

Effects of Goat Browsing Intensity on Preferred Forage Plant Species and Subsequent Honey Bee Visitation

Atana Ekuwom James*,  Kitilit Kibet Jackson and Rachuonyo Anindo Harold

School of Agriculture and Biotechnology, University of Eldoret,
P.O. Box 1125-30100, Eldoret, Kenya

Abstract

In African dryland ecosystems, livestock and pollinators often depend on the same woody vegetation resources, creating important ecological links between herbivory and pollination services. Small East African goats rely heavily on browse plants for nutrition, while honey bees (*Apis mellifera*) depend on flowering plants for nectar and pollen. However, the extent to which goat browsing influences shared plant resources and subsequent honey bee visitation remains poorly understood, particularly in semi-arid rangelands of East Africa. This study assessed variation in plant utilization by Small East African goats and honey bees and examined factors influencing honey bee visitation in Loima Sub-County, Turkana County, Kenya. Vegetation surveys were conducted during wet and dry seasons across pastoral landscapes with evidence of goat browsing. Plant species composition, browsing utilization, flowering intensity and honey bee visitation were recorded within sampling plots. Goat use was assessed based on observed browsing signs, while honey bee visitation was measured through standardized observations of flowering plants. Differences in bee visitation among plant species, seasons, flowering levels and browsing conditions were analysed using multivariate analysis and analysis of variance. Plant species significantly influenced honey bee visitation patterns (Pillai's Trace = 0.664, $p < 0.001$), with visitation concentrated on a small number of flowering woody species. The highest visitation rates were recorded on *Prosopis juliflora*, *Ziziphus mauritiana*, *Maerua subcordata* and *Cadaba rotundifolia*. Honey bee activity was significantly higher during the wet season (17.37 ± 7.36 visits per 30 minutes) compared with the dry season (8.72 ± 6.02 visits per 30 minutes; $p < 0.001$). Flowering intensity was the strongest predictor of visitation, increasing from very low to very high flowering categories ($p < 0.001$). Significant differences were also observed among browsing duration categories ($F = 6.62$, $p < 0.001$), indicating that variation in plant utilization was associated with changes in bee visitation patterns. In conclusion, the findings demonstrate that woody plant species provide an important ecological connection between Small East African goats and honey bees in semi-arid

landscapes. Honey bee activity was primarily regulated by seasonal flowering dynamics and plant resource availability, while goat browsing influenced the condition and availability of shared vegetation resources. Conservation and sustainable management of key browse and flowering species are therefore essential for maintaining both pastoral production and pollination services in dryland ecosystems.

Keywords: Small East African goat; browsing intensity; honey bees; *Apis mellifera*; browse plants; pollination services; dryland ecosystems; Turkana

Correspondence: atanajames2015.aj@gmail.com

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Introduction

Livestock production and apiculture remain among the most important livelihood-based enterprises in many parts of the world, particularly in regions where communities depend on natural resources for survival and economic security. Livestock contributes not only through the supply of meat, milk, hides, fibre and manure but also by acting as a form of household wealth and resilience against environmental uncertainty (Baltenweck et al., 2020; Herrero et al., 2021). In rangeland ecosystems, livestock are also important ecological agents because their feeding activities influence vegetation composition, nutrient cycling and landscape structure. However, increasing livestock numbers, recurrent droughts and changing land-use patterns have raised concerns about maintaining a balance between livestock production and the conservation of ecosystem

functions. Apiculture represents another important nature-based enterprise that links rural livelihoods with ecosystem processes. Honey bees (*Apis mellifera*) contribute to agricultural production and natural ecosystem functioning through their role as pollinators of both cultivated and wild plants. Pollination supports crop production, maintains plant diversity and strengthens ecological interactions within terrestrial ecosystems (Klein et al., 2007; Potts et al., 2016). In addition to these ecological services, beekeeping provides income through honey, beeswax and other hive products, making it an important livelihood option, especially in dryland regions where agricultural opportunities are often limited (Amulen et al., 2017).

Despite being commonly studied as separate activities, livestock production and apiculture are closely connected through their dependence on

plant resources. In dryland ecosystems, the same woody plants that provide browse for livestock often supply nectar and pollen required by honey bees. Therefore, changes in vegetation structure and plant composition caused by herbivory may influence both livestock nutrition and pollinator resources. The effects of browsing are particularly important because they can alter plant abundance, regeneration, flowering patterns and the availability of floral resources used by honey bees (Klein et al., 2007; Dicks et al., 2021). Understanding these relationships is increasingly important in arid and semi-arid ecosystems, where limited vegetation resources are shared among livestock, wildlife and pollinators.

Across Africa, extensive rangelands support millions of pastoral and agro-pastoral households, with livestock production forming the basis of food security, income generation and cultural identity (Mutai, 2022). Among livestock species, goats are especially important in dryland areas because of their ability to withstand harsh environmental conditions, including drought, high temperatures and seasonal shortages of forage (Peacock & Sherman, 2019). Their browsing behaviour allows them to utilize a wide range of woody plants, including leaves, shoots, flowers, fruits and pods, resources that remain available when grasses become scarce. This dietary flexibility enables goats to maintain production under conditions where other livestock species may experience severe nutritional limitations. The Small East African Goat is among the most widely distributed indigenous goat populations in eastern Africa and plays an important role in pastoral and agro-pastoral systems of Kenya, Tanzania and Uganda. Rather than representing a single uniform breed, these goats comprise locally adapted populations that have

developed through long-term selection under diverse environmental conditions. Their tolerance to drought, ability to utilize low-quality forage, disease resilience and reproductive performance make them particularly suited to semi-arid production systems (Kichamu et al., 2024). However, their strong dependence on woody vegetation also means that goat browsing may influence plant species that are important not only for livestock nutrition but also for pollinator communities.

Woody browse vegetation forms a critical component of African dryland ecosystems because it provides forage during periods when herbaceous vegetation is limited. Trees and shrubs often remain productive during prolonged dry seasons due to their deep root systems, drought tolerance and ability to recover after disturbance. For goats, these plants provide valuable sources of protein, minerals and energy when grass availability and quality decline. Beyond livestock production, browse species contribute to soil protection, carbon storage, nutrient cycling and habitat provision, making them essential components of resilient rangeland ecosystems. Many browse species also play a dual ecological role by supporting honey bee populations through the production of nectar and pollen. In East African rangelands, species belonging to genera such as *Vachellia*, *Senegalia*, *Grewia*, *Boscia*, *Commiphora*, *Balanites*, *Terminalia* and *Ziziphus* are important forage plants for goats while also contributing to honey production. Their flowering periods influence the timing and availability of floral resources, which subsequently affects honey bee foraging activity, colony development and honey yields (Amulen et al., 2017; Frazier et al., 2024). This overlap creates an important ecological connection between livestock browsing and pollination

services, where changes affecting browse plants may have consequences beyond livestock nutrition.

The success of African honey bees is closely associated with their ability to exploit highly variable floral environments. The western honey bee (*Apis mellifera*) occurs across Africa in several subspecies, including *A. m. scutellata*, *A. m. adansonii*, *A. m. litorea*, *A. m. monticola* and *A. m. capensis* (Hepburn & Radloff, 1998; Dietemann et al., 2009). In eastern Africa, *A. m. scutellata* is widely distributed and is well adapted to seasonal environments characterized by fluctuating floral availability, high temperatures and periods of resource scarcity. Traits such as extensive foraging ability, colony mobility and tolerance to challenging climatic conditions enable this subspecies to exploit diverse plant communities in African drylands (Dietemann et al., 2009; Pirk et al., 2016; Frazier et al., 2024).

Although herbivory can influence plant communities in different ways, the consequences for pollinators depend largely on browsing intensity. Moderate browsing may increase habitat heterogeneity, stimulate plant growth and maintain diverse vegetation structures that support pollinators. However, continuous or excessive browsing can reduce plant regeneration, suppress flowering and decrease the availability of nectar and pollen resources (Augustine & McNaughton, 2004; Van Klink et al., 2015). Most research examining livestock effects on pollinators has focused on grazing systems dominated by cattle and sheep, particularly in temperate ecosystems. Comparatively little attention has been given to browsing livestock, especially goats and their influence on pollinator resources in African drylands. This knowledge gap is particularly important in sub-Saharan Africa, where pastoralism

and apiculture frequently occur within the same landscapes. Although browse plants are recognized as important resources for livestock and honey bees, limited information exists on how variations in goat browsing intensity affect plant species preferred by both animals and subsequent honey bee visitation. Existing studies have often considered livestock production, vegetation dynamics and honey production separately, leaving the ecological pathways linking these components poorly understood.

Kenya's arid and semi-arid lands provide an appropriate setting for examining these interactions because pastoralism remains a dominant livelihood system, while apiculture continues to gain importance as a complementary enterprise. Turkana County contains extensive pastoral landscapes dominated by indigenous woody vegetation that supports both Small East African goats and honey bees. However, increasing livestock pressure, recurrent drought and environmental change may influence the availability and quality of shared browse resources. Understanding these relationships is therefore important for developing management approaches that support livestock production while maintaining pollination services and ecological integrity. This study examined the influence of goat browsing intensity on preferred forage plant species and subsequent honey bee visitation in Loima Sub-County, Turkana County, Kenya. The study focused on identifying plant species utilized by goats and honey bees, assessing how browsing intensity affects these shared plant resources and determining whether browsing-related changes influence honey bee visitation patterns. By examining the interaction between livestock browsing, vegetation resources and pollinator activity, this

research contributes to a better understanding of sustainable management options for dryland ecosystems where pastoralism and apiculture coexist.

2. Methodology

2.1 Study area

The study was conducted in Loima Sub-County, Turkana County, north-western Kenya. The area covers approximately 9,113 km² and comprises four administrative wards: Kotaruk/Lobei, Loima, Lokirama/Lorengippi and Turkwel. Loima lies within the arid and semi-arid lands (ASALs) of Kenya and is characterized by high temperatures, prolonged dry periods and highly variable rainfall (Figure 1). Rainfall occurs mainly during two seasons influenced by the

Inter-Tropical Convergence Zone and Congo air masses; however, precipitation is generally low and unreliable, resulting in frequent drought conditions. The landscape consists mainly of open plains interspersed with hills and mountain ranges, with elevations ranging from approximately 900 to 1,800 m above sea level. Vegetation is typical of dryland ecosystems and is dominated by woody species, including *Prosopis juliflora*, *Vachellia tortilis*, *Salvadora persica* and other indigenous shrubs and trees, together with drought-tolerant grasses and herbaceous plants. These vegetation communities provide important browse resources for Small East African goats and floral resources for honey bees, making Loima an appropriate location for investigating interactions between livestock browsing and pollinator activity.

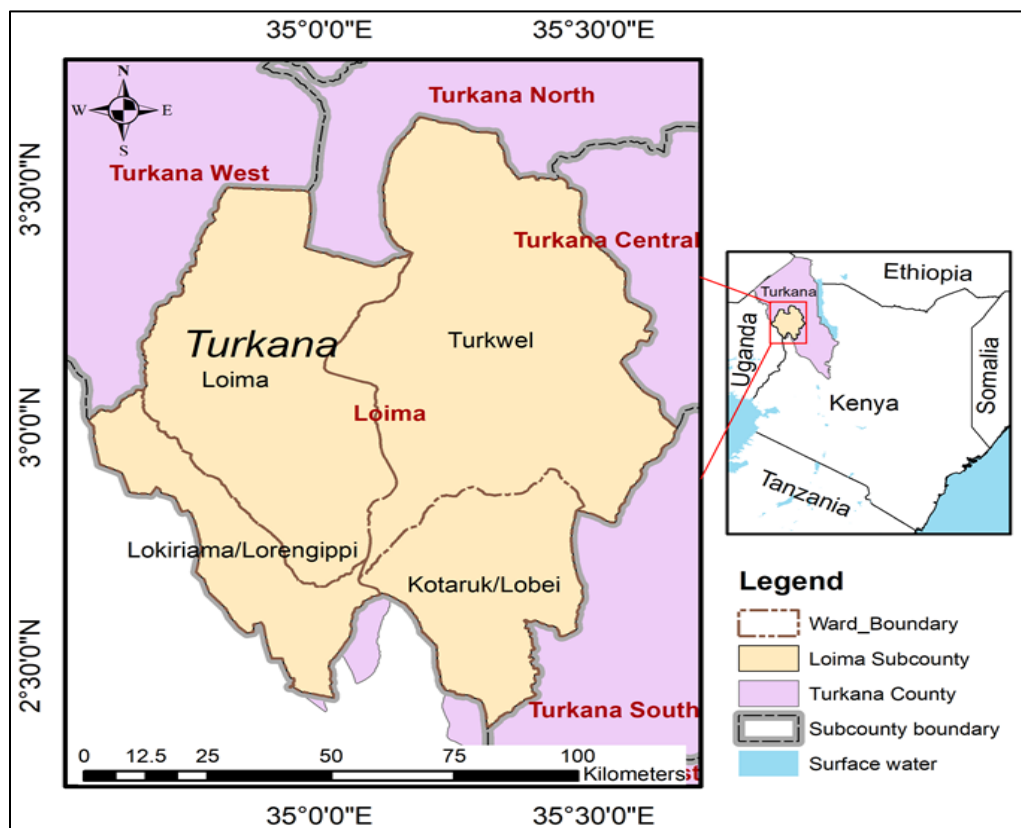


Figure 1: Map showing study area of Loima Sub-County, Turkana County in Kenya

3.2 Study design and sampling approach

The study employed a field-based ecological design to examine the relationship between goat browsing intensity, preferred plant species and honey bee visitation. Data collection was conducted during both wet and dry seasons to capture seasonal differences in vegetation availability, flowering patterns and bee activity. Sampling sites were selected based on the presence of active pastoral grazing areas, evidence of goat browsing and availability of flowering plant species. Preliminary consultations were conducted with local livestock officers, community representatives and experienced pastoralists to identify areas with varying levels of browsing pressure. Selected sites were categorized into different browsing intensity levels based on observable signs of vegetation utilization. Within each selected site, vegetation transects were established and sampling plots were systematically positioned along the transects. Data collected within the plots included plant species composition, abundance, flowering status, evidence of goat browsing and honey bee activity. This approach allowed assessment of how differences in browsing intensity influence plant resources shared by goats and honey bees.

2.2 Assessment of plant preference, browsing intensity and honey bee visitation

Vegetation surveys were conducted to identify plant species utilized by Small East African goats and honey bees. All woody and flowering plant species encountered within the sampling plots were recorded and information on species identity, abundance and flowering status was collected. Plant identification was supported by botanical field guides and verified using taxonomic databases,

including Plants of the World Online (POWO) and World Flora Online (WFO). Where necessary, field identification applications were used to support verification of uncertain species. Goat preference was assessed based on direct observations of browsing signs on individual plants. Indicators considered included removal of leaves, young shoots, flowers, fruits or pods, as well as repeated evidence of utilization. Information obtained from pastoralists was also used to complement field observations, particularly regarding locally preferred browse species and seasonal utilization patterns.

Browsing intensity was assessed using visual indicators of vegetation use within each sampling plot. Sites were classified into low, moderate and high browsing intensity categories based on the extent of browsing damage, frequency of browsing signs and the ability of plants to maintain regeneration. These categories were used to evaluate differences in plant composition and floral resource availability under different browsing pressures. Honey bee visitation was assessed on flowering plant species identified within the vegetation plots. Observations were conducted during periods of active flowering and the number of honey bee visits to each plant species was recorded during standardized observation periods. Only bees observed collecting nectar or pollen were considered active visitors. Visitation rates were compared among plant species and across different browsing intensity levels to determine whether browsing-related changes in vegetation influenced honey bee activity.

2.3 Data analysis

Plant species diversity was calculated using the Shannon–Wiener diversity index (H'), expressed as: $H' = -\sum P_i \ln P_i$

Where:

P_i = the proportion abundance of the i th species = n_i/N

$\ln P_i$ = the logarithm of P_i (n_i/N)

Differences in plant species richness, abundance, flowering resource availability and honey bee visitation among browsing intensity categories were evaluated using analysis of variance (ANOVA). Relationships between goat browsing intensity, plant resource availability and honey bee visitation rates were assessed using correlation and regression analyses. Where necessary, post-hoc comparisons were conducted to determine differences among browsing intensity categories. All statistical analyses were performed using SPSS.

2.4 Ethical considerations

Ethical approval for the study was obtained from the University of Eldoret and research authorization was granted by the National Commission for Science, Technology and Innovation (NACOSTI). Permission to conduct field activities was obtained from relevant county authorities and local community leaders. Participation of community members who provided information on plant use and browsing patterns was voluntary and informed consent was obtained before engagement. Ecological observations and plant assessments were conducted with minimal disturbance to vegetation. All information collected during the study was treated confidentially and used solely for scientific purposes.

3. Results

3.1 Variation in bee visitation and goat use across plant species

A multivariate general linear model was used to examine variation in bee visitation rates and goat use index across plant species. Overall, mean bee

visitation was 13.05 ± 7.98 visits per 30 minutes ($n = 174$), while the mean goat use index across all species was 2.17 ± 0.65 . Considerable variation in bee visitation was observed among plant species. Highest visitation rates were recorded in *Prosopis juliflora* (28.33 ± 4.08), followed by *Ziziphus mauritiana* (25.33 ± 4.08), *Maerua subcordata* (23.83 ± 6.79) and *Cadaba rotundifolia* (23.17 ± 5.78). Relatively high values were also recorded in *Vachellia tortilis* (20.83 ± 6.79) and *Delonix elata* (20.33 ± 5.16). Lower visitation rates occurred in *Vachellia mellifera* (6.83 ± 3.54), *Commiphora boiviniana* (5.33 ± 3.01) while the remaining species exhibited intermediate values (Table 1). Goat use index showed less variability across species, with most species scoring between 1 and 3. Higher use (index = 3) was recorded in species such as *Acalypha fruticosa*, *Grewia tenax*, *Prosopis juliflora*, *Sericocomopsis pallida*, *Vachellia elatior*, *Vachellia mellifera*, *Vachellia senegal*, *Vachellia tortilis* and *Ziziphus mauritiana*. Lower use values (index = 1) were observed in *Cadaba rotundifolia*, *Euphorbia uhligiana*, *Maerua subcordata* and "Unknown_Email", while intermediate values were recorded in the remaining species.

Multivariate tests indicated a significant overall effect of plant species on the combined response variables (Pillai's Trace = 0.664; $F_{0.05(29, 144)} = 9.828$, $p < 0.001$). At the univariate level, plant species also had a significant effect on bee visitation rates ($F_{0.05(29, 144)} = 9.828$, $p < 0.001$), with the model explaining 66.4% of the variation in bee visitation ($R^2 = 0.664$, adjusted $R^2 = 0.597$). Goat use index showed no residual variability within species in the model output, with a constant grand mean of 2.20 ± 0.00 . The grand mean across all observations was 12.84 ± 0.41 for bee visitation and 2.20 ± 0.00 for goat use index.

Table 1: Mean bee visitation rates and goat use index across plant species

Plant species	Bee visitation (Mean±SD)	Goat use index (Mean±SD)
<i>Acalypha fruticosa</i>	11.20±5.26	3.00±0.00
<i>Acalypha frutosa</i>	6.00±0.00	3.00±0.00
<i>Aristida mutabilis</i>	10.33±8.43	2.00±0.00
<i>Balanites aegyptiaca</i>	7.67±3.72	2.00±0.00
<i>Balanites glabra</i>	8.33±4.08	2.00±0.00
<i>Cadaba farinosa</i>	15.50±6.09	2.00±0.00
<i>Cadaba rotundifolia</i>	23.17±5.78	1.00±0.00
<i>Commiphora boiviniana</i>	5.33±3.01	2.00±0.00
<i>Commiphora sp.</i>	6.33±3.01	2.00±0.00
<i>Cordia sinensis</i>	7.83±3.54	2.00±0.00
<i>Delonix elata</i>	20.33±5.16	2.00±0.00
<i>Diospyros scabra</i>	9.33±4.08	2.00±0.00
<i>Euphorbia uhligiana</i>	16.50±6.09	1.00±0.00
<i>Ficus sycomorus</i>	12.83±4.62	2.00±0.00
<i>Grewia bicolor</i>	12.33±4.08	2.00±0.00
<i>Grewia sp.</i>	7.33±3.01	2.00±0.00
<i>Grewia tenax</i>	17.33±6.25	3.00±0.00
<i>Hyphaene compressa</i>	10.83±3.54	2.00±0.00
<i>Maerua subcordata</i>	23.83±6.79	1.00±0.00
<i>Prosopis juliflora</i>	28.33±4.08	3.00±0.00
<i>Salvadora persica</i>	8.83±3.54	2.00±0.00
<i>Sericocomopsis pallida</i>	11.83±7.88	3.00±0.00
<i>Tamarix nilotica</i>	8.33±3.01	2.00±0.00
<i>Tribulus cistoides</i>	10.33±7.34	2.00±0.00
<i>Unknown_Email</i>	3.50±2.07	1.00±0.00
<i>Vachellia elatior</i>	10.33±4.08	3.00±0.00
<i>Vachellia mellifera</i>	6.83±3.54	3.00±0.00
<i>Vachellia senegal</i>	18.33±6.25	3.00±0.00
<i>Vachellia tortilis</i>	20.83±6.79	3.00±0.00
<i>Ziziphus mauritiana</i>	25.33±4.08	3.00±0.00

3.2 Drivers of bee visitation across season, flowering and browsing gradients

Bee visitation differed between seasons, with higher values observed in

the wet season (17.37±7.36) compared with the dry season (8.72±6.02) as illustrated in Figure 2. This difference was statistically significant ($F_{0.05(1, 172)} = 71.91, p < 0.001$).

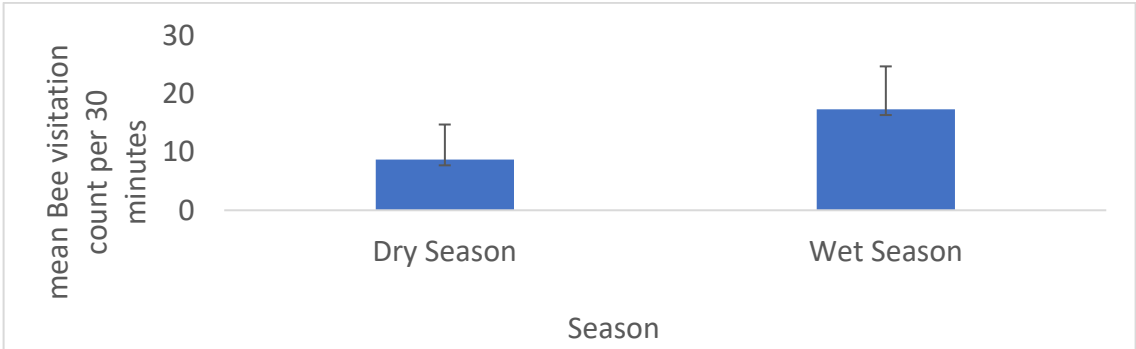


Figure 2: Seasonal variation in bee visitation rates per 30 minutes

Across flowering intensity levels, visitation increased steadily from very low flowering (2.67 ± 0.89) and low flowering (5.44 ± 1.70), through moderate flowering (10.49 ± 2.39) and high flowering

(19.18 ± 5.79), reaching the highest values under very high flowering (22.72 ± 5.29) as portrayed in Figure 3. The differences among categories were statistically significant ($F_{0.05(4, 169)} = 133.98$, $p < 0.001$).

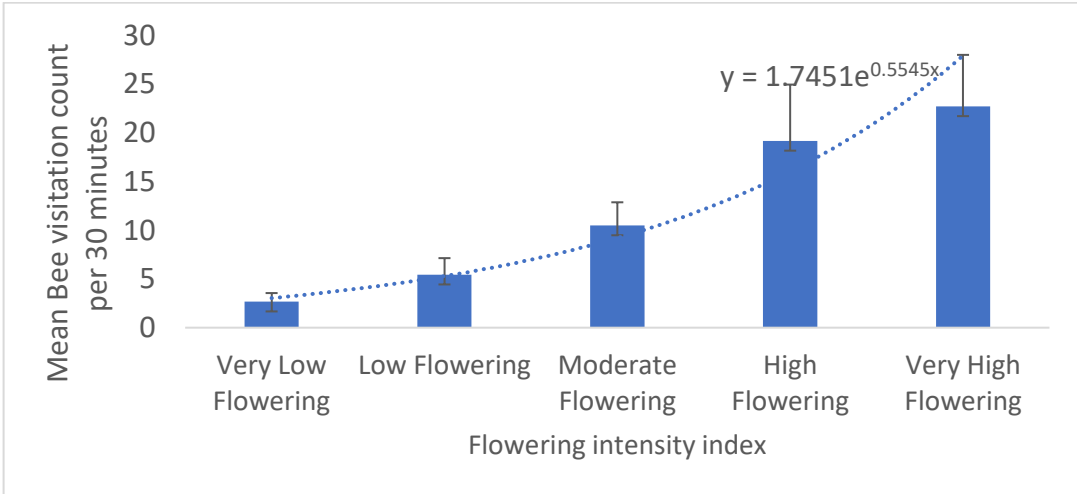


Figure 3: Bee visitation rates across flowering intensity levels

When bee visitation rates were analysed across different browsing durations, clear variation was observed among the time categories, with mean visitation ranging from 6.75 ± 3.20 visits at 16 minutes to 28.50 ± 6.36 visits at 17 minutes as portrayed in Figure 4. Relatively high visitation was also recorded at 18 minutes (28.25 ± 3.77), 10 minutes (25.25 ± 3.77), 19 minutes (21.00 ± 9.90) and 20 minutes

(20.75 ± 6.65), while lower values were observed at intermediate browsing durations such as 3 minutes (9.94 ± 7.91), 4 minutes (9.17 ± 5.78), 5 minutes (10.93 ± 5.60), 6 minutes (9.27 ± 4.66) and 15 minutes (9.17 ± 4.22). Overall, visitation varied considerably across browsing time categories and these differences were statistically significant ($F_{0.05(17, 156)} = 6.62$, $p < 0.001$), with a moderate effect size ($\eta^2 = 0.419$).

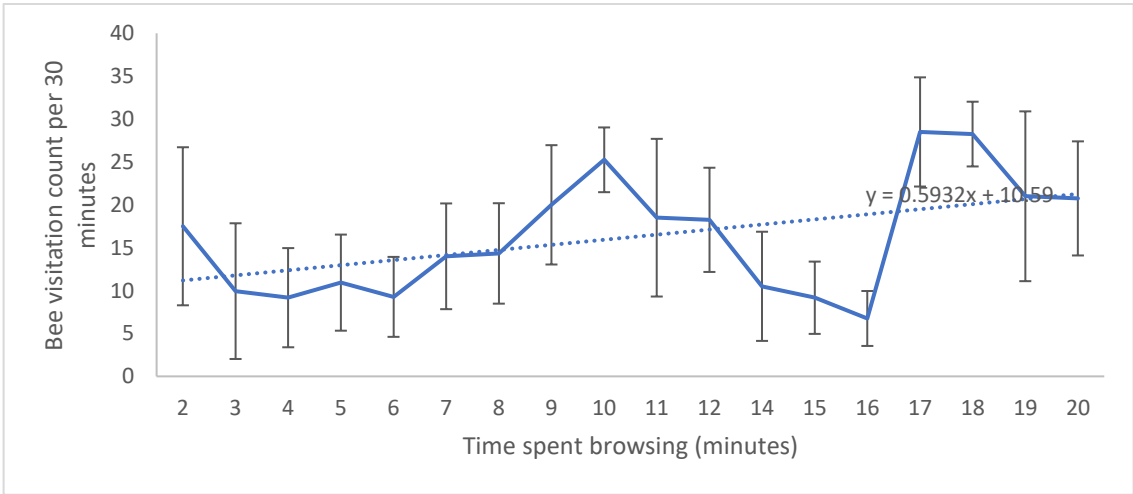


Figure 4: Bee visitation rates across browsing duration categories (minutes).

The combined effect of season and flowering intensity showed that visitation increased more sharply with flowering during the wet season (13.44 ± 1.31 at low flowering to 23.33 ± 1.00 at very high flowering) than in the dry season (8.35 ± 1.21 to 13.55 ± 1.07) and this interaction was statistically significant ($F_{0.05(2, 137)} = 5.14$, $p = 0.007$). When species differences were included in the model, the overall pattern remained the same, with season, flowering intensity, browsing duration and their interaction all contributing to variation in bee visitation, supported by model fit values (AIC = 638.65; BIC = 644.66).

4. Discussion

4.1 Variation in bee visitation and goat use across plant species

The differences in plant use by Small East African goats and honey bees observed in Loima reflect the contrasting ways in which herbivores and pollinators interact with dryland vegetation. Although both depend on the same plant community, the resources they seek and the way they respond to plant availability are different. Honey bees mainly depend on floral rewards, particularly nectar and pollen, while goats utilize a wider range of plant materials, including leaves, young shoots, fruits and pods. This difference in resource requirements explains why bee activity was concentrated on a few flowering plant species, whereas goat browsing was spread across a larger number of plants. The high visitation recorded on *Prosopis juliflora*, *Ziziphus mauritiana*, *Maerua subcordata* and *Cadaba rotundifolia* suggests that these species play an important role in supporting honey bee activity within the study area. In semi-arid landscapes such as Loima, flowering resources are often irregularly distributed because plant

growth is strongly controlled by rainfall availability. Under these conditions, plants that can flower consistently or provide resources during periods of scarcity become particularly important to pollinators. Woody species are especially valuable because many maintain reproductive activity during dry periods when herbaceous vegetation has declined, providing nectar and pollen that allow bee colonies to remain active throughout the year (Eardley et al., 2006; Nicolson, 2011). The dependence of honey bees on a limited number of plant species has also been reported in other African dryland ecosystems. Although savanna landscapes may contain many plant species, only a few usually contribute a large proportion of available floral resources at a particular time. These plants often determine the timing of honey production and influence the ability of bee colonies to survive seasonal shortages.

In East Africa, indigenous trees and shrubs are recognized as important bee forage resources because they are adapted to local environmental conditions and provide flowering opportunities when other resources are limited (Munyuli, 2011; Amulen et al., 2017). The strong association between bees and particular plant species may also be explained by honey bee foraging behaviour. Honey bees are efficient resource collectors and tend to concentrate their activity on plant species that provide greater nutritional rewards. Once a reliable nectar or pollen source is identified, foragers communicate the location to other colony members, resulting in increased visitation to highly rewarding plants (Seeley, 2009). Therefore, differences in bee visitation among plant species in Loima are likely influenced not only by flower abundance but also by differences in nectar quantity,

pollen quality, flowering duration and accessibility of floral structures.

Goat browsing showed a different pattern, with animals utilizing a broader range of plant species. This feeding strategy reflects the ecological adaptations of Small East African goats to dry environments where forage availability changes considerably between seasons. Goats are selective browsers, but their ability to consume a wide variety of woody plants allows them to maintain dietary intake when grasses become scarce or lose nutritional value. In African rangelands, browse species become increasingly important during drought periods because trees and shrubs remain available after herbaceous vegetation has declined (Ngwa et al., 2002; Tefera et al., 2008). The wider range of plants used by goats compared with honey bees reflects the flexibility of goat feeding behaviour. Unlike bees, which require specific floral resources, goats can modify their diets according to what is available within the environment. However, this flexibility also means that repeated browsing can influence vegetation structure over time, particularly where certain species are consistently preferred. Continuous removal of young shoots, leaves and reproductive parts may affect plant recovery, regeneration and future availability of browse resources (Augustine & McNaughton, 2004). Therefore, although goats are well adapted to dryland environments, their browsing patterns can influence the same vegetation resources upon which other organisms depend. Some plant species recorded in this study appear to serve as important links between goat production and apiculture because they provide resources for both groups. For example, *Ziziphus mauritiana* and *Prosopis juliflora* provide browse materials, fruits and pods consumed by goats while their flowers

support honey bee foraging. Such multifunctional species are particularly important in pastoral landscapes because they contribute to several ecosystem services at the same time. However, their shared use creates potential competition between livestock and pollinators if browsing pressure becomes excessive, especially during flowering periods when removal of reproductive shoots may reduce floral availability. The effects of goat browsing on flowering resources are likely to depend on browsing intensity and plant characteristics. Moderate browsing may not always have negative effects and, in some cases, may stimulate new shoot production and maintain a more heterogeneous vegetation structure. However, frequent and intense browsing can reduce plant vigour, limit flower production and interfere with regeneration.

Similar patterns have been observed in African savannas, where herbivore effects on vegetation depend on the balance between disturbance and plant recovery capacity (Augustine & McNaughton, 2004; Díaz et al., 2007). The role of *Prosopis juliflora* in this system requires careful consideration. The species provides important resources for goats and honey bees, particularly in dry periods when alternative forage sources are limited. Its flowers support bee activity, while its pods contribute to livestock feeding. However, its invasive nature in northern Kenya has resulted in major ecological changes in some areas, including reduced native plant diversity and altered rangeland use patterns (Mwangi & Swallow, 2008; Shackleton et al., 2017).

Management strategies should therefore recognize both its short-term benefits as a resource species and its potential long-term impacts on native vegetation communities. Differences among plant species in both goat

browsing and bee visitation are ultimately related to plant traits. Species with abundant flowers, accessible floral structures and longer flowering periods are more attractive to bees, while plants producing nutritious leaves, shoots and pods are more likely to be selected by goats. In dryland ecosystems, where vegetation productivity is limited and concentrated among a few dominant woody species, these plant characteristics determine how resources are shared among different consumers.

The findings from Loima show that woody vegetation forms an important ecological connection between livestock production and pollination services. A relatively small group of plant species supports multiple functions, including providing goat browse, sustaining honey bee colonies and maintaining ecosystem processes. Similar observations from African savannas have shown that woody plants play a central role in supporting biodiversity and ecosystem stability in environments where resources are highly seasonal (Scholes & Archer, 1997; Sankaran et al., 2005). Maintaining these key plant resources through sustainable browsing practices will therefore be important for supporting both pastoral livelihoods and apiculture in semi-arid landscapes.

4.2 Drivers of bee visitation across season, flowering and browsing gradients

Honey bee visitation varied considerably between seasons, with greater activity recorded during the wet season compared with the dry season. This pattern reflects the strong influence of rainfall on plant growth and reproductive activity in semi-arid ecosystems. In drylands, rainfall events often trigger rapid vegetation responses, including leaf development and flowering, resulting in temporary

increases in nectar and pollen availability. During the dry season, reduced plant productivity and fewer flowering resources limit foraging opportunities, causing bees to depend on a smaller number of plant species capable of flowering under stressful conditions (Munyuli, 2011; Amulen et al., 2017). The seasonal pattern observed in this study is consistent with observations from other African dryland ecosystems, where pollinator activity closely follows fluctuations in rainfall and plant phenology. Unlike humid environments where floral resources may be available throughout much of the year, semi-arid landscapes experience pronounced periods of abundance and scarcity. Following rainfall, several woody species flower within a relatively short period, creating important feeding opportunities for honey bees. However, as moisture declines, flowering becomes more scattered and colonies increasingly rely on drought-tolerant plant species that maintain floral production during resource-limited periods (Eardley et al., 2006; Nicolson, 2011).

The higher visitation during periods of increased flowering intensity further demonstrates the importance of floral availability in determining honey bee activity. Plants with greater flower abundance received more visits, suggesting that bees were responding to the quantity of available rewards within the landscape. This behaviour is expected because honey bees optimize their foraging efforts by concentrating on plant species and patches that provide higher returns in terms of nectar and pollen while reducing unnecessary movement between less rewarding resources (Seeley, 2009). Similar relationships between flower abundance and pollinator activity have been reported in tropical and African ecosystems, where seasonal changes in flowering strongly

influence insect visitation patterns (Kehinde & Samways, 2014). The influence of flowering intensity on bee visitation is particularly important in pastoral landscapes because most floral resources are provided by naturally occurring vegetation rather than cultivated crops. In Loima, woody plants represent a major component of the available bee forage, especially during periods when grasses and herbaceous plants become less productive. Species capable of producing flowers during dry periods may therefore contribute disproportionately to maintaining honey bee populations. The loss or decline of such species could have consequences beyond individual plants by reducing the continuity of floral resources required for colony survival.

Browsing pressure also appeared to influence bee visitation, although the relationship is likely mediated through changes in vegetation rather than direct effects on bees. Goats and honey bees share several woody plant species, meaning that changes in plant condition caused by browsing may affect the availability of floral resources. The effects of browsing, however, depend on its intensity and frequency. Moderate browsing may stimulate regrowth in some woody plants by encouraging branching and maintaining younger shoots that can contribute to future flowering. In contrast, repeated and heavy browsing can reduce plant vigour, remove reproductive structures and limit flower production (Augustine & McNaughton, 2004). Similar contrasting effects of herbivory have been reported in savanna ecosystems, where moderate disturbance can increase vegetation heterogeneity and maintain diverse plant communities, whereas excessive herbivore pressure may simplify vegetation structure and reduce ecosystem functioning (Van Klink et al.,

2015). This suggests that goat browsing should not be viewed only as a negative influence on vegetation. Rather, its ecological effects depend on whether browsing remains within the capacity of plants to recover.

The response of individual plant species to browsing is also likely to influence patterns of honey bee visitation. Some woody plants common in African rangelands have evolved under continuous herbivore pressure and possess mechanisms that allow them to tolerate browsing, including rapid shoot replacement and flexible allocation of resources. Other species may experience reduced flowering when frequently browsed because reproductive tissues are removed before maturity. Therefore, differences in browsing tolerance among plant species may partly explain why some plants continued to attract bees while others showed reduced visitation under greater browsing pressure. The interaction between season and flowering intensity further indicates that bee activity is influenced by the broader environmental context. During wet periods, favourable moisture conditions likely increased plant growth and enhanced flowering, strengthening the response of bees to floral abundance. During dry periods, environmental stress may reduce nectar production and shorten flower persistence, meaning that the presence of flowers alone may not always translate into high visitation. Temperature, plant water status and soil moisture are known to influence nectar secretion and pollinator behaviour, particularly in water-limited environments (Nicolson, 2011; Willmer, 2011). These seasonal limitations have important implications for pastoral ecosystems. When floral resources decline during dry periods, both honey bees and livestock become increasingly dependent on a smaller group of resilient

woody species. Continued loss or excessive utilization of these plants may therefore affect multiple ecological functions simultaneously. Maintaining a diverse woody plant community is important not only for sustaining goat browse resources but also for ensuring that honey bees have access to forage throughout the year.

4.3 Conclusion

The findings show that woody vegetation provides an important connection between Small East African goats and honey bees in Loima Sub-County. While goats and honey bees utilize plants differently, both depend on a number of shared woody species that provide browse materials and floral resources. Honey bee visitation varied mainly with flowering intensity and seasonal rainfall, with higher activity recorded when flowering plants were more abundant. Goat browsing influenced these resources through selective feeding on leaves, shoots and other plant parts, which may affect plant structure and future availability of flowers. The study highlights that maintaining healthy populations of key browse and flowering plant species is important for sustaining both goat production and honey bee activity in semi-arid landscapes. Managing browsing pressure while allowing regeneration of preferred plant species can help maintain the vegetation resources that support these interacting components of the ecosystem.

4.4 Recommendations

Conservation efforts should focus on protecting and encouraging regeneration of important woody plant species used by both goats and honey bees. Areas experiencing high browsing pressure should be managed to allow vegetation recovery and reduce

continuous utilization of preferred plants. Pastoral communities should be encouraged to adopt browsing practices that maintain plant availability throughout the year, particularly for species that provide both livestock forage and bee forage. Integrating vegetation management with pastoral and beekeeping activities can help sustain the ecological resources required by both enterprises. Further studies should investigate long-term changes in browse plant populations, flowering patterns and honey bee responses under different browsing conditions to improve understanding of livestock–pollinator interactions in dryland ecosystems.

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