Advances in Entomology, 2023, 11, 239-255
https://www.scirp.org/journal/ae
ISSN Online: 2331-2017
ISSN Print: 2331-1991

Diversity of Insect Flower Visitors on Macadamia within a Monoculture Orchard in Murang'a County, Central Kenya

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How to cite this paper: Njue, N.I., Muthomi, J.W., Chemining'wa, G.N., Nderitu, J.H., Achieng, J. and Odanga, J.J. (2023) Diversity of Insect Flower Visitors on Macadamia within a Monoculture Orchard in Murang'a County, Central Kenya. *Advances in Entomology*, **11**, 239-255.
https://doi.org/10.4236/ae.2023.114017

Received: July 14, 2023
Accepted: September 4, 2023
Published: September 7, 2023

Abstract

Macadamia is cultivated for its nutritious edible kernel. In Kenya, the crop is predominantly grown by smallholder farmers mainly for export markets. Macadamia trees also enhance agro-forestry conservation, in the East African farmlands, by providing habitat and floral resources to beneficial arthropods such as insect pollinators. Allogamy of macadamia flowers is largely dependent on insects that pollinate and consequently influence the nut set, retention and yield. However, there is limited information on macadamia insect flower visitors in Kenya. This article assessed the diversity of insects that forage flowers of macadamia crop, and further evaluated their temporal distribution, in Murang'a county, central Kenya. Insect flower visitors were sampled weekly using a butterfly net for twelve consecutive months, from January 2021 to December 2021. Sixty-one insect species were recorded foraging macadamia flowers in Murang'a county, central Kenya. There was a statistical difference in the Simpson diversity index among weather seasons, dry, long rain, cold and short rain ($p < 0.0005$) and between two flowering patterns, dense and sparse ($p < 0.0005$). The findings of this study confirmed that diverse species of bees, butterflies and true flies forage flowers of macadamia crop in central Kenya, with the honey bee (*Apis mellifera*), a key pollinator species, being the most abundant flower visitor. This study provides strong baseline information, to scientists and farmers, on probable macadamia pollinator species, in central Kenya.

Keywords

Macadamia, Flowers, Insect, Diversity, Kenya

1. Introduction

Macadamia tree is native to Australia [1] [2] [3] [4] [5] and is cultivated worldwide for its nutritious edible kernel and oil [6] [7] [8] [9]. In Kenya, macadamia is an important lucrative cash crop that is predominantly cultivated by smallholder farmers [10] [11] [12]. The smallholder farmers generate seventy percent of the annual production of macadamia nuts [11], whereas the rest is produced by large-scale commercial orchards. The macadamia agro-processing sectors target both local and international markets. North America, Europe, China and Japan are the major international markets for the Kenyan macadamia nuts [11] [13] [14]. Kenya is ranked third globally after Australia and South Africa [11] [12] [15], with a market share of thirteen percent, which accounts for an annual production of 42,500 tonnes of nut-in-shell [11].

Macadamia integrifolia Maiden & Betsche and *Macadamia tetraphylla* Johnson (Proteaceae) are the two species grown in Kenya [16] [17]. The land area under macadamia cultivation, in central Kenya, has expanded spatially over years with Embu, Meru, Kirinyaga, Nyeri, Kiambu and Murang'a being the leading counties in the production of the nuts [18]. The planting of macadamia, also, enhances biodiversity through agro-forestry conservation [19] in the farmlands, which surrounds Mount Kenya, in central Kenya. The iconic Mount Kenya is the most expansive mountainous biodiversity habitat, in Kenya, consisting mainly of native vegetation in protected upland areas and some agro-ecosystems such as monoculture macadamia farms in the midlands.

Flowers of macadamia trees provide nectar and pollen utilized by many beneficial insect species such as insect pollinators that may enhance nut set, retention and yield. For example, [15] [20] [21] reported that the initial nut set and consequent nut retention are dependent on the increased visitation of flowers by the insect pollinators such as bees, butterflies, flies, moths and wasps. Therefore, efficient pollination of macadamia flowers is a prerequisite to producing high nut yields that are of superior quality. A mature macadamia tree produces over two million flowers during peak blossoming season [22]. However, only three percent develop into mature nuts of superior quality [22] [23].

Macadamia pollination is animal-mediated due to the morphological features of its flower and the small area of receptivity on stigmas [24]. The macadamia flower visitors such as *Apis mellifera* (honey bee) and *Trigona* spp. positively influenced the nut yield [2] [20] [24] [25], in Australia. Conversely, the exclusion of insect flower visitors resulted in lower nut-in-shell and kernel weights [15].

The flowers of the macadamia crop are perfect with both male and female parts borne on racemes arising from leaf axils, which are partially self-incompatible [2]. Racemes are pendantsin shape (**Figure 1**) ranging from ten to twenty centimetres long, with between one hundred and three hundred flowers that have small sticky stigmas [26] [27] [28]. The macadamia flowers contain small quantities of fructose, glucose and nectar due to their small sizes. For this reason, tinny-bodied arthropods, specifically, insects are the best pollinators and most abundant flower

Figure 1. Fully flowered macadamia tree and a few immature nuts at Kandara Macadamia Research Centre in Murang'a county within central Kenya. The photos were taken by the first author, in August 2021, using Samsung camera model SM-G991B, Seoul, South Korea.

visitors. However, there is limited information on insect species that pollinate macadamia flowers in Kenya. This study was initiated to assess the diversity of insect flower visitors that forage flowers of macadamia in Murang'a county within central Kenya. The specific objectives of this study were to: 1) generate an annotated checklist of the insect flower visitors that forage on macadamia flowers in a homogenous macadamia orchard at Kandara Macadamia Research Centre in Murang'a county within central Kenya; 2) assess species diversity of the insect flower visitors in four weather seasons; and 3) assess species diversity of the insect flower visitors in two flowering patterns in the study area.

2. Materials and Methods

2.1. Study Area and Weather Seasonality

Field surveys of insect flower visitors were conducted between January 2021 and December 2021, in a homogenous macadamia orchard at Kandara Macadamia Research Centre in Murang'a county within central Kenya. The study area is located between 0˚59'43.9''S, 37˚03'31.0''E and 1˚00'00.7''S, 37˚03'39.2''E, in East Africa. Kandara is a sub-county within Murang'a county that has deep and well-drained red or brown nitosols soils. Total monthly rainfall and mean temperature of the study area ranged from 1.2 mm to 254.2 mm and 17.4˚C to 22˚C, respectively (Table 1). The study area has four weather seasons namely: cold season that occurs during the months of June, July and August, dry (January, February and September), short rain (October, November and December, and long rain (March, April and May).

Table 1. Mean temperature and total rainfall data ranges during the four weather seasons of the study area. The information was summarized from field weather data recorded at Kandara Macadamia Research Centre, from January 2021 to December 2021.

Weather season	Total rainfall (mm)	Mean temperature (˚C)
Cold	2.0 - 8.9	17.4 - 18.3
Dry	1.2 - 94.0	19.7 - 21.0
Short rain	66.6 - 205.4	19.8 - 21.2
Long rain	52.2 - 254.2	19.8 - 22.0

2.2. Study Crop and Its Flowering Patterns

The smooth-shelled *Macadamia integrifolia* is the most predominant species at Kandara Macadamia Research Centre. *Macadamia integrifolia* is an evergreen tree that grows to a height ranging between 12.5 metres to 16.0 metres and with the base width of lower branches ranging between 3.2 metres and 6.6 metres. In central Kenya, the macadamia trees blossoms throughout the year with months of August, September and October having dense flowering whereas January, February, March, April, May, June, July, November and December having sparse blooming. The dense and sparse flowering patterns were described by percentage blossoming, where flowering less than fifty percent was regarded as sparse and 50% and above flowering was termed as dense or fully blossomed, during the survey.

2.3. Sampling Design and Survey of Insect Flower Visitors

The monoculture macadamia orchard, at Kandara sub-county in central Kenya, was sub-divided into five study blocks with each consisting of at least twenty mature trees (**Figure 2**). In each study block, five flowering trees were selected for assessment of insect flower visitors every week. In a study block, a set of five macadamia trees were sampled once every two weeks for insect pollinators.

The sampling of insect flower visitors was carried out for three days per week for twelve months, commencing in January 2021 up to December 2021. The weekly sampling was conducted between 0800 hours and 1700 hours. This sampling protocol was replicated for each of the five study blocks. Thirty minutes were spent to sample insect pollinators that came into contact with the inflorescences on each selected macadamia tree in a block, using butterfly nets. The collected hymenopterans and dipterans collected were transferred into vials containing seventy percent alcohol whereas lepidopteran specimens were preserved in butterfly envelopes as described by [29]. The vials and envelopes containing the sampled insect specimens were transported to laboratory and stored in a freezer at 0˚C (Sanyo, model MCF300SG, Osaka, Japan) for twenty-four hours, in order to relax them and also kill any pests that may be embedded onto the vials or envelops.

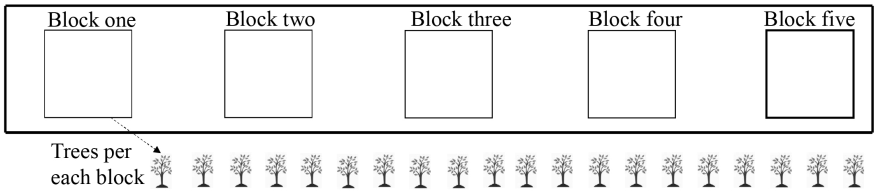

Figure 2. Schematic drawing of the study area with five study blocks depicting twenty mature macadamia trees that were selected for per each study block, from which a set of five trees were sampled once in two weeks for insect pollinators.

2.4. Morphological Identification of the Insect Specimens

All insect specimens were examined under a stereo microscope (Wild Heerbrugg, model M3B, Gais, Switzerland) and sorted into morpho-species at the entomology laboratory of the National Museums of Kenya, in Nairobi. The morpho-species were later identified into species using taxonomic manuals [30] [31] [32] [33]. The fully identified specimens were verified using entomological collections at the National Museums of Kenya and the respective voucher specimens were deposited in the insect collection at the National Museums of Kenya.

2.5. Data Analysis

Species accumulation curves were generated using the biodiversity R package, to assess completeness of survey of the macadamia insect flower visitors in monoculture orchard at Kandara Macadamia Research Centre [34]. Projected species richness, was generated using non parametric tests: Chao, Jackknife one, Jackknife two and Boot [34] [35] [36] [37]. The non-parametric algorithms predicted number of yet-to-be-collected species based on quantification of rarity, which is computed statistically from community data [35]. A Species checklist was computed using Microsoft Office Excel 2016 and the species within each insect family were arranged alphabetically, in ascending order. Diversity evenness of the insect flower visitors was measured using Shannon and Simpson indices.

Mean number of insect flower visitors among the four weather seasons: cold, dry, short rain and long rain, was subjected to analysis of variance (ANOVA) test. T-test was performed to compare mean number of insect flower visitors between the two flowering seasons: dense and sparse. The analyses were computed using statistical software R, version 4.2.1 [34].

3. Results

Sixty-one insect flower visitor species belonging to three orders and eleven families were recorded foraging on macadamia flowers at Kandara Macadamia Research Centre in Murang'a county, central Kenya. The species accumulation revealed there were sixty-one insect species (**Figure 3**) whereas non-parametric species richness estimators predicted 64.99 ± 2.44 for Chao, 68.43 ± 6.56 for Jackknife one, 69.25 ± 3.86 for Jacknife two and 72.96 ± 3.86 species for Boot.

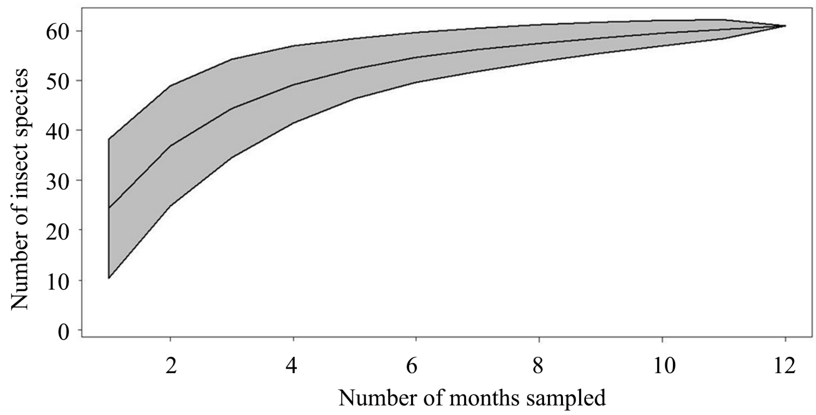

Figure 3. Species accumulation curve of insect flower visitors sampled on macadamia flowers at Kandara Macadamia Research Centre in Murang'a county within central Kenya, from January 2021 to December 2021. The number of calendar months refers to the sampling effort. Grey area represents 95% confidence intervals.

Diptera, Hymenoptera (Apoidea) and Lepidoptera accounted for 39.34%, 32.79% and 27.87%, respectively, of the total number of species recorded in the study (**Table 2**). The most abundant species were *Apis mellifera* (Hymenoptera: Apidae), *Rhyncomya soyauxi* (Diptera: Rhiniidae) and *Isomyia dubiosa* (Diptera: Rhiniidae) (**Table 2**) with total number of individuals: 1480, 797 and 308, respectively. *Apis mellifera*, *Lasioglossum* sp2 and *Braunsapis* sp. were the most abundant among Hymenoptera (Apoidea) (**Table 2**). *Rhyncomya soyauxi*, *Isomyia dubiosa* and *Rhingia apicalis* were the most abundant species among the Diptera (**Table 2**). *Eretis lugens*, *Eurema desjardinsi* and *Pontia helice* were the most abundant species among the Lepidoptera (**Table 2**). The most abundant and key insect flower visitors were the same in different months. They were *Apis mellifera* (Hymenoptera), *Rhyncomya soyauxi* (Diptera), *Isomyia dubiosa* (Diptera), *Rhingia apicalis* (Diptera), *Lasioglossum* sp2 (Hymenoptera), *Braunsapis* sp. (Hymenoptera) and *Lasioglossum* sp1 (Hymenoptera) (**Table 2**), in descending order.

Cold season, long rain, short rain and dry season accounted for 33.04%, 25.89%, 20.54% and 20.54% of the total number of species recorded in the study area, respectively. There was statistical difference in mean ± SE number of species among the four weather seasons (ANOVA; $F = 8.617$, $p = 0.00013$) (**Figure 4**). There was statistical difference in mean ± SE number of species between the two flowering patterns (t-test; $t = 4.139$, $p = 0.0001487$) (**Figure 5**). The mean ± SE number of species per month was 6.74 ± 1.31. There was statistical difference among mean ± SE monthly species number (ANOVA; $F = 13.92$, $p < 0.0001$) (**Figure 6**). The peak mean ± SE number of species began from the month of May to October with July recording the highest mean ± SE number of species. Tukey's pairwise comparison of weather seasons revealed significant differences between the following pairs: dry and cold, long rain and cold. Short rain and cold, long rain and dry, short rain and dry, and short rain and long rain were not significantly different.

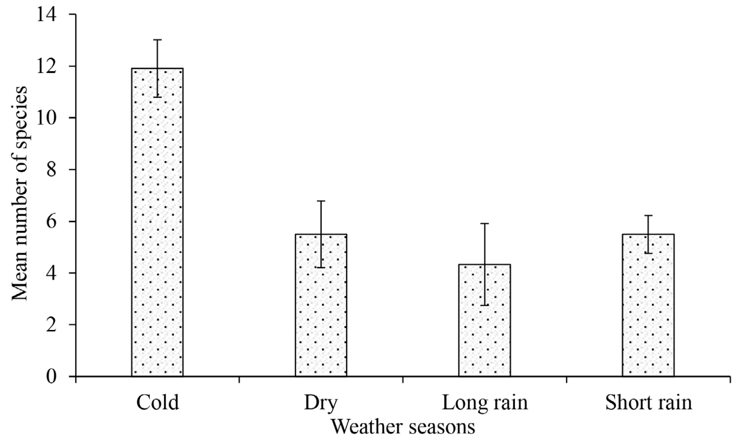

Figure 4. Mean ± SE number of insect pollinator species in four weather seasons sampled on macadamia flowers at Kandara Macadamia Research Centre in Murang'a county within central Kenya, from January 2021 to December 2021.

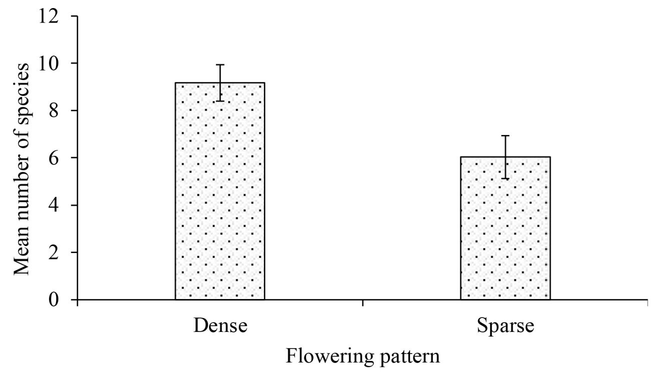

Figure 5. Mean ± SE number of insect pollinator species in dense and sparse flowering patterns sampled on macadamia flowers at Kandara Macadamia Research Centre in Murang'a county within central Kenya, from January 2021 to December 2021.

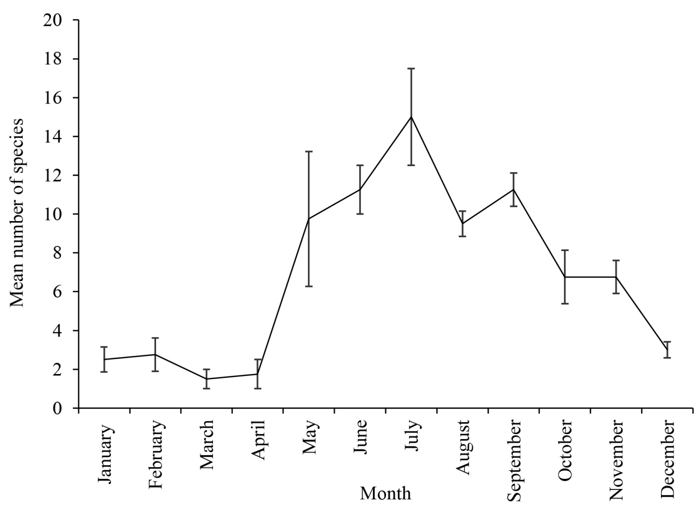

Figure 6. Annual trendline of mean ± SE number of insect pollinator species sampled on macadamia flowers at Kandara Macadamia Research Centre in Murang'a county within central Kenya, from January 2021 to December 2021.

Table 2. List of insect flower visitors found foraging on macadamia inflorescences at Kandara Macadamia Research Centre in Murang'a county within central Kenya, from January 2021 to December 2021. Dry, cold, long rain and short rain are weather seasons while dense and sparse refers to the flowering patterns. √ refers to presence of a species in weather and macadamia flowering seasons whereas blank refers to absence. The calendar months that fall within weather seasons and flowering patterns are described in materials and methods.

Order	Family	Species	Log abundance	Common name	Author/year	Dry	Cold	Short rain	Long rain	Dense	sparse
Hymenoptera	Apidae	*Amegilla fallax*	1.78	Blue-banded bees	Smith, 1879		√			√	√
		Amegilla sp.	1.78	Blue-banded bees	Friese, 1897		√			√	√
		Apis mellifera	4.17	Honey bee	Linnaeus, 1758	√	√	√	√	√	√
		Braunsapis sp.	2.51	Reed bees	Michener, 1969	√	√	√	√	√	√
		Ceratina aereola	1	Small carpenter bees	Vachal, 1903		√				√
		Ceratina sp.	1.9	Small carpenter bees	Latereille, 1802	√	√			√	√
		Xylocopa flavorufa	1	Carpenter bee	DeGeer, 1778				√		√
		Xylocopa nigrita	1	Carpenter bee	Fabricius, 1775	√					√
	Halictidae	*Halictus tinctulus*	1.7	Mining bees	Cockerell, 1937		√				√
		Lasioglossum sp1	2.51	Sweat bees	Curtis, 1833	√	√	√	√	√	√
		Lasioglossum sp2	2.67	Sweat bees	Curtis, 1833	√	√	√	√	√	√
		Lasioglossum sp3	2.3	Sweat bees	Curtis, 1833	√	√	√	√	√	√
		Lipotriches sp.	2.08	Sweat bees	Gerstaecker, 1858				√		√
		Nomia sp.	1	Sweat bees	Latereille, 1804			√			√
		Seladonia sp.	1.3	Sweat bees	Robertson, 1918			√			√
		Thrinchostoma sp.	2.26	Sweat bees	Saussure, 1890	√	√	√	√	√	√
	Megachilidae	*Heriades* sp.	1.7	Armored-resin bees	Spinola, 1808	√	√			√	√
		Megachile basalis	1.6	Leaf cutter bees	Smith, 1853	√	√			√	√
		Megachile bombiformis	1	Leaf cutter bees	Gerstaecker, 1858			√			√
		Megachile rufiventris	1	Leaf cutter bees	Guerin-Meneville, 1834	√				√	
Diptera	Rhiniidae	*Isomyia dubiosa*	3.49	Nose flies	Villeneuve, 1917	√	√	√	√	√	√
		Rhingia apicalis	2.76	Nose flies	Matsumura, 1905	√	√	√	√	√	√
		Rhyncomya soyauxi	3.9	Nose flies	Karsch, 1886	√	√	√	√	√	√
		Stomorhina lunata	2.41	Nose flies	Fabricius, 1805	√	√	√	√	√	√
		Stomorhina rugosa	2.23	Nose flies	Bigot, 1888	√		√		√	
		Stomorhina sp.	2.45	Nose flies	Rondani, 1861	√	√		√	√	√

Continued

	Syrphidae	*Allograpta calopus*	1	Hoverflies	Loew, 1858						√
		Asarkina fiorii	1.3	Hoverflies	Bezii, 1903		√				√
		Betasyrphus sp.	1	Hoverflies	Matsumura, 1917				√		√
		Eristalinus dulcis	1.3	Hoverflies	Karsch, 1887	√	√				√
		Eristalinus quinquelineatus	1.7	Hoverflies	Fabricius, 1781	√	√				√
		Eristalinus taeniops	1	Hoverflies	Wiedemann, 1818			√			√
		Ischiodon aegyptius	1.6	Hoverflies	Bigot, 1884			√			√
		Paragus longiventris	1.48	Hoverflies	Loew, 1858		√			√	√
		Phytomia incisa	1.48	Hoverflies	Wiedemann, 1830	√	√			√	√
		Rhingia pulcherrima	1.7	Hoverflies	Bezii, 1908		√	√			√
		Syritta sp.	1.6	Hoverflies	Lepeletier & Serville, 1828		√	√		√	√
		Toxomerus sp.	1.78	Hoverflies	Macuart, 1855	√	√		√	√	√
	Calliphoridae	*Chrysomya albiceps*	2	Blow fly	Wiedemann, 1819	√	√	√		√	√
		Chrysomya chloropyga	1.7	Blow fly	Wiedemann, 1818		√	√		√	√
		Hemipyrellia sp.	1.3	Blow fly	Townsend, 1918		√				√
		Pericallmyia spinigera	1.85	Blow fly	Villeneuve, 1915		√	√	√	√	√
		Phumosia imitans	2.36	Blow fly	Villeneuve, 1916	√	√	√	√	√	√
		Tricyclea bifrons	1.78	Blow fly	Malloch, 1929		√	√		√	√
Lepidoptera	Hesperidae	*Eretis lugens*	1.6	Savannah elf	Rogenhofer, 1891		√				√
		Spialia dromus	1	Forest sandman	Plotz, 1884				√		√
		Zenonia zeno	1	Orange-spotted hopper	Trimen, 1864				√		√
	Lycaenidae	*Lampides boeticus*	1	Bean butterfly	Linnaeus, 1767				√		√
		Leptotes pirithous	1	Lang's short-tailed blue	Linnaeus, 1767				√		√
		Zizula hylax	1	Gaika blue	Fabricius, 1775				√		√
	Nyamphalidae	*Acraea eponina*	1	Small orange acraea	Cramer, 1780		√				√
		Junonia sophia	1	Little pansy	Fabricius, 1793				√		√
		Junonia terea	1	Soldier pansy	Drury, 1773				√		√
		Neocoenyra gregorii	1	Eyed ringlet	Butler, 1894				√		√
		Ypthimomorpha itonia	1	Swamp ringlet	Hewitson, 1865				√		√
	Pieridae	*Belenois creona*	1	African caper	Cramer, 1776		√				√
		Colotis antevippe	1	Large orange tip	Boisduval, 1836		√				√
		Eurema desjardinsi	1.3	Anled grass yellow	Boisduval, 1833				√		√

Continued

		Eurema sp.	1	Grass yellow	Hubner, 1819		√	√
		Pontia helice	1.3	Common meadow white	Linnaeus, 1764	√		√
Lepidoptera	Erebidae	*Pseudonaclia* sp.	1	Tiger moth	Butler, 1876		√	√

Cold weather season had the highest mean Shannon H diversity index (3.61 ± 0.18), followed by long rain (3.37 ± 0.16), dry (3.14 ± 0.12) and short rain (3.15 ± 0.13) (**Table 3**). The mean Shannon H diversity index among the four weather seasons was not significantly different ($p = 0.0503$) (**Table 3**). Conversely, there was significant statistical difference in mean Simpson D diversity index among four the weather seasons ($p < 0.0005$) with the cold being the highest (0.98 ± 0.07) while dry had the lowest (0.95 ± 0.03). There was no statistically significant difference of mean Shannon H diversity index ($p = 0.06704$) between two flowering patterns: dense and sparse (**Table 3**). On the contrary, there was a significant statistical difference of mean Simpson D diversity index ($p < 0.0005$) between the two flowering patterns (**Table 3**).

4. Discussion

Macadamia flowers, at Kandara Macadamia Research Centre in central Kenya, attracted diverse number of insect flower visitors from three orders, namely: Diptera, Hymenoptera and Lepidoptera. The diverse number of species recorded foraging on the flowers implies that macadamia tree provides floral resources and possibly habitat to the insect flower visitors, some of which are important pollinators that influence nut set, retention and yield. The presence of different species on macadamia flowers implies that the crop is generalist in its pollination provision requirements. This is corroborated by [20] [28] who reported that pollination of macadamia flowers are largely dependent on insect pollinators.

Macadamia blossoms massively and hence the need for diverse insect flower visitors to effectively pollinate the flowers to enhance nut set and development of mature nuts [38] [39]. For effective pollination, the racemes of macadamia flowers require fifty daily visits by bees, each lasting for approximately six hours or a total of about 150 bee visits [23]. The macadamia flowers are only receptive for three days after opening [23] hence the need for efficiency in their pollination by diverse insect species.

Honey bee, *Apis mellifera*, was the most abundant flower visitor that was recorded throughout the year and possibly the most significant contributor to pollination of macadamia crop, which concurs with [20] [23] [40]. *Apis mellifera* was, further, reported as the most important pollinator of the African flora [41]. In this study, *Apis mellifera* foraged flowers to collect both nectar and pollen, and they were observed to have many swift visits on different macadamia flowers compared to other recorded insect flower visitors. The social ability of *Apis mellifera* to recruit nest mates to forage flowers [42] [43] and its active competitive

Table 3. Diversity evenness: Shannon H and Simpson D, of the insect pollinator species sampled on macadamia flowers at Kandara Macadamia Research Centre in Murang'a county within central Kenya, from January 2021 to December 2021.

Diversity indices	Weather season				Flowering pattern (%)	
	Dry	Cold	Short rain	Long rain	Dense	Sparse
Shannon H	3.14 ± 0.12	3.61 ± 0.18	3.14 ± 0.13	3.37 ± 0.16	3.30 ± 0.11	4.08 ± 0.20
Simpson D	0.95 ± 0.03	0.98 ± 0.07	0.96 ± 0.08	0.97 ± 0.04	0.96 ± 0.15	0.98 ± 0.12

ability [44] may have enhanced its dominance and abundance in the study area. This character could have contributed to lesser recording of other bee pollinators on macadamia crop at the study area.

Apis mellifera competes with stingless bees for the floral resources [45] [46] and the two species may not be present concurrently on the same flower. Moreover, [47] established that the number of stingless bees on macadamia orchards was strongly influenced by distance from the colony while the distribution of honey bees was closely related to daily floral display. Bees such as *Lassiglosum* sp, *Braunsapis* sp. and *Ceratina* sp. were recorded foraging the flowers throughout the year in central Kenya. Generally, stingless bees are important pollinators of macadamia flowers in Australia [48] and, also, in central Kenya. Due to their non-aggressive foraging style and competitive ability, any species of stingless bee had less numbers of individuals than the *Apis mellifera*, in this study. This was similar scenario of other bee species including *Lipotriches* sp., *Nomia* sp., *Seladonia* sp., *Thrinchostoma* sp., *Megachile basalis*, *Megachile bombiformis* and *Megachile rufiventris* that were recorded foraging macadamia flowers. Diverse bee species complements each other in pollination of crops and, thereby, contributing to generation of better yields [49] [50]. However, *Trigona* sp. was not recorded in this study, as observed in Australia [15] [24], and this calls for further survey.

The presence of high number of species from three dipteran families: Rhiniidae, Calliphoridae and Syrphidae, that were recorded foraging flowers, implies that they could be pollinators of macadamia in central Kenya. This scenario was reported by [51] in Australia where he identified twenty species from three families: Calliphoridae, Rhiniidae, and Syrphidae pollinating horticultural crops. In Malaysia, [52] noted that *Eristalinus* spp. (Syrphidae) and *Chrysomya* spp. (Calliphoridae) are the most efficient and abundant pollinators of mango flowers. The true flies have diverse body sizes that are adapted to different flower morphology [53] [54], a character that allows these insects to complement other pollinators. Species in the family Syrphidae have been shown to compliment bee pollination [55].

They have hairy body that collects pollen as they forage flowers. Adult true flies visit flowers for their nutritional needs thus collect nectar which is the source of their carbohydrates and pollen which provides protein [56]. The collected pollen is transferred to other flowers during subsequent visits, which leads to allogamy. Generally, dipterans are important pollinators of many crops, including macadamia.

Butterflies were observed foraging macadamia flowers, a scenario that has been reported by [57]. In Brazil, [21] reported butterflies as the most abundant and important pollinators of macadamia flowers. Generally, butterflies visit flowers to collect nectar as their food that is collected with their proboscis adapted even for long tubular flowers and in the process their bodies come into contact with the anthers thus pollen sticks on their tiny scales which is transferred to subsequent flowers they visit [58] [59].

High mean number of species that occurred during dense flowering pattern was correlated to abundant floral resources provided by macadamia, a finding that concurs with [60] who reported that insect pollinators depend on flower resources. However, floral resources were highly limited during sparse flowering pattern and weather was warming. Dense flowering pattern fell in between cold and dry weather seasons; a warm transition period that allowed enhanced reproductive ability and growth of insect pollinators. Conversely, there was lower mean number of insect flower visitors during sparse period, which coincided with long rain season.

The choice of butterfly net as the sampling tool [61] was mediated by the need to protect morphology of collected specimens and also to highly minimize damage to macadamia flowers. Reduced damage to flowers, during survey, allowed normal production level of macadamia nuts in the study area, whereas protection of specimen morphology enabled correct taxonomic identification of the pollinator species. However, employment of diverse sampling tools could have led to an increase in the number of pollinator insect species sampled. This scenario was confirmed by species accumulation curve that almost reached asymptote and relatively high number of predicted insect species that were generated by the non-parametric algorithms: Chao, Jackknife one, Jacknife two and Boot, compared to the sampled species. This challenge could be addressed by long-term biodiversity insect surveys, where rare singleton species are recorded frequently, which results in species accumulation reaching asymptote or peak [62] [63] [64]. Further sampling efforts may lead to an increase in number of insect species that forage macadamia flowers in central Kenya.

5. Conclusion and Recommendations

This article provides strong baseline information, to scientists and farmers, on probable macadamia pollinator diversity, in central Kenya. The findings of this study confirmed that diverse species of bees, butterflies and true flies forage flowers of macadamia crop in central Kenya, with the honey bee (*Apis mellifera*), a key pollinator species, being the most abundant flower visitor. The study, therefore, recommends sustainable conservation of the insect flower visitors in the farmlands. There is, also, a need to investigate the specific efficiency of bees, dipterans, lepidopterans, and other insect species, in the pollination of macadamia flowers in the diverse agro-ecological zones in Kenya.

Acknowledgements

This study was supported by the government of Kenya, through National Research Fund. Macadamia Research Centre, Kenya Agricultural and Livestock Research Organization, National Museums of Kenya and the University of Nairobi provided technical advice during field surveys and laboratory investigations.

Data Availability

The data is available in this article.

Conflicts of Interest

The authors declare no conflict of interest.

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