Avocado (Persea americana) yield as influenced by pollinators in Murang'a County, Kenya

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ABSTRACT

Aim: The aim of this study was to determine the contribution of biotic pollination on avocado fruit set and yields.

Method and Materials: The experiment was set out at Murang'a County for three seasons from August 2015 to March 2017 in12 farmer fields, each with five randomly selected trees. On each tree, two randomly selected terminal branches with inflorescences of the same age and size were labelled, one bagged with a mosquito net(1.2mm mesh size) to deny insect visits and another left open for unlimited visitation. Data collected included identity of flower visitor and the number of individuals observed visiting per each species. Additionally, fruit set and yield data were collected. Data were analyzed using Student's T-test in Genstat12th Edition.

Results: Common visitors were Apis mellifera (87.3%), Chrysomya putoria (5.3%), Eristalis tenax (3.1%) and Polistes sp. (2.7%). There was high significant difference (P <0.001) in fruit set per terminal branch with bagged having 9.38 fruits and un-bagged with19.85 fruits. Further, highly significant difference(P= 0.002) existed in fruit yield per terminal branch; 0.165 and 0.464 fruits on bagged and un-bagged, respectively, translating to 64.5% pollination deficit. Significant differences also existed for seed weight (P=0.001), seed cavity equatorial diameter (P=0.001) and fruit equatorial diameter (P=0.035).

Conclusion: It was confirmed that bee pollination remains key role in avocado production, thus bee colony management is critical in avocado orchards for high and quality yields.

Keywords: Apis mellifera, avocado, fruit set, pollinators, pollination deficit, yield.

Introduction

Approximately 75% of the crop species used for food depends on insect pollination to some degree [1]. However, the actual degree of pollinator dependency for some of these major crops is not known. While some crops depend entirely on insect pollinator visits to set fruit, many others are only partly dependent on animal pollination and can produce more than 90% of the maximum seed or fruit yield without pollinators [1,2,3].

Wild pollinators have been recorded as more effective crop pollinators than honey bees, doubling fruit set as corresponding levels of visitation by honeybees [4]. Additionally, [5,6] observed that interactions between wild pollinators and managed honey bees may lead to more effective pollination than either alone on sunflower.

On crops where honey bees are not effective pollinators, studying other species of pollinators is very important in order to understand the possible collaborations between the pollinating groups [7].

Pollination studies are scarce especially in East Africa making conservation and utilization of wild bees a big challenge. However, a few studies have been documented on bee diversity in natural habitats [8,9] and on some cultivated crops and wild crops [10,11]. In addition, previous research has focused mainly on exploring the effects of pollinators on fruit or seed set [4,11], which is a more direct measure of plant reproduction. However, yield measurements have the potential to better reflect economic value [13,14] and hence, farmers' curiosity. Pollinator exclusion experiments are less common for most crops and especially on fruit trees [15,16].Therefore, the need to document the diversity and abundance of pollinators' fauna in both agro-ecosystems and

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natural habitats, as well as pollination deficit of major crops in Kenya is urgent.

Avocado trees typically produce more than one million flowers, of which less than 0.3% contributes to fruit set [17]. Pollination is a major restrictive factor to avocado production in Israel, California and South Africa [18,19].Its flower morphological assemblies do not seem to favor a specific pollinator [20], thus, different insects including honey bees which are its main pollinators in agricultural landscapes [21] could effectively pollinate it.

Insects' visits have been noted to significantly increase fruit set in most avocado cultivars worldwide [22]. Additionally, [21] observed that only a few or no fruit set after caging subtropical avocado to prevent pollination by insects. Avocado flowers are known to suffer from insufficient pollination activity even when honey bee colonies are placed inside the orchards resulting in low fruit yields [21,23] hence the need to document other possible pollinators that complement the honey bees' pollination function. Lack of pollination is one of the limiting factors in commercial avocado production in Israel [18] and better understanding of the pollination and fertilization processes may lead to improved fruit set and increased yield in avocado.

In its native region (neotropics), avocado is naturally pollinated by a widespread collection of insects, predominantly stingless bees and social wasps [24,25]. In other parts of the world, avocado flower visitors include honeybees (Apis mellifera L.), flies (Chrysomya megacephala), native wasps (Brachygastra mellifica), stingless bees (Apidae, Meliponinae), the bombus sp. and even thrips [18,19,20,21,22,25,26]. In Kenya's Murang'a County, a leading producer of Hass avocado for export, several insects were found to visit avocado flowers. These included honeybees, flies, wasps, butterflies, ants and beetles [27]. There are two Hass avocado blooming seasons per year, with peak flowering in March and September. In addition, Hass avocado female and male flower phases overlapped from 1200 – 1659 h lasting between one to three hours in that locality [27]. They also noted most avocado flower visitors (Hymenopterans and Dipterans) during this period, which is suggested as the most suitable time for pollination since farmers in the area practice pure stands of Hass avocado variety.

Methods and Materials

This study was carried out in farmers' fields situated between longitudes 37°0′0′′E; 37°2′0″E and latitudes 0°54′0″S; 0°56′30″S in Kandara, 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). The average annual rainfall is ranges from 1400- 2000 mm [28]. 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 180C to 210C. The soils are deep, well drained; weathered Humic Nitisols (locally known as red Kikuyu loams) with moderate to high inherent fertility [28].

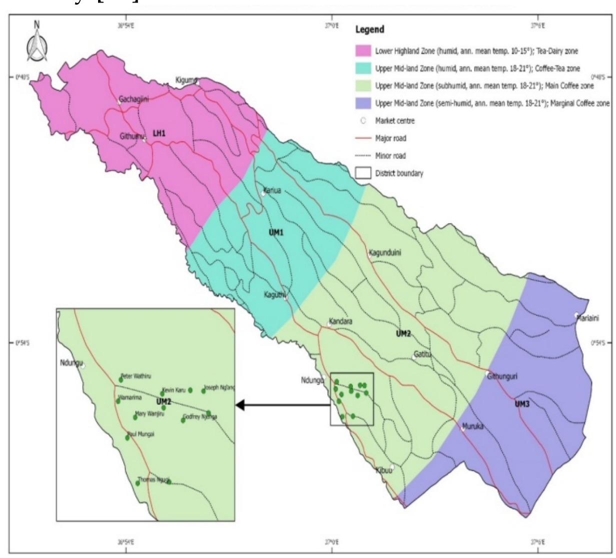

Figure 1: Study site -(Source: Matolo Nyamai, 2018)

The study was conducted for three cropping seasons (August 2015 -July 2016; April - October 2016 and August 2016 - March 2017). Twelve farms were randomly selected in Upper Midland 2 (UM2) agro-ecological zone of Kandara which leads in exported avocado (variety Hass) production. A minimum distance of about 10 m and 200 m was maintained from tree to tree and between farms, respectively. Pollinator diversity and abundance data were collected for about 10 minutes on each tree, in every farm, weekly throughout the blooming period from 0900 h to 1700 h. Each sampling started from a different farm to ensure unbiased observations, by allocating different times of the day to different farms/plants. 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 velocity, no rain, and dry vegetation [29], 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.

In addition, a pair of terminal branches with inflorescences of the same age and size (two-four inflorescences and 200 to 300 flower buds were used for each pair) were labeled on each of the 95 randomly selected avocado trees. One of the terminal branch was bagged with mosquito net of 1.2 mm mesh size to deny pollinators visits and another left open for unlimited access by pollinators (Figure 2).

Figure. 2A(Bagged)

Figure. 2B (Un-bagged)

Figure. 2C (both bagged and Un-bagged)

Figure. 2A(Bagged)

Figure. 2A(Un-bagged)

Figure 2: Avocado terminal branches. (A) Bagged; (B) Un-bagged; (C) Bagged and Un-bagged at close proximity; (D) Fruit set for bagged; (E) Fruit set Un-bagged

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 (in four to six weeks), the nets were removed and the fruits on the labeled terminal branches counted for fruit set data and left to develop until harvest. Yield data 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 were determined between the bagged and un-bagged treatments using fruit physical counts. Fruit characteristics (fruit weight (g), fruit polar diameter (mm), fruit equatorial diameter (mm), seed weight (g), seed cavity polar and equatorial diameters (mm)) were noted and differences between fruits from bagged and un-bagged treatments calculated.

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. Tables on pollinator abundance and diversity were created and data were analyzed using Shannon Weiner Index for diversity index and evenness (- [∑ Pi ln Pi]). Evenness is the diversity index divided by ln (N). Where, N is the number of species noted visiting avocado flowers. Data on fruit set, yield and fruit characteristics from bagged and un-bagged terminal branches were analyzed for significance using student's T-test at 0.05 level of significance in Genstat 12th Edition.

Results

Diversity and abundance of avocado flower visitors in Murang'a County, Kenya

Combined abundances for the three seasons showed that nine insect species in four orders (Hymenoptera, Diptera, Lepidoptera and Coleoptera) were observed on avocado flowers. Hymenoptera and Diptera orders contributed to more than 99% of the flower visitors' abundances recorded on avocado flowers. Five species (Iridomyrmex reburrus (Shattuck, 1993), Apis mellifera (Linnaeus, 1758), Polistes sp. (Latreille, 1802), Meliponula ferruginea (Lepeletier, 1841) and Halictus species (Latreille, 1804) in the order Hymenoptera and two species, Chrysomya putoria (Wiedemann, 1818) and Eristalis tenax (Linnaeus, 1758) in order Diptera were observed visiting avocado flowers. Flower visitors with high abundances were honey bees (87.3%) blow flies (5.3%), hoverfly (3.1%) and wasps (2.7%). Other insect species were rare visitors on avocado flowers and included ants (0.73%), stingless bees (meliponula bees (0.45%) and sweat bees (0.23%), formicoma beetle (0.17%) and butterflies (0.06%). The pollinator diversity index and evenness in Murang'a for the three seasons were very low (Table 1). There were nine species with diversity index of 0.25 (Table 1) and ln (9) was 2.20. The evenness was 0.11 which was very low for the insect visitors noted on avocado flowers based on known normal evenness of one when all flower visitors have equal abundances (Table 1).

Effect of avocado pollination deficit

A total of 891 fruitlets set from the bagged terminal branches while un-bagged terminal branches set 1885 fruitlets (this was done between four to six weeks after labeling of the inflorescences) which was a 211.7% increase in fruit set after exposure to insect pollinators (Table 2). A highly significant difference ($P<0.001$) in fruit set between the bagged (Mean 9.38±1.79) andun-bagged (Mean 19.85±1.79) was recorded (Table 2). Total fruit yield was 45 fruits from the un-bagged terminal branches and 16 fruits from the bagged terminal branches. This translated to a 281.3% increase in fruit yield, considering fruit abortion of 98.2% and 97.7% in bagged and un-bagged terminal branches respectively; which could have been due to other factors such as pests, nutritional soil water deficiency among others. There was a significant difference ($P= 0.002$) in fruit yield between the bagged (Mean0.17±0.07) andun-bagged (Mean 0.46±0.07) fruits per terminal branch in the three seasons. This translated to 64.5% pollination deficit, which confirms the world recorded pollination deficit of avocado (Table 2).

On fruit parameters for the three seasons, there were highly significant ($P<0.001$) differences in seed cavity equatorial diameter and in seed weight ($P<0.001$) between fruits from the bagged and un-bagged terminal branches. There was also significant difference in fruit equatorial diameter ($P=0.035$). However, there were no significant difference in fruit polar diameter ($P=0.947$), in fruit weight ($P= 0.055$) and in seed cavity polar diameter ($P=0.136$), respectively between fruits harvested from bagged and un-bagged terminal branches (Table 3).

Table 1: Avocado pollinators' diversity, abundance and diversity index for three seasons combined (September – October 2015; March - May 2016 and September – October 2016).

Order	Species	Common name	No of observations	% abundance	Pi	ln Pi	- (P_i * ln P_i)
Hymenoptera	*Apis mellifera*	Honey bee	1,548	87.31	0.873	-0.059	0.051
Diptera	*Chrysomya putoria*	Blow fly	94	5.302	0.053	-1.276	0.068
Diptera	*Eristalis tenax*	Hoverfly	54	3.046	0.03	-1.516	0.046
Hymenoptera	*Polistes* sp.	Wasp	48	2.707	0.027	-1.567	0.042
Hymenoptera	*Iridomyrmex reburrus*	Ant	13	0.733	0.007	-2.135	0.016
Hymenoptera	*Meliponula ferruginea*	Meliponula bee	8	0.451	0.005	-2.346	0.011
Hymenoptera	*Halictus species*	Sweat bee	4	0.226	0.002	-2.647	0.006
Lepidoptera	*Drypta ruficollis*	Butterfly	3	0.169	0.002	-2.772	0.005
Coleoptera	*Colias electo*	Formicoma beetle	1	0.056	0.001	-3.249	0.002
Total			**1,773**	**100**	**1**	**-17.566**	**0.246**

Table 2: Mean avocado fruit set and yield (log10 (n+1)) on bagged and un-bagged terminal branches in Kandara, Murang'a in three seasons (August 2015 - July 2016; April - October 2016 and August 2016 - March 2017)

Treatment	Fruits set per terminal branch	Yield per terminal branch	% fruit drop	% fruit set increase	% yield increase	% deficit
Bagged	1.76±0.11[b]	0.05±0.01[b]	98.2			64.45
Un-bagged	2.62±0.10[a]	0.12±0.02[a]	97.7	211.6	281.3	
t-value	-5.78	-3.16				
df	188	161				
p-value	<0.001	0.002				

Table 3: Mean yield parameters for avocado fruits harvested from bagged and un-bagged terminal branches in Kandara, Murang'a in three seasons (August 2015 - July 2016; April - October 2016 and August 2016 - March 2017)

Treatment	Fruit weight (g)	Fruit equatorial diameter (mm)	Fruit polar diameter (mm)	Seed weight (g)	Seed cavity equatorial diameter (mm)	Seed cavity polar diameter (mm)
Bagged	112.6±7.03	53.06±1.32	74.06±2.56	7.13±1.07	22±0.84	27.94±1.13
Un-bagged	133±7.65	57.07±1.28	73.87±1.49	15.41±1.7	27.29±1.12	30.4±0.88
t- value	-1.96	-2.18	0.07	-4.04	-3.78	-1.51
df	48	43	59	59	56	59
p-value	0.055	0.035	0.947	<0.001	<0.001	0.136

Discussion

A number of insects were found visiting avocado flowers in Kandara. These comprised honeybees, blow flies, hoverflies, wasps, ants, meliponula bees, halictus bees, beetles and butterflies. This is in agreement with other findings that avocado pollination is effected by insects from different taxa [19,20,25,26]. Honeybees were the most active insects observed visiting the avocado flowers during the study period. Similar observations were made by [18,19,21] that honeybees are its main insect pollinators in most agricultural landscapes.

Observations for each flower visitor for the three seasons showed that honey bees had the highest visits at all times of the day with 1548 observations. Blow flies were second with 94 observations while hoverflies and wasps had 54 and 48 observations throughout the study period. Combined observations for Hymenopterans showed that they were the leading pollinator insect group with 91.43%, Dipterans (8.35%), Coleopterans (0.17%) and Lepidopterans (0.06%) of the total visits. This is in agreement with [30,31] that Dipterans are second in importance as pollinators after the Hymenopterans in most crops.

Fruit set was recorded in bagged inflorescences during the study. Alike results were reported by [32,33,34] and they concluded that increased fruit set in the bagged inflorescences could have been due to airborne pollen or small insects like thrips inside the flowers that effected self-pollination. Since nets do not hinder the airborne pollen flow [35,36], it implies that the difference observed between these treatments was as a result of insects' pollination.

The results of this study showed that insect flower visitors contribute significantly to fruit yield (quantity) increase and high seed quality (weight and size) which may be of importance during seedling growth as observed on mango [37]. This study was supported by the findings of [18,21,38] that pollination is a limiting factor in avocado production, and insects are very important as flower visitors effecting avocado pollination [39].

Conclusion

This study confirmed that honeybees are important visitors of avocado flowers. Blow flies, hoverflies and wasps could also be important pollinators especially when honeybees' visitation is low. Based on the evidence, it is recommended that honey bee colonies could be introduced in avocado orchards for increased pollination hence improvement in avocado yields. Insect pollinators' conservation could enhance their abundances and their diversity leading to a possible compliment resulting to increased avocado yields. Experiments to compare differences in efficiencies of different insect pollinators could be set including their pollen load studies to differentiate the avocado flower visitors from pollinators since not all flower visitors are pollinators. Nutrient content (oil and minerals) in the fruits from the bagged and un-bagged terminal branches could be determined to understand other benefits due to insect pollination. These will be useful for the purposes of pollination management planning and policy formulations.

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