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ORIGINAL RESEARCH ARTICLE

Abundance and community composition of flower visiting insects of avocado (*Persea Americana* Mill) in the East African region

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Abstract
Pollination of avocado flowers is essential for fruit production and is facilitated by various insect taxa. Currently, there is limited information available on the community structure of the pollinators of avocado crops in East Africa. We duly present the distinct groups of insects visiting avocado flowers across two most important avocado producing countries in the East African region. Insects were swept from avocado flowers along transects and sorted by morphological features that classified them into orders, families, and genera. Five common orders were identified, namely: *Coleoptera, Diptera, Heteroptera, Hymenoptera,* and *Lepidoptera.* The relative abundance of *Hymenoptera* and *Diptera* were highest (49% and 22% respectively) hence we further identified them to the families and genera taxonomic groups. Three *Dipteran* families were found (*Calliphoridae, Muscidae,* and *Syrphidae*) from which we recognized five genera: *Chrysomya, Spilogona, Eristalinus, Phytomia and Syritta*. *Hymenoptera* on the other hand were placed into two general groups; bees and wasps. For bees, family *Apidae* was represented by *Apis, Ceratina, Meliponula,* and *Xylocopa* whereas seven diverse wasp families (*Braconidae, Philanthidae, Vespidae, Ichneumonidae, Eumeninae, Thynnidae* and *Pompilidae*) were also noted. The occurrence of *Coleoptera* and *Lepidoptera* varied across the three orchards while the rest of the orders remained unaffected. We further recorded the insect's potential pollinator functions and concluded that the main pollinators of avocado flowers in the region are members of *Syrphidae* and *Apidae* families. This information serves as a foundation for avocado pollination studies in the East African region that are important for improving pollination services and insect pollinators' conservation.

Keywords Pollination · Morphological features · Insect orders · Genera · Kenya · Tanzania

Introduction

Pollination accounts for the production of estimated 87.5% angiosperm species worldwide (Ollerton et al. 2011), 35% of which directly serves humanity as food sources across the globe (Klein et al. 2007). Insect-mediated pollination has the greatest share in the key ecosystem service accounting for the production of most single crops (Klein et al. 2007). Avocado (*Persea americana* Mill), is a tree crop of the family *Lauraceae* that is recognized globally for its nutritional and cosmetic versatility for human health (Dreher and Davenport 2013; Duarte et al. 2016). In East Africa, Kenya is the largest producer of the fruit with production of 196,555 metric tons in 2018 alone (FAO 2020). Although avocado production data is currently not available in the FAO database for Tanzania, cultivation and trade of avocados have been reported from the country (Juma et al. 2019).

Using the FAO dataset on cultivated crops, Aizen et al. (2009) found out that avocado is unfortunately one among several crops whose yields have decreased over the years in spite of increased cultivation areas. Their findings proved that yields do not necessarily improve with increased cultivation areas. This fact then begs for new sustainable farming practices that would enhance yields especially for the region that earns a lot of revenue from avocado fruit exports. Despite spirited efforts to eradicate pest and disease and limit post-harvest losses, information is still lacking on how the ecosystem service of pollination could also be included in these efforts to enhance avocado yield for avocado farmers in these two countries.

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One of the major factors that contribute to yield of most angiosperm species is the amount of fruits that set after pollination (Pashte and Kulkarni 2015). A positive correlation between fruit set and pollinator functional group (FG) richness as established by Albrecht et al. (2012) insures plant reproductive success. While conducting their routine foraging for various floral rewards, pollinator insects usually unwittingly pollinate avocados as they transfer pollen stuck on their various body parts from one flower to another (Perez-Balam et al. 2012). These flower foragers include diverse species of bees and wasps (*Hymenoptera*), flies (*Diptera*), and butterflies (*Lepidoptera*) (Mehmood et al. 2015; Pérez-Balam et al. 2012) that exist in wild communities (flies and solitary bees) and managed colonies (honeybees and stingless bees) (Ish-Am and Eisikowitch 1993; Peterson 1955). The diversity of these arthropod pollinators gives the flower a rare advantage of experiencing different pollination behaviour that has a positive net effect on its pollination (Brittain et al. 2013).

The increasing global threats to pollinators such as pests and diseases, pesticides, land use intensification and invasive species (Dicks et al. 2020) have led to declines in pollinator populations (Vanbergen et al. 2013). An example is in a UK study where Biesmeijer et al. (2006) documented declines in bee and hoverfly pollinator species that was succeeded by parallel declines in out-crossing plant species of Britain and Netherlands that depended entirely on these insects for pollination.

As an outcrossing species, avocado is at a high risk of suffering insufficient pollination owing to the diminishing pollinator communities. Pollination of avocado flowers by insects is well studied in other regions of avocado mass production like Mexico (Perez-Balam et al. 2012), Spain (Perez-Balam et al. 2012), California (Davenport 2019), Israel (Perez-Balam et al. 2012) and South Africa (Toit and Swart 1993). The most abundant pollinator is the Western honeybee, *Apis mellifera*, followed by stingless bees and a range of dipteran flies, but with quite region-specific flower visitor communities. While the honeybee is globally distributed, many other species have a limited range of distribution and might not occur in Africa, while related species of the same group do occur. This could be true for stingless bees which are frequently found visiting avocado flowers in South and Central America (Can-Alonzo et al. 2005) however, related species do occur in Africa (Ndungu et al. 2017).

The lack of sufficient knowledge on pollination systems in avocado orchards in East Africa therefore presents a huge gap in understanding the identity and impact of pollinator communities on avocado production for this region. In order to improve pollination services it is required to know the identity of those communities. We present an inventory of insects, their abundance and diversities in three avocado production sites of Kenya and Tanzania in order to highlight the insect groups that could be paramount for avocado pollination in these countries. Our intention is to use this knowledge to build a foundation for further research on pollinators of avocados and how the ecosystem service may be manipulated for increased production of avocados in the East Africa region.

Materials and methods

Sampling locations

Sample collection was conducted in three major avocado growing sites of Murang'a in Kenya, Siha, and Lushoto districts of the United Republic of Tanzania. Murang'a County lies at an elevation of 1,267 m above sea level and experiences a tropical climate with average temperature and precipitation at 20.0˚C and 1,195 mm respectively (Climate-data.org). Siha District is elevated at 1,115 m above sea level; the region experiences a warm and temperate climate and with annual temperature and precipitation at 20.5˚C and 1,189 mm respectively (Climate-data.org). Lushoto district, on the other hand, sits at an elevation of 1,378 m above sea level, experiences a warm and temperate climate with annual temperature and precipitation averages of 17.3˚C and 1,074 mm respectively (Climate-data.org). The farms at were located at 0°55′4.71°S, 37°10′22.00°E; 3°9′56.35"S, 37°4′25.22"E; and 4°35′42.26°S, 38°18′58.97°E for Murang'a, Siha and Lushoto sites respectively.

Insects were sampled from two large scale production zones in Murang'a and Tanzania and a smallholder farming plot in the district of Lushoto. The two large-scale sites were supplemented with at least two honeybee hives per farming plot while four stingless bee hives were observed in the Lushoto farm. While the orchard setting in Murang'a comprised of numerous avocado plots (2.1 ha each) bordering one another with intervals of hedges and tall trees, Siha consisted of fewer plots that were at least three times larger than Murang'a plots. Moreover, Siha farms bordered the great Kilimanjaro forest which is a wealthy ecosystem harboring diverse animal species. We chose 13 plots in the Murang'a orchard with average measurements of 400 m × 600 m and eight plots in the Siha orchard with average sizes of 400 m × 900 m. The farm in Lushoto was approximately 400 m^2 tucked within the Usambara mountains. The farm entailed an intercropped system of mango and avocado trees where we counted a total of 35 avocado trees. Other avocado trees were also sighted within a 2 km range from the sampling site. Sample collection occurred during the major avocado flowering season between September and November 2018.

Sampling technique

Line transects were place along the width of individual plots at intervals of 200 m in Murang'a and Siha locations thus resulting into three and five transects respectively per farming plot. Random scan sampling technique was employed in Lushoto, where a third of the number of trees per farm was used for sampling hence 15 trees were sampled from a total of 35 trees. Each farming plot was sampled twice for all the three sites; in the morning from 9 am to 12 pm and afternoon from 2 to 5 pm in order to accommodate insects that visit at different times of day. Murang'a and Siha farms were each sampled for five days while the Lushoto farm was sampled in two days. Collection time per tree was limited to 10 min. Insects were directly obtained from flowers by the use of sweep nets and sweeping out insects that were sighted visiting the avocado inflorescences. The specimens were immobilised by exposing them to cotton swabs soaked in absolute ethanol (98%) followed by immediate storage in absolute ethanol in collection tubes.

Sample processing

Specimens were removed from ethanol and set at a sterilized work surface and left to dry for 15 min to facilitate accurate identification. Identification was done using a Zeiss® light microscope (Carl Zeiss GmbH, Germany) attached with a digital camera. Digital images of the samples were captured using the ZEN image suite (Jena, Germany). The two most abundant insect orders across the three sites were subjected to further identification up to the genus level. Identification of these respective taxonomic groups was assisted by the use of an insect identification key (Eardley et al. 2010).

Data analysis

Tabular data were tailored and loaded into R studio for analyses. Abundance of specimens in each order per site were plotted in a bar chart using the ggplot2 package in R. Shannon–Weaver diversity indices (SWDI) for the orders from each site were also calculated using the Microsoft Excel spreadsheets then jack-knifed over orders. The SWDI dataset was also loaded in R studio where we applied a one-way ANOVA along with an LSD post hoc test (package *DescTools*, Signorelli et al. 2020) conducted to query for the effect of geographical location and farm sizes on insect order diversity.

The distribution of the insect orders across the three regions was tested using Monte Carlo statistics for RxC tables (http://rxc.sys-bio.net, Blüthgen et al. 2006). We used the row- and column-wise Kullback–Leibler-distance to infer regions and orders that contributed to the overall diversity.

Results

A total of 619 individual insects were collected in the sampling points (Murang'a $n=329$; Lushoto $n=105$; Siha $n=185$). These were grouped into the five distinct orders of *Coleoptera, Diptera, Heteroptera, Hymenoptera,* and *Lepidoptera* as illustrated in Fig. 1 and Table 1. depicting

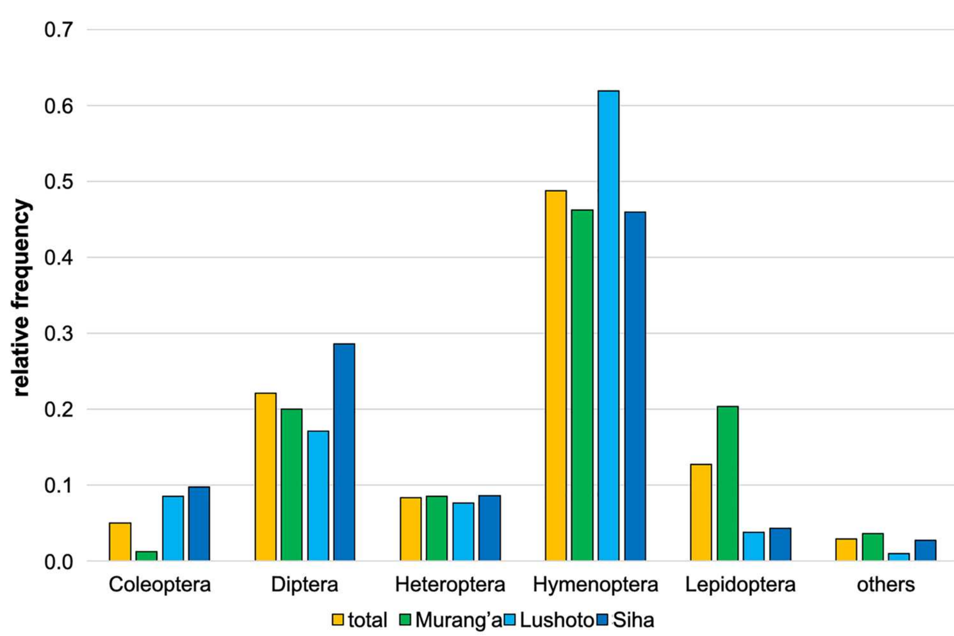

Fig. 1 Relative frequencies of the six insect groups sampled across three regions in Kenya and Tanzania. Lushoto had the highest frequency for Hymenoptera while Siha and Murang'a had the highest relative frequencies for Diptera and Lepidoptera respectively. The most common insects across the three regions are Hymenoptera, Diptera and Lepidoptera

Table 1 Insects collected from avocado fields of Kenya and Tanzania grouped by orders. Under Others, we grouped a range of different orders (e.g. Odonata, Orthoptera) which overall contribute less than 5% of the total insects. Values indicate the abundance while in brackets are the relative frequencies per region

Site	*Coleoptera*	*Diptera*	*Heteroptera*	*Hymenoptera*	*Lepidoptera*	Others	Total
Murang'a	4	66	28	152	67	12	329
	(0.01)	(0.20)	(0.09)	(0.46)	(0.20)	(0.04)	
Lushoto	9	18	8	65	4	1	105
	(0.09)	(0.17)	(0.08)	(0.62)	(0.04)	(0.01)	
Siha	18	53	16	85	8	5	185
	(0.10)	(0.29)	(0.09)	(0.46)	(0.04)	(0.03)	

abundance of each insect order in the three respective sites. SWDI values showed that the abundance of insects per order was significantly different across the three sites (ANOVA, $F = 3.88$, $p \leq 0.05$). Murang'a and Siha showed an SWDI of 0.77 and were not significantly different in an LSD post hoc test, while Lushoto had an SWDI of 0.66 and differed remarkably from the other regions (LSD post hoc test, Murang'a-Lushoto: $p \leq 0.05$; Siha-Lushoto: 0.03). Of all the five orders represented, orders *Diptera* and *Hymenoptera* had the highest abundance while *Coleoptera* and *Lepidoptera* were the least abundant across the three sites.

Although the orders *Coleoptera* and *Lepidoptera* had the least representation across the three sites, their presence in the orchards had the greatest significant effect on the overall diversity (Monte Carlo statistics for RxC matrices, $p < 0.0001$) with an overall frequency of 5 and 12%, respectively as represented in Table S1.

Hymenoptera were further classified into two generalized groups: the wasps and bees. Wasps had a total of 6 families scattered across the regions while the bees identified belonged to the Apidae family. In Apidae, we managed to recognize four genera and it is only the genus *Apis* that was represented across the three studied sites, *Ceratina* was found only in Murang'a while *Xylocopa* and *Meliponula* were only observed in Lushoto (Table 1). Classification of the Diptera resulted in three families; the *Calliphoridae, Muscidae* and *Syrphidae* from which we extracted six genera (Table 2). We additionally provided morphological evidence for the relevance of each of these genera in pollination such as presence of body hairs for trapping pollen particles (Table 3).

Discussion

Our results reveal that five major insect orders visited flowers in the sampled avocado orchards of Kenya and Tanzania. Whereas all the orders were represented, Diptera and Hymenoptera had the highest representation across the three orchards. We also noted that the abundance at Lushoto was significantly lower than in Murang'a and Siha, probably due to the orchard size and farming practice differences. According to Carvalheiro et al. (2010), farming practices had a remarkable effect on pollinator populations occurrence and densities in semi-natural habitats of Serbia during summer. In the study, tillage improved insect pollinator densities while proximity to natural habitats and places of high biodiversity affected pollinator species occurrence. Shuler et al. (2005) also reported effect of tillage on pollinator density in curcubit farms though other practices such as pesticide use or supplementation of farms with honeybees did nothing to affect the same.

The results of the Shannon–Weaver diversity analysis also showed that diversity of insects in Murang'a and Siha are

Table 2 Classification of Diptera and Hymenoptera into families and genera. For wasps only families were identified

	Diptera			*Hymenoptera*	
	Calliphoridae	*Muscidae*	*Syrphidae*	Bees (*Apidae*)	Wasps
Murang'a	*Chrysomya Hemipyrellia*	*Spilogona*	*Eristalinus Syritta Phytomia*	*Apis Ceratina*	Braconidae Eumeninae Ichneumonidae Philanthidae Pompilidae Thynnidae Vespidae
Lushoto	*Hemipyrellia*		*Eristalinus*	*Apis Meliponula Xylocopa*	Vespidae
Siha	*Chrysomya Hemipyrellia*	*Spilogona*	*Eristalinus*	*Apis*	Vespidae Philanthidae

Table 3 Overview of flower visitors at avocado (*Persea americana*) in East Africa including their inferred function and evidence for it

Order	Family	Species	Function	Supporting evidence
Coleoptera	diverse	diverse	`Mess-and-soil pollinators ‘	Hairy body Dense setae and pubescence
Diptera	Calliphoridae	*Hemipyrellia sp.*	pollinators	Hairy body
		Chrysomya sp.	pollinators	Hairy body
	Muscidae	*Spilogona sp.*		
	Syrphidae	*Eristalinus sp.*	pollinator	hairy body
		Phytomia sp.	pollinator	hairy body
		Syritta sp.	pollinator	hairy body
Heteroptera	diverse	*diverse*	herbivore	
Hymenoptera	Apidae	*Apis mellifera*	pollinator	hairy body, known role as pollinator
		Ceratina sp.	pollinator	hairy body
		Meliponula sp.	pollinator	hairy body, known role as pollinator
		Xylocopa sp.	pollinator	hairy body
	Braconidae	*Zelodia sp.*	parasitoid	none
	Philanthidae	*Philanthus sp.*	predator	none
	Ichneumonidae	*Charops sp.*	parasitoid	none
	Pompilidae	*Ageniella sp.*	predators of spiders	none
	Thynnidae	*Methocha sp.*	parasitoid	none
	Vespidae	*Eumenes sp., Belonogaster sp.*	predator	none
Lepidoptera	diverse	diverse	Pollinators	Hairy body
others	diverse	diverse	Several predators and herbivores	none

similar, a factor that may be attributed to similar farming practices and the presence of beehives in each farming plot in both orchards. While the importance of honeybees to avocado pollination is quite undisputed, the contribution of specific fly families and genera to the same still remains subject to discussion (Eardley and Mansell 1996). Although the Diptera have previously been associated with erratic visitation rates, they are still great in pollinating avocados especially in the absence of honeybees or in farms where honeybee abundance is low (Eardley and Mansell 1996; Ish-Am et al. 1999). The most common Diptera foraging on avocado belong to the family Syrphidae (hoverflies) though other flies have been recorded in Pakistan (Mehmood et al. 2015). Ssymank et al. (2008) identified syrphid Diptera as the most important fly pollinators of avocado with admirable qualities such as flower constancy and predation on plant pests such as aphids in a UK study on temperate ecosystems. Orford et al. (2015) additionally established insignificant differences in pollen loads by syrphid and non-syrphid Diptera, ascertaining that other Diptera are equally as important to the avocado in matters of pollination. Ish-Am et al. (1999) also observed that honeybees foraged less on avocado flowers in the vicinity of other more attractive flowers in the orchards of Mexico. Similar observations have likewise been noted for South Africa (Eardley and Mansell 1996) and this probably agrees with Peña and Carabalí (2018) since the overall effectiveness of the honeybee for pollination of avocado flowers is tied to foraging activity.

Stingless bees, on the other hand compete with honeybees for forage and the dominance of one group in a particular habitat diminishes the other (Roubik 1978). This is a likely explanation for the presence of stingless bees in Lushoto, a region that had fewer honeybees compared to Murang’a and Siha in our study. We also attribute this phenomenon to the stingless bee husbandry that we found in progress at our site in Lushoto. Pollination of avocado by wild bees in the region unfortunately remains largely unexplored, and presently only Luvonga (2015) observed the presence of *Ceratina* in a farm in Taita, Kenya, and their utility in the pollination of the avocado could be the subject of more research. *Ceratina* was absent in the Tanzanian farms and this could be as a result of the higher elevations of the two sites that may not favour their habitation although more research needs to be done to ascertain this.

While studying the California almond, Brittain et al. (2013) observed farms that hosted non-*Apis* bees present experienced more visits by honeybees, a behaviour that culminated into effective pollination of the crop. It is likely therefore, that the presence of *Ceratina* within Murang'a farms could be beneficial in the overall pollination of avocados in the vicinity. Although wasps were also identified from avocado farms, their potential as efficient pollinators was ruled out due to their inability to trap and ferry pollen on their bald bodies (Ish-Am et al. 1999; Pérez-Balam et al. 2012). Moreover, most of the wasp families identified predate on smaller insects and their presence within the farms could negatively affect pollinator availability. Although the functionality of honeybees for pollination of avocado flowers is a known subject, other insects that also perform this ecosystem service have relatively been ignored. Our study testifies that pollinating insects that frequently visit avocado blooms are mainly of orders Diptera and Hymenoptera that are present in diverse genera and species. The global decline of honeybee colonies in the northern hemisphere serves as a trigger for the identification and conservation of alternative pollinator insects for pollination sustainability (Ellis et al. 2010; Neumann and Carreck 2010). We, therefore, encourage further studies to decipher optimal farm conditions that would enable the thriving of pollinators in our avocado farming systems.

Conclusion

The value of insect pollinators mainly of the orders Diptera and Hymenoptera cannot be overlooked especially in the East African region where there is potential for increased production of this crop for subsistence and export. From the study we conclude that honeybees are the dominant pollinators of avocados since they occur across the three regions and in high abundance. *Ceratina* was the only pollinator unique to Murang'a while *Xylocopa* dominated at Lushoto. Both genera play their unique roles in facilitating pollination and its therefore imperative to quantify their effectiveness in pollinating avocados. We also noted the genera *Eristalinus* (Syrphidae) and *Chrysomya* (Calliphoridae) in all the regions and conclude that the avocado farming ecosystem could be a strong enabler for their survival, a state that should be preserved in order to encourage habitation by other Dipteran pollinators.

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Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

Aizen MA, Garibaldi LA, Cunningham SA, Klein AM (2009) How much does agriculture depend on pollinators? Lessons from long-term trends in crop production. Ann Bot 103:1579–1588. https://doi.org/10.1093/aob/mcp076

Albrecht M, Schmid B, Hautier Y, Muller CB (2012) Diverse pollinator communities enhance plant 265 reproductive success. P Roy Soc B 279:4845–4852. https://doi.org/10.1098/rspb.2012.1621

Biesmeijer JC, Roberts SPM, Reemer M, Ohlemüller R, Edwards M, Peeters T, Schaffers AP, Potts SG, Kleukers R, Thomas CD, Settele J, Kunin WE (2006) Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. Science 313:351–354. https://doi.org/10.1126/science.1127863

Blüthgen N, Menzel F, Blüthgen N (2006) Measuring specialization in species interaction networks. BMC Ecol 6:9. https://doi.org/10.1186/1472-6785-6-9

Brittain C, Williams N, Kremen C, Klein AM (2013) Synergistic effects of non-*Apis* bees and honey bees for pollination services. P Roy Soc B 280:20122767. https://doi.org/10.1098/rspb.2012.2767

Can-Alonzo C, Quezada-Euán JJG, Xiu-Ancona P, Moo-Valle H, Valdovinos-Nunez GR, Medina-Peralta S (2005) Pollination of 'criollo' avocados (*Persea americana*) and the behaviour of associated bees in subtropical Mexico. J Apicult Res 44:3–8. https://doi.org/10.1080/00218839.2005.11101138

Carvalheiro LG, Seymour CL, Veldtman R, Nicolson SW (2010) Pollination services decline with distance from natural habitat even in biodiversity-rich areas. J Appl Ecol 47:810–820. https://doi.org/10.1111/j.1365-2664.2010.01829.x

Davenport TL (2019) Cross- vs. self-pollination in 'Hass' avocados growing in coastal and inland orchards of Southern California. Sci Horticult 246:307–316. https://doi.org/10.1016/j.scienta.2018.10.051

Dicks LV, Breeze TD, Ngo HT, Senapathi D, An J, Aizen M, Basu P, Buchori D, Galetto L, Garibaldi L, Gemmill-Herren B, Howlett B, Imperatriz-Fonseca V, Johnson S, Kovács-Hostyánszki A, Kwon YJ, Lattorff HMG, Lungharwo T, Seymour C, Vanbergen A, Potts SG (2020) A global assessment of drivers and risks associated with pollinator decline. Res Square 1–21. https://www.researchsquare.com/article/rs-90439/v1

Dreher ML, Davenport AJ (2013) Hass avocado composition and potential health effects. Crit Rev Food Sci Nutr 53:738–750. https://doi.org/10.1080/10408398.2011.556759

Duarte PF, Chaves MA, Borges CD, Mendonça CRB (2016) Avocado: Characteristics, health benefits, and uses. Ciênc Rural 46:747–754. https://doi.org/10.1590/0103-8478cr20141516

Eardley CD, Kuhlmann M, Pauly A (2010) The bee genera and subgenera of sub-Saharan Africa. ABC Taxa 7:1–138

Eardley CD, Mansell MW (1996) The natural occurrence of insect pollinators in an avocado orchard. South African Avocado Growers' Association Yearbook 19:36–38

Ellis JD, Evans JD, Pettis J (2010) Colony losses, managed colony population decline, and colony collapse disorder in the United States. J Apic Res 49:134–136. https://doi.org/10.3896/IBRA.1.49.1.30

FAO (2020) FAOSTAT: Food and agriculture data. http://www.fao.org/faostat/en/#home

Ish-Am G, Barrientos-Priego F, Castañeda-Vildozola A, Gazit S (1999) Avocado (*Persea americana* Mill.) pollinators in its region of origin. Rev Chapingo Serie Horticult 5:137–143

Ish-Am G, Eisikowitch D (1993) The behaviour of honey bees (*Apis mellifera*) visiting avocado (*Persea americana*) flowers and their contribution to its pollination. J Apicult Res 32:175–186. https://doi.org/10.1080/00218839.1993.11101303

Juma I, Fors H, Hovmalm HP, Nyomora A, Fatih M, Geleta M, Carlsson AS, Ortiz RO (2019) Avocado production and local trade in the southern highlands of Tanzania: a case of an emerging trade commodity from horticulture. Agronomy 9:11–749. https://doi.org/10.3390/agronomy9110749

Klein AM, Vaissiere BE, Cane JH, Steffan-Dewenter I, Cunningham SA, Kremen C, Tscharntke T (2007) Importance of pollinators in changing landscapes for world crops. P Roy Soc B 274:303–313. https://doi.org/10.1098/rspb.2006.3721

Luvonga EB (2015) Diversity and pollination activity of flower visiting insects associated with avocado along the slopes of Taita Hills in Kenya. MSc thesis, Masinde Muliro University of Science and Technology, Kenya. http://34.250.91.188:8080/xmlui/handle/123456789/168, Accessed 19 Aug 2020

Mehmood K, Hussain S, Mustafa N, Bodlah I, Ahmad M (2015) Insect pollintors visiting citrus (*Citrus limon*) and avocardo (*Persea americana*) fruit trees. Asian J Agri Biol 3:23–27

Ndungu NN, Kiatoko N, Ciosi M, Salifu D, Nyansera D, Masiga D, Raina SK (2017) Identification of stingless bees (*Hymenoptera: Apidae*) in Kenya using morphometrics and DNA barcoding. J Apicult Res 56:341–353. https://doi.org/10.1080/00218839.2017.1327939

Neumann P, Carreck NL (2010) Honey bee colony losses. J Apic Res 49:1–6. https://doi.org/10.3896/IBRA.1.49.1.01

Ollerton J, Winfree R, Tarrant S (2011) How many flowering plants are pollinated by animals? Oikos 120:321–326. https://doi.org/10.1111/j.1600-0706.2010.18644.x

Orford KA, Vaughan IP, Memmott J (2015) The forgotten flies: the importance of non-syrphid Diptera as pollinators. P Roy Soc B 282:20142934. https://doi.org/10.1098/rspb.2014.2934

Pashte VV, Kulkarni SR (2015) Role of pollinators in qualitative fruit crop production: a review. Trends Biosci 8:3743–3749

Peña JF, Carabalí A (2018) Effect of honey bee (*Apis mellifera* L.) density on pollination and fruit set of avocado (*Persea americana* Mill.) Cv. Hass J Apic Sci 62:5–14. https://doi.org/10.2478/JAS-2018-0001

Perez-Balam J, Quezada-Euan JJ, Alfaro-Bates R, Medina S, McKendrick L, Soro A, Paxton RJ (2012) The contribution of honey bees, flies and wasps to avocado (*Persea americana*) pollination in southern Mexico. J Poll Ecol 8:42–47. https://doi.org/10.26786/1920-7603%282012%296

Peterson PA (1955) Avocado flower pollination and fruit set. California Avocado Society Yearbook 39:163–169

Roubik DW (1978) Competitive interactions between neotropical pollinators and Africanized honey bees. Science 201:1030–1032. https://doi.org/10.1126/science.201.4360.1030

Shuler RE, Roulston TH, Farris GE (2005) Farming practices influence wild pollinator populations on squash and pumpkin. J Econ Entomol 98:790–795. https://doi.org/10.1603/0022-0493-98.3.790

Signorelli A et al (2020) DescTools: Tools for Descriptive Statistics. R package version 0.99.37.https://cran.r-project.org/package=DescTools

Ssymank A, Kearns CA, Pape T, Thompson FC (2008) Pollinating flies (*Diptera*): a major contribution to plant diversity and agricultural production. Biodiversity 9:86–89. https://doi.org/10.1080/14888386.2008.9712892

Toit AP, Swart D (1993) Notes on foraging activity of honeybees in an avocado. South African Avocado Growers' Association Yearbook 16:37–38

Vanbergen AJ, International Pollinator Initiative (2013) Threats to an ecosystem service: pressures on pollinators. Front Ecol Environ 11:251–259. https://doi.org/10.1890/120126