasite balance, all of which interact with changes in the environment [74]. Seasonal absconding has also been observed in other regions of tropical Africa, often linked to changes in colony size and composition resulting from a decrease in vegetation flowering [70]. However, with honey reserves or supplemental feeding provided to the colony, brood rearing can continue, and the likelihood of absconding will be minimized. Hatjina et al. [75] also discovered that the timing of colony development is strongly linked to the availability of food sources, whereas the balance between the colony and the host-parasite is determined by a number of factors, including the environment, climate, and beekeeping practices. Understanding the factors that contribute to absconding and other beekeeping challenges is critical for the sector success and honey bee population conservation. Thus, by implementing effective beekeeping practices and promoting sustainable agriculture, we can contribute to the long-term viability of beekeeping as well as the valuable ecosystem services provided by honeybees. These findings are significant as they provide insight into the factors that contribute to absconding in colonies under different treatments and agroecologies. Therefore, it is important to consider these factors when working with honeybee colonies to ensure their well-being and productivity.

3.4. Honey Yield

In the current study, the honey yield per colony revealed that the type of treatment administered had a significant impact on the yield. The results showed that colonies under treatment A produced a significantly higher amount of honey compared to those under treatment D in both Gedo and Bako apiary sites. Specifically, a colony under treatment A produced up to 252.9% and 252.1% more honey than a colony under treatment D in Gedo and Bako, respectively. This means that a colony under treatment A produced more than 2.5 times the amount of honey produced by a colony under treatment D (Figure 2). The statistical analysis of the results showed that the difference in honey yield was highly significant ($p<0.001$). These results indicate that treatment A is more effective than treatment D in enhancing honey production per colony.

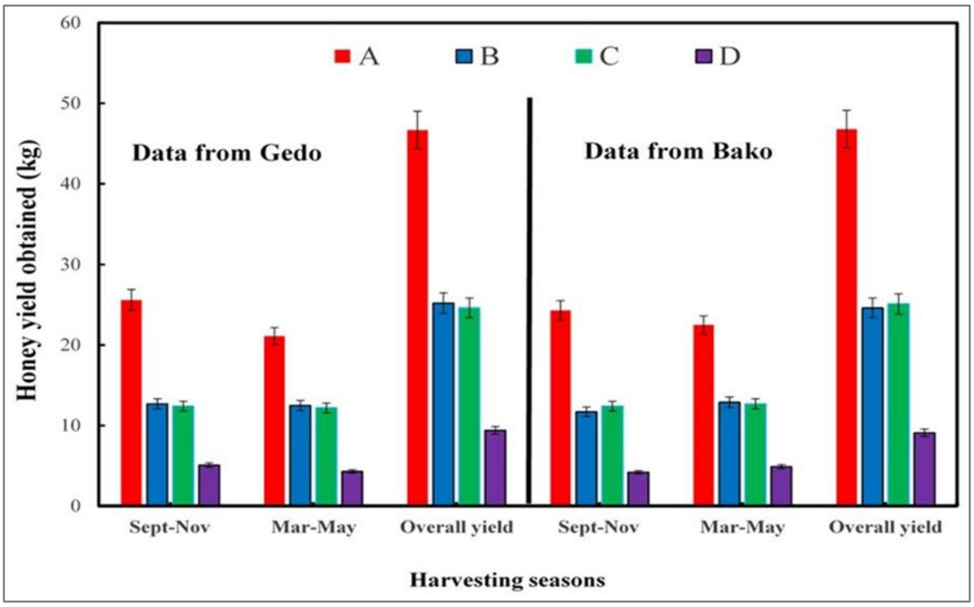

Figure 2. *Effect of different treatments on annual honey yield at Gedo and Bako apiary sites.*

The results of several studies have consistently shown that larger bee colonies produce more honey than smaller colonies [50-52, 55, 68, and 76]. This has been confirmed by a current study, which found that when comparing the total honey production of ten colonies treated with treatment D to that of a colony under treatment A, the amount of honey obtained was 350% higher. The difference in honey yield between treatments can be attributed to the higher rate of worker brood rearing in treatment A compared to treatment D. This increases the number of forager bees that can collect nectar from various sources, resulting in a larger overall honey production. This is further supported by Table 1, which demonstrate the correlation between the amount of brood and the number of foragers.

Furthermore, this study shows that the honey yield in treatments B, C, and D is significantly lower than in treatment A, implying that colonies with higher brood production efficiency and worker population can store more honey [52, 68]. A number of factors influence a colony's success in the world of beekeeping. One of the most important factors is the colony's population size and how it interacts with the surrounding environment. The amount of nectar collected and the amount of honey that can be stored for consumption are determined by the colony's interactions with its environment. It is important to note that colony productivity, which refers to honey yield and annual feed balance, is closely related to the adult bee population force and the colony's annual cycle. This means that the ability of a colony to use available floral resources is proportional to the size of its adult bee population and the timing of the annual cycle. The productivity of a honeybee colony is closely tied to both the size of its adult bee population and the quality of the environment around it [75]. This implies that a colony will be more productive if it is close to a significant amount of floral resources. The study also revealed that the beekeeper's management practices play a significant role in the colony's productivity. For instance, implementing a proper feeding schedule during periods of inadequate nectar flow can greatly increase a colony's productivity. Thus, the findings of this study suggest that beekeepers should prioritize the establishment of strong colonies in order to maximize honey production.

4. Conclusion

The study found significant variations in brood-rearing, pollen storage, absconding rate, and honey yield across treatments and seasons at both study sites. However, there were no significant differences in absconding rate and honey yield between the two agro-ecologies. Providing beehive shade and supplementing feed was found to significantly improve honeybee colony productivity in the two Ethiopian agro-ecologies. The study highlights the importance of supplementary feeding during dearth periods and the use of permanent beehive sheds to address low productivity and high colony absconding rates. Further research and surveillance are recommended to identify other factors that may influence the production and productivity of local honeybee colonies.

Abbreviations

ANOVA	Analysis of Variance
AR	Absconding Rate
CRD	Complete Randomized Design
EIAR	Ethiopian Institute of Agricultural Research
SD	Standard Deviation
SE	Standard Error

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Author Contributions

Tolera Kumsa Gemeda, Kibebew Wakjira Hora designed the study, and development of the protocols, Taye Negera Iticha and Shimu Debela Lema data collection, and execution of the experiments. Tadele Alemu Hunde and Shimu Debela Lema were involved in the interpretation of the data, drafting of the manuscript, and the subsequent revision and editing processes until the final version was approved by all authors.

Conflicts of Interest

The authors declare no conflicts of interest.

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