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Research Article

A Comparative Study of the Impact of Avocado, Sunflower, and Courgette on Bee Productivity in Rwanda: A Case Study of Burera District

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Abstract

Bees are vital insects in agricultural production systems. In addition to crop pollination, bees produce honey, a valuable food commodity. Bees' attraction to plants differs according to species and plant morphology. The objective of this study was to compare the effects of Avocado, sunflower, and courgette crops on bee foraging behaviour, nectar collection efficiency, and honey production. The research focused on the Gatebe Sector, Rwambogo Cell, Murambo Village, characterized by its temperate climate and rich agricultural landscape. Bee visitation rates were measured at different times of the day, while honey production was tracked in colonies near the crops. The diversity of bee species visiting each crop was assessed using the Shannon-Wiener Index. The results revealed that sunflowers attracted the highest number of bees, particularly during midday, followed by avocado and courgette. Nectar collection efficiency and total honey yield were highest in sunflower, with peak activity from 12:00 p.m. to 4:00 p.m. Avocado showed moderate bee visitation and honey production, with a narrow peak period from 10:00 a.m. to 2:00 p.m. Courgette produced less honey, with a peak nectar collection period from 9:00 a.m. to 12:00 p.m. In terms of bee species diversity, sunflower exhibited the greatest richness, followed by avocado and courgette. Sunflower consistently yielded the highest total honey (14.5 kg), followed by avocado (11.5 kg) and courgette (8.0 kg). Sunflower attracted the highest species diversity, followed by Avocado while courgettes had the lowest diversity, with only 4 species. The findings suggest that sunflower cultivation in home gardens enhances bee productivity and supports a diverse pollinator community, making it an optimal choice for boosting both honey production and pollinator health. The study underscores the importance of selecting appropriate crops to optimize bee activity and improve agricultural sustainability in smallholder farming systems.

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Keywords

Bees' Pollination, Biodiversity, Crop Yields, Honey Production, Burera District

1. Introduction

Bees play a crucial role in pollination, which is essential for the reproduction of many crops and the production of honey and other bee-related products [18, 5]. Rwanda, an agricultural country with diverse crops, is increasingly looking for ways to boost bee productivity to improve crop yields and honey production. Home gardens, which combine different plant species, offer a unique environment to assess the impact of various crops on bee behavior and productivity [14].

Avocado (*Persea americana*), sunflower (*Helianthus annuus*), and courgette (*Cucurbita pepo*) are commonly cultivated in home gardens in Rwanda. These crops are not only important for their direct agricultural benefits but also for their potential role in supporting bee populations through floral resources [2, 17, 6]. This study investigates the influence of these three crops on bee productivity in Burera District, located in the northern region of Rwanda, with a focus on bee visitation rates and honey production.

Bees are key pollinators for a wide range of crops, including those grown in home gardens. Research has shown that effective pollination can increase crop yield by up to 50%, especially for crops like courgette and sunflower [8-10].

Avocado is known to have specialized flowering patterns that depend on bee pollination. Studies suggest that bees, particularly stingless bees, are crucial for maximizing avocado yields [19]. Sunflower is highly attractive to bees due to their large, brightly colored flowers and high nectar production. Studies indicate that sunflowers can support bee populations by providing abundant forage resources. Courgette (zucchini) also benefits significantly from bee pollination. Courgettes are often pollinated by a range of bee species, including honeybees and wild bees, which affect fruit set and quality [11].

Bee foraging behavior is influenced by various factors, including temperature, flower availability, and time of day. Typically, bees are more active during the warmer parts of the day, with peak nectar collection times being between 10 a.m. and 4 p.m. [23]. The study will also look at seasonal patterns of bees foraging within a year.

Rwanda has a favorable climate for beekeeping, with numerous floral resources available throughout the year. However, the relationship between crop diversity and bee productivity in local gardens remains underexplored. While the significance of pollinators, especially bees, in agricultural productivity is well-established, there is limited empirical research on the specific effects of different crops on bee activity in Rwanda. In Burera District, home gardens are a central part of subsistence farming, yet little is known about how crops such as avocado, sunflower, and courgette affect bee populations and productivity. This knowledge gap hinders the development of strategies to improve pollinator health and optimize crop yields in these gardens. The study aims to fill this gap by comparing the effects of these three crops on bee productivity.

2. Objectives

The overall objective of this study was to evaluate the comparative impact of avocado (*Persea americana)*, sunflower (*Helianthus annuus*), and courgette (*Cucurbita pepo*) on bee productivity in home gardens in Burera District, Rwanda. The specific objectives were to assess the rate of bee visitation to flowers of avocado, sunflower, and courgette in Burera home gardens; to assess the bee foraging behavior and the best time for nectar collection from these three crops; to compare the honey production from bee colonies kept in proximity to these three crops; and to determine the species composition of bees attracted to each crop type.

3. Methodology

3.1. Study Area Description

The study was conducted in the Burera District, located in the Northern Province of Rwanda, a region characterized by fertile volcanic soils and a favorable climate for agricultural activities. Burera is known for its rich biodiversity, including an abundance of crops, livestock, and diverse ecological landscapes. The area is heavily dependent on smallholder farming, and home gardens play a crucial role in local food security and livelihood [3].

3.1.1. Geographical Location

The research was specifically carried out in Gatebe Sector, Rwambogo Cell, and Murambo Village, situated in the western part of the Burera District. This area is approximately 2,000 meters above sea level, and it experiences a temperate climate with a mix of dry and rainy seasons [15]. The average annual rainfall in this region is about 1,400 mm, with a temperature range of 18 ℃ to 25 ℃, making it suitable for

both highland and lowland crop cultivation [21].

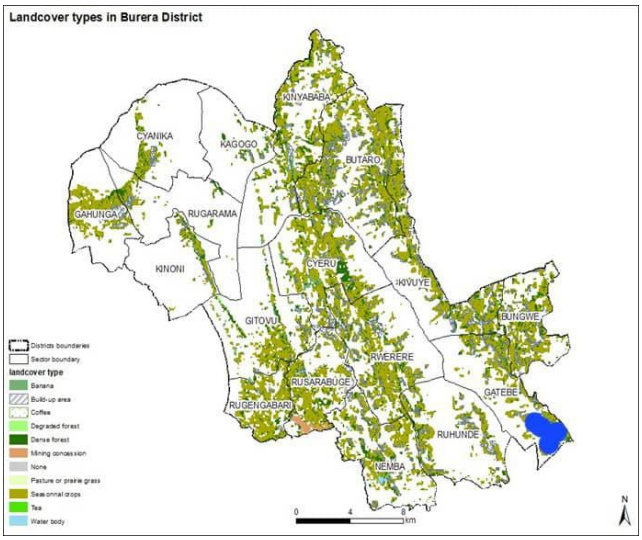

Figure 1. *Map of Burera-Gatebe Sector location.*

3.1.2. Agricultural Practices

Agriculture in this area is primarily subsistence-based, with families growing a variety of crops for food and income. Common crops include beans, maize, peas, Irish potatoes, sweet potatoes, bananas, and vegetables. Additionally, fruit trees such as avocados, tamarillo, and bananas are widely cultivated for consumption and trade [15, 16]. Sunflower and courgette (zucchini) are also increasingly popular due to their potential for enhancing local diets and providing income to smallholder farmers. These crops are grown in a mixed cropping system in the home garden setting, which is practiced by local households to meet their daily food and financial needs.

3.1.3. Flora and Fauna

Murambo Village is located in a rich ecological zone, where a variety of flowering plants coexist. The region's flora includes both native and introduced plant species. The climate supports the growth of plants that are ideal for nectar and pollen production, making the area an excellent environment for bee populations [7]. The village is home to a variety of native bee species, including Apis mellifera (the European honeybee), which is the focus of this study. Additionally, the presence of other pollinators, such as butterflies, birds, and wild bees, contributes to the ecological balance and biodiversity of the area [13].

3.2. Experimental Design

The study focused on three key crops, namely avocado, sunflower, and courgette, which are commonly grown in Burera home gardens. The study was carried out during the flowering seasons of each crop.

3.3. Sampling Techniques

A set of flowers from each crop (avocado, sunflower, courgette) was randomly selected for observation. Observations were made at regular intervals (i.e., morning, midday, and afternoon) to account for different activity levels. Bee visitation rates were recorded based on the number of bees visiting each flower within a specified period.

Bee colonies located near the crops were monitored for honey production over the study period. The weight of honey produced by colonies was recorded at regular intervals (bi-weekly) using standardized honey harvesting techniques. Collected bees were identified by species, and a species richness index was calculated for each crop.

3.4. Data Analysis

Descriptive statistics (mean, standard deviation) will be used to summarize bee visitation rates and honey production. ANOVA will be conducted to compare the means of bee visitation and honey production across the three crops. It was also to determine the significant differences in bee activity, nectar collection, and honey production across the three plant species. However, bee species diversity will be assessed using the Shannon-Wiener Index.

4. Results and Discussions

4.1. Results

Sunflower experienced the highest bee visitation across all periods, with a total of 350 visits (Table 1). The peak bee visitation was during midday (150 bees per 100 flowers), which aligns with typical bee activity patterns. Bees tend to be most active during the warmer parts of the day when flowers are fully open and nectar availability is at its peak.

Avocado showed moderate bee visitation, with 83 visits in total. There was little variation across the periods, indicating that bees are consistently visiting these flowers throughout the day, with a slight peak during midday (30 bees per 100 flowers). This may suggest that avocado flowers have a steady but lower attraction to bees. This may be due to the flowers' unique morphology (small, clustered flowers) or nectar availability, which could influence visitation rates.

The courgette crop had the lowest bee visitation, with a total of 53 visits. The visitation rate is quite low across all periods, but it is notably steady throughout the day. This could indicate that courgette either do not attract bees as much as the other crops or that their flowers are less rewarding in terms of nectar and pollen. Another possibility is that courgette may be pollinated more by other means, such as wind or other insects, rather than bees.

Table 1. *Bee visitation rate for each crop.*

Bees Visited				
Crop	**Morning (7-9 AM)**	**Midday (12-2 PM)**	**Afternoon (3-5 PM)**	**Overall total**
Avocado	25	30	28	83
Sunflower	100	150	80	350
Courgette	15	20	18	53

During the morning, bees visited all three crops, with the lowest visitation rates for sunflower and courgette compared to midday and afternoon. This could reflect a delay in bee activity as they start their foraging, or it could be related to lower temperatures or limited nectar availability in the early morning. However, the visitation rate for avocados in the morning is relatively steady, suggesting that their flowers may be more consistently accessible or attractive during this time.

The midday period saw the highest overall visitation rates for sunflower and avocado crops. This is the period when bees are likely most active due to warmer temperatures and optimal floral conditions. Sunflower, in particular, had a large number of bees visiting (150 bees per 100 flowers). This may be due to maximal nectar availability and flower openness. Avocado experienced moderate peak bee visitation (30 bees per 100 flowers), consistent with the expected activity patterns of bees during this time.

In the afternoon, the visitation rate for sunflower dropped but remained high compared to the other crops (80 bees per 100 flowers). This may be due to a decrease in nectar availability with a change in environmental factors such as temperature and wind. Bee visitation in Avocado remained consistent throughout the day. Courgette had a consistent but low visitation rate with little fluctuation throughout the day. This reinforces the notion that courgette may not be as attractive to bees as the other crops.

Nectar collection:

The best time for bee nectar collection depends on various factors, such as plant species, bee activity, and environmental conditions (Table 2).

Table 2. *Best time for bee nectar collection.*

plant species	The average number of bees visiting per hour	Peak time for nectar collection	Total honey yield (kg)
Avocado	25	10:00 a.m - 2:00 p.m.	8.5
Sunflower	110	12:00 p.m - 4:00 p.m.	20.5
Courgette	15	9:00 a.m - 12:00 p.m.	4.8

Avocado trees had a moderate level of bee visitation, with about 25 bees per hour. The peak nectar collection time for avocados is relatively narrow, from 10:00 a.m. to 2:00 p.m., indicating that bees are most active during the late morning and early afternoon. During this time, avocado flowers likely offer the best nectar availability, attracting bees more consistently. However, the total honey yield of 8.5 kg suggests that while bees visit throughout the day, the overall nectar production is moderate compared to sunflower.

In terms of maximizing nectar collection, 10:00 a.m. - 2:00 p.m. is the ideal window, as bees are most effective during this period. This also correlates with optimal environmental conditions such as moderate temperatures and abundant sunlight, which may enhance nectar flow.

Sunflower is highly attractive to bees, with 110 bees visiting per hour, which was the highest among the three test crops. The peak time for nectar collection for sunflower was from 12:00 p.m. to 4:00 p.m., a late-day window compared to avocado and courgette. This timing suggests that sunflower provide an abundant nectar source during the afternoon when bees are actively foraging.

The total honey yield of 20.5 kg was the highest among the three crops, which reflects both the volume of bees visiting and the quantity of nectar produced by the sunflower. This makes sunflower an excellent choice for beekeepers who want to maximize honey production. The peak nectar

availability aligns with the warmest part of the day, which may enhance the overall nectar flow.

Courgette (zucchini) attracted fewer bees than both avocado and sunflower, with only 15 bees visiting per hour. The peak nectar collection time was during the early morning to late morning (9:00 a.m. - 12:00 p.m.), which was a shorter window than in sunflower and avocado. This suggests that courgette may have a relatively short period of peak nectar availability, after which the nectar may be depleted or less accessible to bees.

With a total honey yield of 4.8 kg, courgette produce significantly less honey compared to sunflower or avocado, indicating that although bees visit them, the nectar supply is not as abundant or long-lasting. Nonetheless, courgette is still beneficial for supporting bee populations, especially in the morning hours.

Table 3. *Honey production (kg) per bee colony per month.*

Crop	Month 1	Month 2	Month 3	Total Honey (Kg)
Avocado	3.5	4.2	3.8	11.5
Sunflower	4.8	5.2	4.5	14.5
Courgette	2.2	3.0	2.8	8.0

The results in Table 3 indicated that avocado trees tend to bloom at specific times, and their flowers provide a relatively steady nectar flow, which is reflected in the gradual increase in honey production from Month 1 to Month 2. The slight dip in Month 3 could indicate a reduction in flowering intensity as the season progresses, or other environmental factors may have limited nectar availability. Generally, avocado trees flower between late winter and spring, so their flowering period aligns well with the honey production trend seen here. The production peaks in Month 2, which could coincide with peak flowering and nectar availability from avocado blossoms.

Sunflowers are known for their abundant nectar production, especially in their peak blooming period. The steady increase in honey production from Month 1 to Month 2 suggests that the sunflower blooms were in full swing during this time, offering a high quantity of nectar to the bees. The slight drop in Month 3 might indicate that the flowers are beginning to wane, or the bloom period has passed. However, sunflowers usually produce a lot of nectar, which is why the total honey yield (14.5kg) remains the highest across the three crops. The peak production in Month 2 aligns with the common peak bloom period of sunflowers.

Courgette (zucchini) flowers provide a moderate amount of nectar. While their flowers tend to bloom over a prolonged period, they don't produce as much nectar as sunflowers or avocados, which is reflected in the lower honey production. The gradual increase in honey production from Month 1 to Month 2 could suggest a peak in the blooming of courgette flowers, but as the crop matures, there may be a decline in nectar availability, which results in a slight dip in Month. Overall, the courgette crop is less productive in terms of honey yield compared to sunflower and avocado, which could be due to smaller or less intense flower blooms or a more limited nectar flow.

Species diversity:

The diversity of bee species that visit crops plays a crucial role in pollination services, which directly influence crop yield and quality (Table 4). The Shannon-Wiener Index (H') is a widely used metric to quantify biodiversity, considering both the richness (number of species) and evenness (distribution of individuals across species).

Avocado had 5 bee species observed, which indicates a moderate level of species richness for this crop. An H' value of 1.62 suggests a moderate level of biodiversity. This value reflects a balance between species richness and evenness. The index is not high, meaning that while there are some species present, their populations are not extremely diverse or evenly distributed.

The moderate diversity of bees in avocado may reflect the specific floral and environmental conditions necessary for avocado trees, which may not attract as many species as in more open crops. Avocado is typically grown in subtropical and tropical environments, and specific bee species might be better suited for pollination in these regions. However, further studies into the evenness of the species would provide additional information on how pollination occurs.

Sunflower attracted 8 bee species, which is relatively high compared to avocado and courgette. Sunflower is known for its bright, attractive flowers, which are particularly appealing to bees, especially honeybees and bumblebees. With an H' value of 2.15, sunflower had the highest bee species diversity. The high index reflects both higher species richness and a relatively even distribution of individual bees across those species. The sunflower's large, easily accessible blooms may support a large variety of bee species, providing more options for foraging.

The relatively high diversity of bees in sunflower suggests that this crop attracts a broad range of bee species. This diversity could enhance the crop's pollination success, as different bee species might pollinate at different times of day or under varying environmental conditions. Furthermore, greater species diversity in pollination could increase overall pollination efficiency and reduce dependence on a single bee species, which is beneficial for both crop yield and ecosystem stability.

Courgette (zucchini) had the fewest bee species, with only 4 species observed. This relatively low species richness may indicate that fewer bee species are specialized or attracted to courgette flowers, which are typically smaller and more open. The H' value of 1.47 suggests low biodiversity, and it was the lowest of the three test crops. This could imply that while a

small number of bee species visit courgette, their populations are small and not well-distributed.

Table 4. *Bee species diversity for each crop.*

Crop	Total species observed	Shannon-Wiener Index (H')
Avocado	5	1.62
Sunflower	8	2.15
Courgette	4	1.47

The relatively low diversity of bee species visiting courgette could reflect the crop's specific floral characteristics or its growing environment. Courgette has a simple flower structure that might not be as attractive to a wide variety of bees compared to the other crops. Additionally, courgette is often grown under warm conditions, which could limit the diversity of bee species active during that period. However, this could also be a sign that the pollination system for courgette may be more dependent on a few species, which could make the crop more vulnerable if those species decline in numbers.

4.2. Discussions

Sunflowers had the highest bee visitation rate, followed by avocado and courgette. This may be due to the larger floral display and greater nectar availability in sunflowers. Avocado flowers, with their complex structure, attracted fewer bees, which may limit their overall contribution to bee productivity in home gardens.

These results have been supported by Smith *et al.*, [22], who showed that avocado trees produce copious amounts of nectar and are known to attract a wide range of pollinators, including bees. Studies have shown that bees are particularly attracted to avocado flowers, which provide both nectar and pollen [20]. The interaction between bees and avocado flowers may vary seasonally, which influences the timing of nectar collection and honey production [4].

Sunflower is a significant source of nectar and pollen for bees, especially in temperate climates [10]. Sunflower fields are often visited by large numbers of honeybees, contributing to increased hive productivity and the diversity of pollens collected by bees. The foraging behavior of bees on sunflowers depends on flower density, environmental conditions, and flower morphology [12].

Courgette is widely cultivated for its edible fruits, and it's an important pollinator attractant. These plants produce substantial amounts of nectar, and bees are the primary pollinators for courgettes [10]. The timing and frequency of bee visits to courgette flowers are affected by plant maturity and flower availability [1].

Bee colonies near sunflowers produced the most honey, which is consistent with the high bee visitation rate for this crop. Avocado trees also supported moderate honey production, while courgettes, despite being attractive to bees, contributed less to honey yields. Sunflower fields supported the highest bee species diversity, which may reflect sunflowers' broad appeal to various pollinator species. The lower species diversity on courgette plants suggests that fewer bee species are specialized in pollination.

5. Conclusion and Recommendations

Sunflower emerged as the most attractive crop for bees, with high visitation rates and honey yield, especially during the afternoon hours. This is supported by the high bee species diversity observed on sunflower plants, which contributes to the overall effectiveness of pollination. Avocado, while attracting fewer bees than sunflower, still offers moderate honey yields, with a relatively stable bee visitation throughout the day. In contrast, courgette is the least attractive to bees, with low visitation and low honey production.

Recommendations:

1. Sunflower should be prioritized as a key crop for beekeepers looking to maximize honey production. Incorporating sunflower fields near hives could significantly boost both pollination efficiency and honey yield.
2. This one you have already indicated in the introduction that farmers practice mixed cropping.Farmers and beekeepers may want to plant courgette in combination with other more bee-attractive crops to enhance pollination services.
3. Research on the temporal dynamics of nectar flow and its correlation with bee activity could help optimize foraging strategies for both wild and managed bee populations.
4. Efforts to conserve biodiversity should focus on supporting habitats with a variety of flowering plants that provide high nectar yields and attract multiple bee species.

Abbreviations

ANOVA	Analysis of Variance
IPRC	Integrated Polytechnic Regional College
JKUAT	Jomo Kenyatta University of Agriculture and Technology
KG	Kilogram
NISR	National Institute of Statistics of Rwanda
RAB	Rwanda Agricultural and Animal Resources Development Board
RMA	Rwanda Meteorology Agency

Conflicts of Interest

The authors here declare that there is no conflict of interest in the publication of this article.

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