HIGH POLLINATOR DIVERSITY AND SPECIES EVENNESS INCREASES AVOCADO *(PERSEA AMERICANA)* YIELD

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Abstract

Avocado (*Persea americana*, Lauraceae) production in Kenya is effected by insect pollinators. There is lack of information on the diversity and abundances of avocado pollinators as well as their effects on the yield. This study was to determine the influence of pollinator diversity and abundances on avocado yields in farmers' fields in Murang'a County, Kenya. Data collected included identity of flower visitor and the number of individuals observed visiting per species in each season. Later, on each tree, two terminal branches with inflorescences of the same age and size were randomly identified, one bagged to deny visits by pollinators and another left open for unlimited access by pollinators. Additionally, fruit set and yield data were collected from the two treatments and compared. Data were analyzed using analysis of variance and means separated using Students' T-test in 10th edition Discovery Genstat software. Species diversity was analyzed using Shannon-Weiner Index. Pollinator diversity was higher in season two (nine insect species) as compared to season one and three (six insect species each). Abundances of Dipterans was higher in season two (40.32%) than in season one (4.68%) and three (4.53%). Fruit yield per terminal branch was highest in season two (*mean*: 1.00) than in season one (*mean:* 0.45) and season three (*mean*: 0.35) from the un-bagged terminal branches. On the bagged treatment, fruit yield of mean 0.27 was recorded in season two while yields in season one and three were (*means*: 0.14 and 0.18) fruits per terminal branch, respectively. This translated to over 185% and over 92% yield increase in fruit yield per terminal branch in un-bagged and bagged treatments, respectively when pollinator diversity increased in season two. The study confirmed that high pollinator diversity and higher species evenness increased avocado yields in Murang'a, Kenya. We recommended that wild pollinator conservation is key for increased avocado yields.

Key words: Abundance, avocado, Dipterans, diversity, yield

Introduction

Avocado (*Persea Americana* Mill*)* is an important crop in several tropical and subtropical regions around the world (Knight, 2002). In Israel, California and South Africa, pollination is a major restrictive factor to its production (Ish-Am*,* 2005; Ish-Am and Lahav, 2011). In contrast, very few pollination studies on fruit trees have been carried out in Kenya. Avocado flowers are known to suffer from inadequate pollination activity even when honeybee colonies are placed inside the orchards resulting in low fruit yields

(Vithanage, 1990; Ish-Am and Eisikowitch, 1998; Gazit and Degani, 2002).

The avocado flowers morphological assemblies do not seem to fit a specific pollinator (Wysoki *et al.,* 2002), thus, it could be factual that diverse insects could excellently pollinate it. In Central and South America, including Mexico and the Caribbean, where the avocado originated, it is naturally pollinated by an extensive array of insects, mainly stingless bees and social wasps (Ish-Am *et al.,* 1999; Can-Alonzo *et al.,* 2005). Honeybees (*Apis mellifera* L.), flies *(Chrysomya megacephala),* native wasps *(Brachygastra mellifica),* stingless bees (*Apidae, Meliponinae*), the *bombus spp.* and even thrips are major avocado flowers visitors that increase fruit set in most cultivars *(*Gazit and Degani, 2002; Wysoki *et al.,* 2002; Can-Alonzo *et al*., 2005; Afik *et al*., 2006; Gazit and Ish-Am, 2006; Ish-Am and Lahav, 2011; Balam *et al.,* 2012). Recent studies in Kenya have established that different insects in the orders Hymenoptera, Diptera, Lepidoptera and coleopteran were important avocado flower visitors and they were all recorded during the male and female flower phase overlap period (Mulwa *et al.,* 2019).

Pollinator diversity is very essential since pollinators complement each other in effecting pollination (Gikungu, 2006). Interactions between wild pollinators and managed honeybees may lead to more effective pollination than either alone on most agricultural crops (Greenleaf and Kremen, 2007; Carvalheiro *et al.,* 2011). Additionally, wild pollinators are known to increase fruit set independent of honeybee visits (Garibaldi *et al.,* 2013). However, the contributions by pollinators other than bees have not been studied well notwithstanding their potential to contribute to crop production. A recent global meta-analysis has shown that wild pollinators are more effective- crop pollinators than honeybees, enhancing fruit set by twice as much as equivalent levels of visitation by honeybees (Garibaldi *et al.,* 2013). On crops where honeybees are not effective pollinators, understanding other species of pollinators is very important to apprehend the possible interactions between the pollinating groups (Gemmill-Herren *et al.,* 2014).

However, increasing or sustaining high pollinator diversity can augment yield quantity and stability by improving the pollination effectiveness of honeybees (Greenleaf and Kremen*,* 2006) and lessen the risk of pollination failure due to climate change (Rader *et al.,* 2013; Bartomeus *et al.,* 2013). Pollination service by non-bees is a latent insurance against bee population drops. Non-bee pollinators including flies, beetles, moths, butterflies, wasps, ants, birds, and bats, among others performs 25–50% of the total number of flower visits (Rader *et al.,* 2016).

The status of research on African pollination biology reviewed in 2004 (Rodger *et al.,* 2004) observed that relatively little work had been done on pollination biology in Africa. Data on pollinator diversity in many countries of Africa remained largely unfamiliar. Thus, pollination studies have been slowed down in several countries of Africa, especially in East Africa, and this makes conservation and utilization of wild pollinators a big challenge. However, a few studies have been documented on bee diversity in natural habitats (Gikungu, 2002; Martins, 2004) and on some cultivated crops and wild crops (Njoroge, 2004; Morimoto *et al.*, 2004). This study was therefore undertaken to evaluate the diversity and abundance of avocado flower visitors as well as their effects on fruit yield. Additionally, there is urgent need to document the diversity and abundance of pollinators' fauna in both agro-ecosystems and natural habitats of Kenya for a coordinated conservation of pollinators.

Materials and Methods

This study was carried out in farmers' fields at Kandara, which is situated between longitudes 36º51'E, 37º7'48"E and latitudes 0º47'24"S, 0º58'12"S within Murang'a County, Kenya (Figure 1). The sub county has four main agro-ecological zones, Lower Highland 1 (LH1), Upper Midland 1 (UM1), Upper midland 2 (UM2) and Upper Midland 3 (UM3). Average annual rainfall is variable and ranges between 1400- 2000 mm (Jaetzold *et al.,* 2006). The rainfall pattern is bimodal and rainy seasons are clearly separated with long rains season in March – May and short rains season in October - December. Avocados are mainly grown in UM2 with annual mean temperature between 18^0C to 21^0C mostly in Ng'araria location (MOA, 2013). The soils are deep, well drained; weathered Humic Nitisols (locally known as red Kikuyu loams) with moderate to high inherent fertility (Jaetzold *et al.,* 2006).

The studies were conducted for three cropping seasons (August 2015 - July 2016; April - October 2016 and August 2016 - March 2017) for season 1, 2 and 3, respectively. Twelve farms were randomly selected in Kawendo area which is in Upper Midland 2 (UM2) agro-ecological zone of Kandara and leads in exported avocado (variety Hass) production. A minimum distance of about 10 m and 200 m was maintained from tree to tree and intra farms, respectively. Pollinator diversity and abundance data were collected on each tree, in every farm, weekly throughout the blooming period from 0900 h to 1700 h. The observer walked slowly around each tree observing inflorescences at a distance of within 1m, counting flower-visiting insects around the entire trees circumference (360°) for a period of 10 minutes per tree. All flowers located from the outer canopy to the trunk of the tree were observed. This was possible because of the open nature of the canopy and the tendency for inflorescences to be located nearer the outer canopy of the tree than buried in foliage within the tree. Where a flower-visiting species was particularly abundant, a hand-held counter was used to record numbers.

Each sampling started from a different farm to ensure unbiased observations. It was assumed that the number of flower visitors entering each tree was equivalent to the number of visitors exiting in the tree and the same assumption was used to compensate the possibility of one flower visitor being counted twice. Further, minimizing duration of observation ensured avoidance of double counting. Data included the identity of flower visitor, number of individuals observed visiting per species, time of the day and duration (seconds) taken by an individual on the flower per visit. The observations were done only under good weather conditions: temperature of 15°C and above, low wind speed, no rain, and dry vegetation (Westphal *et al.,* 2008), with at least three samplings per season. Data collection was done from the onset of the main blooming period, that is, when 10% or more of the plants had started to bloom. Insects were collected using sweep nets for three flowering seasons (September 2015- October 2015; March 2016 – May 2016 and August 2016 – October 2016), preserved in 70% alcohol and taken to KALRO – Kabete Entomology laboratory for identification.

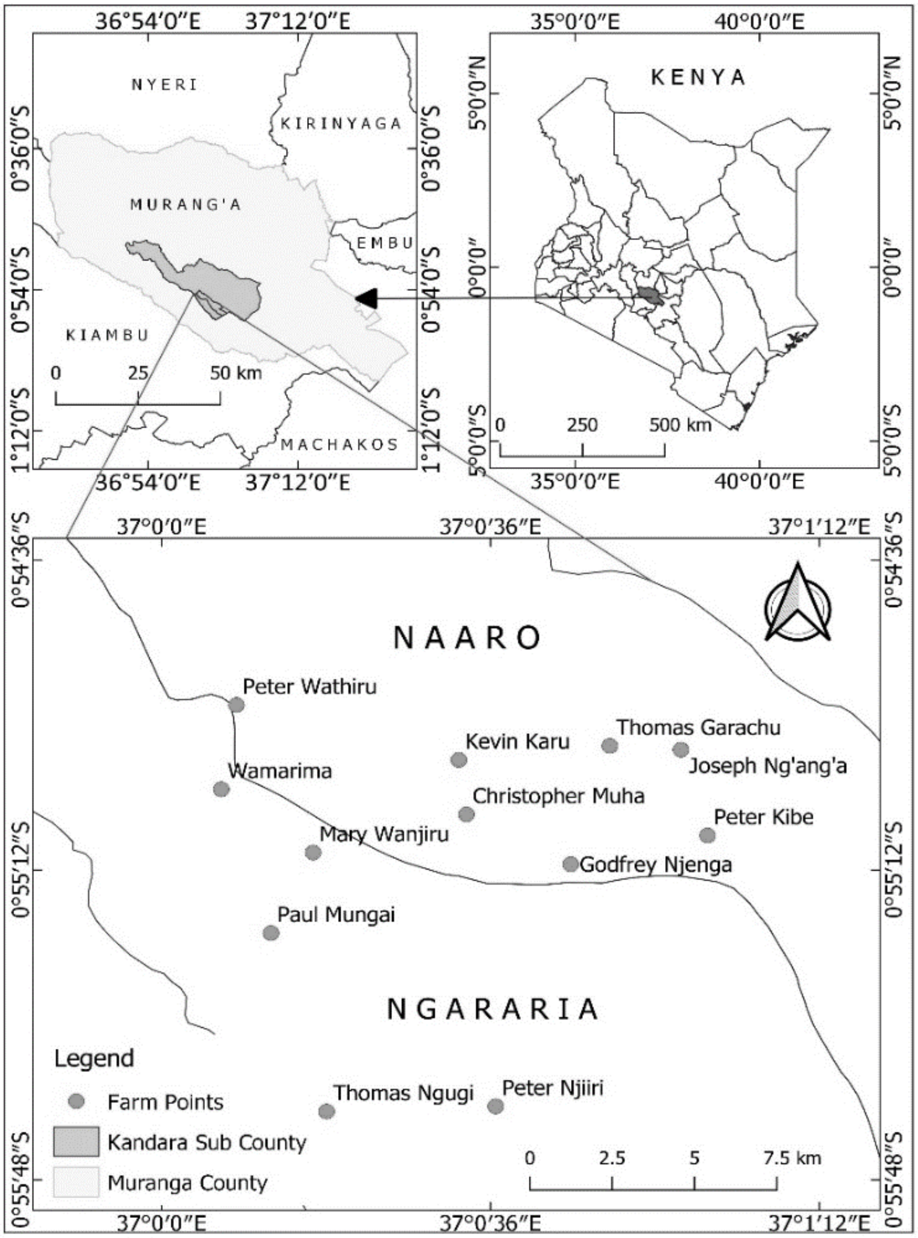

Figure 1: Map of the study site in Murang'a County, Kenya (Source: Mutungi R. M., 2019)

In addition, two randomly selected terminal branches with inflorescences of the same age and size were identified on 95 trees, one bagged to deny pollinators visits and another left open for unlimited access by pollinators to represent 2 treatments replicated 95 times. The un-bagged treatment was freely accessible to autonomous self-pollination, wind- and insect-pollination. In the second treatment (bagged), all flowers were enclosed in nylon mosquito nets (1.2mm mesh size) of an appropriate size to cover the terminal branch. Thus, in the bagged-treatment all flowers were exposed to wind- and self-pollination, but not to insect pollination. Net manipulations were done carefully and in most cases before anthesis to avoid increased levels of self-pollination (nets were put over the flower buds before the onset of flowering).

As soon as flowers wilted, the nets were removed and the fruits on the tagged terminal branches counted for fruit set data and left to develop until harvest. Fruit set data involved physical fruit counts. Yield data (number of fruits) were collected at the end of the seasons after the fruits were mature which ranged from five to nine months depending on seasonal weather. The differences in fruit numbers was determined between the bagged and un-bagged treatments using fruit physical counts.

Data analysis

Data on avocado flower visitors' identity and the number of each species found visiting avocado flowers were collected and entered into excel data sheets for analysis. Data on diversity were analyzed using Shannon Weiner Index for diversity index (H') according Shannon & Weiner (1949) using the following formulae;

$$H = \sum_{i=1}^{n} p_i lnp_i$$

where,

H – The Shannon-Weaver diversity index

P_i – The proportion of individuals belonging to species i/the total number of insects

ln – The natural log, that is, 2.78

Evenness is the diversity index divided by *ln(N)*,

where, N is the number of species noted visiting avocado flowers.

Data on fruit yield in different seasons were analyzed using ANOVA and means separated using Students' T- test in 10th edition Discovery Genstat software at 0.05 level of significance.

Results

The results show that various insects visited the avocado flowers during the three seasons study period (Table 1). More insect species (high pollinator diversity) were observed visiting avocado flowers in season two (nine species) as compared to season one and three (six species). Also, more Dipterans were observed in season two than in season one and three which had high frequencies of honeybees compared to season two. In addition species evenness of 0.72 was recorded in season two as opposed to that in season one (0.2) and in season three (0.17) (Table 1).

There was a significant difference ($p = 0.049$) in avocado yield per terminal branch (0.64±0.14) when pollinator diversity and the frequency of *Dipterans* increased in season two relative to season one (0.28±0.07) and three (0.26±0.08) in both bagged and un-bagged terminal branches. (Figure 2).

Discussion

Several insects were found visiting avocado flowers in Kandara. These included honeybees, blow flies, hoverflies, wasps, ants, *meliponula* bees, *halictus* bees, butterflies and beetles. This is in agreement with other findings that avocado pollination is effected by insects from different taxa (Gazit and Degani, 2002; Wysoki *et al.,* 2002; Can-Alonzo *et al*., 2005; Afik *et al*., 2006; Gazit and Ish-Am, 2006; Klein *et al.,* 2007; Ish-Am and Lahav, 2011; Balam *et al.,* 2012). Honeybees were the most dynamic insects observed visiting avocado flowers during the study period. This was also observed by Gazit and Degani (2002), Ish-Am (2005) and Ish-Am and Lahav (2011) that honeybees are its main pollinators in most agricultural landscapes.

Table 1: Avocado flower visitors' diversity and abundance for 3 seasons in Kandara, Murang'a County (August 2015 - July 2016; April - October 2016 and August 2016 - March 2017)

Pollinator	Frequency Season 1	Frequency Season 2	Frequency Season 3	Frequency three seasons
Apis mellifera (Linnaeus, 1758)	736	66	746	1548
Meliponula ferruginea (Lepeletier, 1841)	2	4	2	8
Halictus species (Latreille, 1804)		2	2	4
Iridomyrmex reburrus (Shattuck, 1993)	2	11		13
Polistes sp. (Latreille, 1802)	16	24	8	48
Chrysomya putoria (Wiedemann, 1818)	15	61	18	94
Eristalis tenax (Linnaeus, 1758)	22	14	18	54
Colias electo (Linnaeus, 1763)		3		3
Drypta ruficollis (Dejean, 1831)		1		1
Species richness	6	9	6	9
Species evenness	0.2	0.72	0.17	0.11
Diversity index	0.35	1.59	0.31	0.25
n	791	186	794	1,773

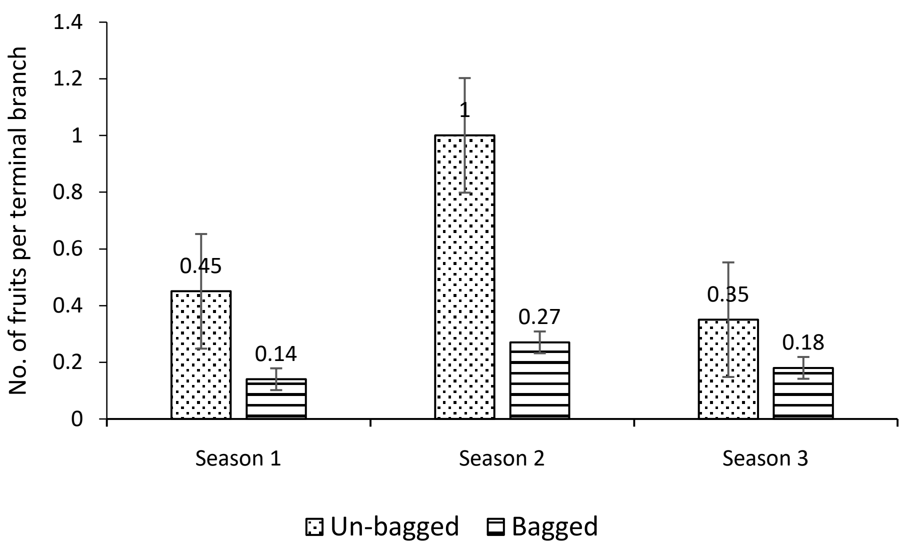

Figure 2: Mean number of fruits harvested from un-bagged and bagged terminal branches in season one (August 2015 -July 2016), two (April - October 2016) and three (August 2016 - March 2017).

Increase in pollinator diversity, decrease in honeybee frequencies in addition to increased abundances of Dipterans increased avocado yields by more than 185% and over 92% in un-bagged and bagged terminal branches, respectively in season two as compared to seasons one and three. Similar findings were observed by Greenleaf and Kremen (2007), Carvalheiro *et al.* (2011), Garibaldi *et al.* (2013) that interactions between wild pollinators and honeybees contributes to increased yields in most crops. High species evenness (0.72) in season two was associated to increased avocado yield per terminal branch than evenness of 0.2 and 0.17 in seasons one and three, respectively.

High pollinator diversity in season two as compared to season one and three could be associated to the warm and dry weather conditions experienced in Kenya in the months of January and February which promotes increased insect populations. This is supported by findings by Silva et al. (2011) that highest abundance of most arthropods is noted in the transition period from the end of the dry season to the start of the rainy one. This increase in species richness and evenness could have led to the higher fruit set and fruit yield per terminal branch recorded in season two as compared to season one and three which had low species richness (six species) and lower species evenness of 0.2.

The higher abundances of *A. mellifera* noted in season one and three as compared to season two could have been due to the warm and dry weather conditions experienced in this area during the months of September. Dry and warm weather is known to promote foraging by *A. mellifera*. This is based on the assumption that the density and population of honey bees is likely to be high in warmer conditions (Bergh, 1967; Eardley and Mansell, 1996).

Conclusion and Recommendations

This study confirmed that an increase in pollinator diversity on avocado flowers, combined with increased Dipteran frequencies improved avocado yields in Murang'a County. Based on the evidence, we recommend that conservation of the natural habitats for increased pollinator diversity and abundances of non-managed flower visitors (Dipterans) for improvement of avocado yields. Continuous monitoring of avocado flower visitors' populations within Kandara and the whole of Kenya is necessary. This will help in understanding the pollinators' stability for the purposes of pollination management planning and policy formulations.

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