Pollination of Acacia woodlands and honey production by honey bees in Kitui, Kenya

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Abstract

Acacia woodlands dominate arid and semi-arid areas across the world and are an important source of livelihood supporting activities. This is also the case in Kenya, where the Acacia woodlands are under pressure, partly due to the extractive activities that generate household income, such as collection of fuelwood, building poles, charcoal burning and livestock fodder. There is an apparent dilemma between the extractive and non-extractive use of the Acacia woodlands, and a need to develop income generating activities that also conserve and support the natural basis. Honey production is a widespread activity in Kenyan Acacia woodland areas, and thus a potential candidate for the task, but information on pollination of wild plants in the tropics in relation to livelihood sustenance and natural resource conservation is scarce. Therefore, this study investigates to what extent honey bees (*Apis mellifera*) visit and pollinate *Acacia brevispica* in Kitui County, Kenya. The study also assesses the occurrence of Acacia pollen types in honeys produced within the study area. The results show that honey bees were the most numerous flower visitor and pollinator of *A. brevispica*, while Acacia pollen was the predominant pollen type in the sampled honeys. This shows that honey bees provide pollination services to *A. brevispica* for the return of pollen and nectar for the production of honey, which is a source of income for local households. Understanding the link between pollination of *A. brevispica* and honey production can help to facilitate conservation efforts for the benefit of the woodlands and its inherent biodiversity as well as for local livelihoods.

Introduction

Plant-pollinator interactions contribute to biological diversity, maintenance of ecosystem functions, agricultural productivity, food security and livelihoods (Potts et al., 2003, 2010). Unfortunately, this interaction is threatened by human induced factors, such as urbanization (Potts et al., 2010), intensification of agricultural land use, intensive use of chemicals, and the introduction of genetically modified and alien species (Krebs, Wilson, Bradbury & Siriwardena, 1999; Richards, 2001; Ricketts, 2004; Tscharntke, Klein, Kruess, Steffan-Dewenter & Thies, 2005). Habitat loss and fragmentation may result in reduced pollinator diversity (Vazquez & Simberloff, 2002) and lower number of pollinators (Lennartsson, 2002; Potts et al., 2003), pollination deficits and low seed output due to pollen limitation (Jennersten, 1988); all of which negatively affect plant populations as well as agricultural production (Foley et al., 2005). However, human activities may also have a positive role in the plant-pollinator interaction, such as pollination services of managed bees in natural environments (Chamberlain & Schlising, 2008).

Mutual interactions between plants and pollinators can be complex and is associated with a number of factors.

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For instance, visitation rates of a plant by pollinators can be influenced by factors, such as climatic conditions, pollinator type and characteristics, and flower morphology and physiology (Conner & Rush, 1996; Richards, 2001; Ushimaru, Watanabe & Nakata, 2007). Previous studies have shown that there is a relationship between pollination limitation, visitation rate and abundance of pollinators (Herrera, 2000; Larson & Barrett, 1999; Morandin & Winston, 2005). Pollinators can be specialists, i.e. pollinators visiting one or specific plant species, but generalists that visit and pollinate many and diverse plant species are more common (Ghazoul, 2006; Johnson & Steiner, 2000). The honey bee is an example of a generalist pollinator (Aslan, Liang, Galindo, Hill & Topete, 2016; Olesen & Jordano, 2002).

Forests surrounding agricultural farms have been found to have a positive impact on abundance and diversity of pollinators (Klein, Cunningham, Bos & Steffan-Dewenter, 2008; Ricketts, 2004) as well as the survival of the plants (Kolehmainen & Mutikainen, 2006). This has also been indicated in studies conducted in Kenya (Karanja, Njoroge, Gikungu & Newton, 2010). Forests provide important foraging, nesting, roosting and mating sites for most pollinators (Ricketts, 2004; Roubik, 1995). Absence or change in natural habitats/forests interrupts plant-pollinator relationships (Goulson, Nicholls & Rotheray, 2015; Richards, 2001; Winfree, Aguilar, Vazquez, Lebuhn & Aizen, 2009) and may lead to depressed agricultural output and loss of livelihoods (Karanja et al., 2010). Besides creating a habitat for pollinators, forested areas also play an important role for many rural communities, especially in areas with widespread poverty and subsistence agriculture where collection of non-timber forest products is undertaken as an important livelihood activity (Wunder, Angelsen & Belcher, 2014). Such activities are undertaken in dry forests and woodlands in Kenya where trees in the natural environment have a supporting role for rural livelihoods. However, these areas may come under pressure from the very same activities (Barrow & Mlenge, 2003; Kiage, Liu, Walker, Lam & Huh, 2007; Mureithi, Verdoodt, Njoka, Gachene & Ranst, 2016).

As such, maintenance of pollination services and pollinator populations is a significant task, not only geared towards conservation of natural resources (Stone, Raine, Prescott & Willmer, 2003), but also for the sake of maintaining or enhancing agricultural productivity, food security and rural livelihoods. In order to understand the importance of pollination services for the regeneration and production of different plant species, natural and managed, information on the flower visitors and their importance for seed or fruit set is required (Martins, 2008; Stone et al., 2003).

Acacias spp. are thorny plant species in the Fabaceae family, which thrive well in tropical and subtropical habitats, particularly in arid and semi-arid regions (Marshall et al., 2012; Ross, 1981; Stone et al., 2003). The genera includes woody shrubs and trees, which can translate to bushlands and forests (Ross & Gordon-Gray, 1966). The growth form of the plant species are attributed to climatic and edaphic conditions in the growing area. Acacia plants are self-incompatible and exhibit little or no self-fertilization (Muona, Morant & Bell, 1991) and rely on insects for pollination (Stone et al., 2003; Tandon & Shivanna, 2001; Tybirk, 1993). Floral rewards of Acacia plants to their visitors are nectar and pollen (Stone et al., 2003; Stone, Willmer & Rowe, 1998), and they are important food resources to a variety of insects (Adgaba et al., 2017; Martins, 2014). Bees, wasps, flies and butterflies have been documented as flower visitors of most Acacia spp. (Stone et al., 2003; Tybirk, 1993).

Acacia trees also constitute an important wild resource for rural communities in dry zone areas across the world (Moncur, Mitchell, Fripp & Kleinschmidt, 1995). The trees are used for livestock fodder (Nyambati, Sollenberger, Karue & Musimba, 2006), medicine (Ibrahim & Ibrahim, 1998; Wanzala, Syombua & Alwala, 2016), timber, poles, charcoal and fuel wood (Dlamini & Geldenhuys, 2009; Stone et al., 2003, 1998). Acacia plants also supports life forms as well as provide pollen and nectar for production of honey (Martins, 2014). This is the case in the Arid and Semi-arid Lands (ASAL) of Kenya, where a number of *Acacia spp.* are important sources for livelihood. In Kitui County, Kenya, trials have also been undertaken for the production of wild silk, but the Acacia woodlands are mostly known for the production of a unique quality honey, which has a high demand and good reputation in the region of production as well as at a national level (Egelyng et al., 2017). Honey production in the area forms an important source of livelihoods for the local communities where several beekeeping groups have been established.

Acacia woodlands in Kitui have been under pressure, due to extractive activities which are undertaken by local households for income generation (ICIPE, 2009). These activities include collection of fuel-wood, building poles, charcoal burning, and livestock fodder. The Ministry of Agriculture in Kitui, County, Kenya has emphasized the need to develop non-extractive and woodland 'friendly' income generating activities. Therefore, the local communities in the area have been supported in undertaking honey production activities for income generation. However, little is known on the relationship between pollination of *Acacia spp.* in Kitui and livelihood sustenance as well as conservation of natural resources.

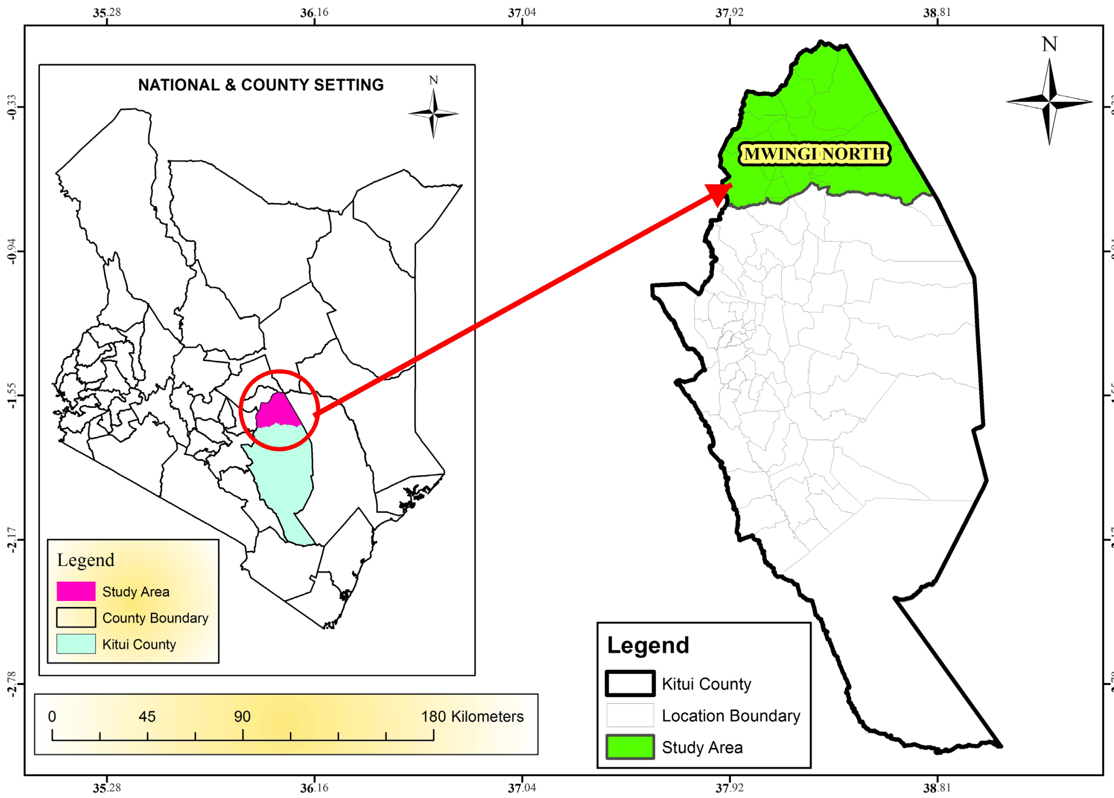

Figure 1: A map of Kenya showing the study area (Kitui County) and sampling site (Mwingi North) (Source: Own compilation using data which was derived from survey of Kenya)

Furthermore, information on the utilization of *Acacia spp.*, and other surrounding vegetation by honey bees, in production of honey has not been documented. Understanding the link between visitation and pollination of *Acacia spp.* by honey bees, and the production of good quality honey can increase the awareness of the double role of beekeeping for income generation and pollination services to a woodland species under pressure. Therefore, this study aims to investigate to what extent honey bees visit and pollinate the naturally occurring woody plant, *A. brevispica*, which is one of the key species in the Acacia woodlands in Kitui County, Kenya.

Methodology

Study area

This study was carried out between January-May, 2016 in Kitui, Kenya, which falls within the semi-arid zone in Kenya (Figure 1). The County is located between latitudes 0^{0} 10^{i} and 3^{0} 0^{i} South and longitudes 37^{0} 50^{i} and 39^{0} 0^{i} East. Kitui is home to the Mumoni tropical forest reserve, which is adjacent to communal and private lands. Beekeepers place their hives in the forest, communal and private lands. Small scale agriculture, pastoralism, and beekeeping are the main sources of livelihoods in the study area (Ayuya et al., 2015; ICIPE, 2009).

Acacia and *Commiphora spp*. are the most dominant and widespread vegetation types in the study area (ICIPE, 2009). Various Acacia plants flower at different times during the rainy season. During the studied season, *A. brevispica* was the only flowering *Acacia spp*. *A. brevispica* was also the dominant flowering plant with conspicuous white flowers that could be observed throughout the study area. A smaller part of the study area is covered with small-scale agricultural farms where crops, such as mangoes, cassava, sorghum, millet, beans, and maize are grown. Temperatures in the study area range between 14^{0}C and 34^{0}C, with September being the hottest month when most bee flora dries up. The area experiences frequent droughts due to erratic and unreliable rainfall, ranging between 500-700 mm annually.

Data Collection

Abundance and diversity of flower visitors and pollinators of *A. brevispica*

To determine diversity, abundance of flower visitors and pollinators of *A. brevispica*, observations were carried out in four farms (2 ha each) located 2 km from the Mumoni forest in Mwingi North, Kitui. The distance between the farms was 1 Km. Each of the four farms had similar plant species belonging to different families, including Acacia trees. In each farm, 14 Acacia trees were selected based

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Table 1: Composition of flower visitors and abundance

		Number of visitors on observed flowers				
Visitor/Study Site	**Insect group**	**Farm 1**	**Farm 2**	**Farm 3**	**Farm 4**	**Total number of visits on flowers**
Apis mellifera	Honey bee	109	126	148	159	542
Lipotriches spp.	Bee			8		8
Lasioglossum spp.	Bee		11			11
Braunsapis spp.	Bee	1	10			11
Belenois aurota	Butterfly	16	31	9	9	65
Polistes spp	Wasp	1				1
Calliphora spp	Fly	1	6			7
Syrphus spp	Fly			5		5

on their form and structure. In each of the tree, five branches with similar form, size, and shape were selected in the middle of the crown for observation. Each branch had an average of five flowers. Pollinator exclusion bags (nylon mesh of 10µm hole size) were placed around the selected branches when flowers were at bud stage to prevent unobserved flower visitors (Hansted, Grout, Eilenberg, Dencker & Toldam-Andersen, 2012; Martins, 2008; Martins & Johnson, 2009). Flower visitor observations were carried out between 8 a.m. to 4 p.m. on sunny days when flower visitors were active. The exclusion bags were opened once and each flower was observed until it had been visited by a single visitor. Flower visitors were observed for a maximum of 10 minutes after which re-bagging was done to ensure that no other pollinator visited the flowers. Flower visitors, their abundance and behaviour on the flowers were recorded. Visited flowers were marked using a ribbon tape and numbered differently for easy monitoring. The pollinator exclusion bags were removed after fading of the visited and bagged flowers. The mature pods on the marked branches were harvested, opened and the number of seeds counted. To investigate if A. *brevispica* would set seed after self-pollination, 20 branches from the trees were selected and bagged for observation of flower visitors. Additional 20 branches were marked and left uncovered to allow for open pollination. Seed set (the proportion of flowers that developed seeds) was calculated as the number of seeds counted/potential ovules.

Collection of honey samples for pollen analysis

To assess the occurrence of Acacia pollen in honey produced within the study area, eight unprocessed honey samples were collected from hives placed in areas surrounding the four test farms. The honey samples were harvested and collected during the study season. Each sample was placed in a clean and closely tight container to avoid contamination. Containers with the honey samples were labelled and stored under room temperature (25°C).

Pollen analysis was carried out by a specialist in the Palynology section at the National Museums of Kenya. The analysis was executed based on methods of melissopalynology described by Louveaux, Maurizio and Vorwohl (1978) and Von Der Ohe, Oddo, Piana, Morlot and Martin (2004). Pollen grains were extracted from collected honey samples and identified using a collection of reference pollen slides and photographic atlas. Pollen types found in the honey were recorded and occurrence percentages in each honey sample were calculated. All of the honey samples were analyzed during the same time period to ensure uniform conditions and comparability.

Results

Flower visitors of *A. brevispica* and seed set

Flowers of *A. brevispica* were visited by different insect groups belonging to three orders; Hymenoptera (bees and wasps), Diptera (flies), and Lepidoptera (butterflies)

Table 2: Seed set (%) for *A. brevispica* flowers exposed to different visitors (open pollination) and those visited once by honey bees

	Seed Set (%)	
Site	**Flowers pollinated honey bees**	**Open pollinated**
Farm 1	29.56	50.47
Farm 2	34.66	63.28
Farm 3	30.60	49.56
Farm 4	40.83	60.75
Mean	**33.91 (±0.33)**	**56.01 (±0.19)**

(Table 1). Bees were the most diverse groups of insects visiting *A. brevispica*, with honey bees being the most frequent visitors (Table 1). Aggression of honey bees was observed on occasions where other visitors made an effort to land on flowers in which honeybees were foraging.

Seed set in *A. brevispica* was only recorded in the flowers visited by honey bees and those left for open pollination throughout the flowering period. No seed set was found in flowers excluded from visitors, or flowers visited by other insects, such as solitary bees (i.e. *Lipotriches spp., Lasioglossum spp. and Braunsapis spp.*), butterflies, wasps, and flies. On average, flowers visited by honey bees only had a seed set of 33.9% (n= 280), while flowers left for open pollination, and thus possibly visited by any local pollinator had a 56.0% (n=20) seed set (Table 2).

Pollen types found in honey samples collected from study area

A total of 22 pollen types, belonging to 14 plant families were, observed in the honey samples. Of these, 21 were identified to genus level and only one to species level (Table 3). Of the pollen type identified, two were from agricultural crops, namely Sorghum and *Zea mays*. Acacia pollen was the predominant pollen type (>45%) in all of the honey samples, thus the most important floral resource for honey bees in this study. The Acacia pollen were certainly from *A. brevispica* since it was the only flowering *Acacia spp*. in the study area during the studied season. Other pollen types were represented as secondary pollen (16-45%), important minor pollen (3-15%), and minor pollen (<3%) (Jones & Bryant, 2014; Louveaux et al., 1978).

Discussion

Honey bees were the most abundant insects visiting *A. brevispica*. Similar observations were made in other Acacia visitation studies in Hawaii (Aslan et al., 2016), Mexico (Raine, Pierson & Stone, 2007; Raine, Willmer & Stone, 2002) and India (Tandon & Shivanna, 2001). The abundance of honey bees visiting *A. brevispica* in Kitui was attributed to the presence of colonized bee hives, which results from beekeeping activities within the study area as well as the presence of wild honey bees in tree hollows within the natural environment of the study site. Honey bees also have a good communication system (waggle dance) and they take advantage of flowers with promising floral rewards which can be foraged on with minimal cost (time and energy) (Couvillon et al., 2012).

The results of this study also show that visitation of *A. brevispica* by honeybees contributed to the reproduction of the plant. Recorded seed set from flowers visited by honey bees, unlike those visited by other insects, was attributed to aggression of honey bees during foraging (Badano & Vergara, 2011; Martins, 2004; Vergara & Badano, 2009), where honey bees were observed chasing away other visitors who tried to forage on the flowers of *A. brevispica*. Reproduction success was also attributed to contact of honey bees with stamens and pistil of flowers during foraging. This result concurs with findings of other studies which noted that honey bees competes with other pollinators for floral resources (Schaffer et al., 1983; Steffan-Dewenter & Tscharntke, 2000; Thomson, 2006). Furthermore, their presence in agricultural fields may decrease the diversity of other floral visitors who are likely to be efficient pollinators (Badano & Vergara, 2011). Zero seed set in flowers visited by solitary bees, butterflies, wasps and flies suggest that organisms visiting plants may not necessarily pollinate the flower, even though they collect the floral rewards (Spears,1983; Stone et al., 2003). Higher seed set in open pollinated flowers may be as a result of the flowers being exposed to more visits or by diverse visitors. Previous studies note that visitation frequency of plants by pollinators (Aslan et al., 2016; Benachour & Louadi, 2013; Couvillon et al.,

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Table 3: Pollen types found in the honey collected from the study site

Pollen Type	Family	Pollen Type Percentage							
		HS1	HS2	HS3	HS4	HS5	HS6	HS7	HS8
Acacia spp.	Fabaceae	64	62	48	69	55	65	53	46
Justicia spp.	Acanthaceae	1		5	1	3		2	3
Leucas spp.	Lamiaceae	10	2		2	6	4	3	3
Ocimum spp.	Lamiaceae	17		13	10	5	8	4	7
Maesa spp.	Myrsinaceae	1		5		6		1	2
Sorghum spp.	Poaceae		2					1	
Cyphostem-ma spp.	Vitaceae	1							1
Euphorbia spp.	Euphorbiaceae	1	6	4	6	10	1	3	4
Allophylus spp.	Sapindaceae	1						1	1
Vernonia spp.	Asteraceae	3	18	10	2	3	8	10	7
Ageratum spp.	Asteraceae		1					1	
Solanum spp.	Solanaceae		2						1
Aspilia spp.	Asteraceae		4	10				3	5
Cucumis spp.	Cucurbitaceae			5		3	3	2	
Leonotis spp.	Lamiaceae				5			4	2
Ipomoea spp.	Convolvulaceae				1	3	2	2	3
Maerua spp.	Capparaceae				1				
Ricinus spp.	Euphorbiaceae					5	2		2
Commelina spp.	Commelinaceae						2	1	
Acalypha spp.	Euphorbiaceae						1	2	1
Zea mays	Poaceae	1			2				2
Bidens spp.	Asteraceae		2				4	3	

2015) and diversity of visitors (Stone et al., 2003; Winfree et al., 2009) enhance successful pollination. Lack of seed set on flowers that were excluded from pollinators implies that *A. brevispica* requires pollination for reproductive success (Harsh, 2000).

Occurrence of Acacia pollen types in the honeys collected from the study area confirm that Acacia plants are an important floral resource for bees, as also noted by Martins (2014). Results also indicated that honeybees have the ability to forage on a great diversity of flowering plants, including agricultural crops (Martins, 2004; Roubik, 1992; Villanueva-G & Roubik, 2004; Waser, Chittka, Prince, Williams & Ollerton, 1996) for their survival and reproduction (Roubik, 1992). Higher pollen percentages of Acacia pollen types, as compared to other pollen types (Table 3), could be attributed to honey bees preferences for *A. brevispica* as well as their availability and floral rewards offered by the plants (Fidalgo & Kleinert, 2010; Roubik, 1993).

The results of this study represent an opportunity to link pollination of Acacia woodlands, in this case *A. brevispica*, to both an income generating activity as well as to the contribution of the regeneration of the woodlands through pollination services by the honey bees. Given the current focus on sustainable development of arid and semi-arid areas by the Government of Kenya (2010), benefits derived from interactions between honey bees and Acacia woodlands could form an example of the necessity for sustainable utilization and conservation of dry land forests ecosystems in Kenya. All of the honeys sampled were classified as unifloral honey (i.e. Acacia honey), based on the predominant Acacia pollen type. Acacia honey from Kitui has a high reputation and demand as well as price premium in the market, which is attributed to the quality of the honey based on its link to origin (Egelyng et al., 2017). Fetching premium prices from Acacia honey can form an incentive for producers to conserve Acacia woodlands and other bee floral resources in order to enhance sustainable production. This has been the case for Oku white honey from Cameroon, which fetches premium prices based on its acidic flavour and unique white colour; characteristics which are attributed to two dominant white flower plants, namely *Nuxia congesta* and *Schefflera abyssinica*, present in the Oku forest (WIPO, 2014). To sustain production of Oku honey, producers and other actors within its production region have made efforts in enhancing regeneration and conservation of bee floral sources (WIPO, 2014). Increased benefits from honey production are likely to increase honey production activities, and to some extent, this may result in environmental pressure. There is, therefore, a need for policy support in beekeeping for honey production and pollination.

Conclusion

Findings of this study indicate that honey bees are important pollinators of a natural woody plant, *A. brevispica*, and are also an important floral source in honey production. Encouraging beekeeping in the study area for honey production can lead to pollination of the woodlands, thereby facilitating conservation of bees, their food resources and other biodiversity as well as local livelihoods. Therefore, this study suggests that conservation initiatives in the study area need to incorporate sustainable beekeeping practices. The results of this study also creates an opportunity to market honeys produced in the study area using labels which indicate a link of a product to the geographical origin, such as floral sources, for the honeys. This is anticipated to enhance product premium prices, which would create incentives for natural resource conservation and sustained production.

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Conflict of Interests

The authors hereby declare that there is no conflict of interests.

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