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Insect Pollinator Diversity and Their Influence on Yield and Quality of *Capsicum annuum* Linné (Solanaceae), Machakos, Kenya

Eva Wanza Soli[1*], K. Onyambu Gladys[1], N. Kioko Esther[2]

[1]Zoology Department, School of Biological Sciences, College of Pure and Applied Sciences, Jomo Kenyatta University of Agriculture and Technology (JKUAT), Juja, Kenya
[2]Invertebrate Zoology Section, Zoology Department, National Museums of Kenya (NMK), Nairobi, Kenya
Email: *solievawanza@gmail.com

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Abstract

Capsicum annuum (L.) yields have remained low due to poor quality fruits in developing countries such as Kenya, which could be attributed to inadequate insect pollination among other factors. The present study was conducted after the short and long rain seasons in 2018 to assess the diversity and abundance of insect pollinators of *C. annuum* and to determine their influence on yield. The experiment was laid out in a Randomized Complete Block Design with bagged and un-bagged pollination treatments. Insect pollinator assessment was conducted between 07:00 hours to 21:00 hours for one month during each season. Yield and quality were compared between the pollination treatments. During the entire study 13 insect pollinator species (3 orders, 7 families) were recorded on *C. annuum* flowers. *Apis mellifera* was the most abundant insect pollinator during the two seasons. The highest species diversity was recorded after the long rain season (H' = 1.85). With respect to time, species richness was the highest in the afternoon after the short rains and the highest in the morning after the long rains. The average yield parameters from both seasons showed that open pollination treatments had increased fruit weight (66.5%), seed weight (54.5%) fruit length (28%) and fruit diameter (30%) when compared to treatments bagged throughout. Findings from this study have shown that insect pollinator diversity varies seasonally and significantly influences the yield and quality of *C. annuum*. This calls for the need to practice sustainable agriculture so as to conserve insect pollinators of *C. annuum* for improved vegetable production in semi-arid lands of Kenya.

Keywords

Insect Pollinators, Diversity, *Capsicum annuum*, Yields, Machakos, Kenya

1. Introduction

Capsicum annuum Linné, 1753 commonly referred to as green pepper or bell pepper, belonging to the family Solanaceae, is a small perennial shrub native to South America (Mexico) and Central America and is currently cultivated worldwide [1]. In Kenya, *C. annuum* is mainly cultivated by small scale farmers in green houses or outdoors for local consumption and income generation [2]. *C. annuum* fruits are mostly used as a spice in food because they are cheap, strongly flavoured and colourful making the meal appetizing and can be cooked as vegetables or eaten raw in salad. The dried fruits can be ground to a powder and used as an ingredient in curry powders [3]. *C. annuum* fruits are highly nutritious as they contain lycopene, folic acid, calcium, beta carotene and vitamin A and C that have anti-oxidative, anti-cancer and anti-coagulative properties that protect the body from oxidative damage, cancer and cardiovascular diseases [4].

The flower of *C. annuum* is usually pentameric, bisexual, hypogynous and 10 - 15 mm in diameter and is borne at the intersection between stems and leaves at the point where the stem splits into a fork. The flower undergoes self-pollination to set seeds and fruits [5] [6]. The inflorescence may vary from one to seven flowers at one node with flowers possessing green sepals and white petals possessing stamens with pale blue to purple anthers. The pistil bears an ovary that contains 2 - 4 carpels. The stigma is borne at the tip of the slender style [7]. Flower anthesis occurs at sunrise but this varies among cultivars. The flowers remain open for less than 24 hours and usually close at different times of the day to prevent drying of the stigma which remains receptive for 2 days after anthesis. Pollen grains become fertile a day before anthesis and are released 1 - 4 hours after flower opening depending on the cultivar [6].

Although the flowers of *C. annuum* are capable of self-pollination, the introduction of insect pollinators has a positive effect on fruit quantity and quality. There is an increasing demand globally to increase pollination of green pepper most especially in green houses and this can be achieved through insect pollination [1]. *C. annuum* (sweet pepper) pollination has been studied in Brazil using the stingless bee *Melipona subnitida* which led to the production of heavier fruits that were less malformed and with more seed numbers compared to self pollinated flowers [1]. Bumble bees such as *Bombus terrestris* have been reported to improve the pollination of greenhouse hot pepper (*C. annuum*) leading to heavier and longer fruits with more seed numbers [5]. In Kenya, wild bees, ants and other biotic organism have been recorded as pollinators of *C. annuum* [2]. These insect pollinators have a positive contribution in the production of *C. annuum* mainly because they increase the fruit weight, fruit size and number of seeds [2] leading to better market prices for small holder farmers in Kenya [8]. Pollination studies using stingless bee *Hypotrigona gribodoi* have also been reported in Kenya. *C. annuum* plants pollinated by *H. gribodoi* had bigger and heavier fruits and seeds compared to those self pollinated or pollinated by feral pollinators and were therefore an efficient pollinator of green pepper [9].

Despite the importance of insect pollinator in *C. annuum* production, information on the diversity and abundance of insect pollinators of *C. annuum* in semi arid lands of Kenya is lacking. Previous studies have focused on pollination by social and solitary bees (Hymenoptera) [5] [6] [9] yet other invertebrates belonging to other insect orders are potential pollinators of crops [10] but less studied despite their economic benefits to agro-ecosystems [1]. Data on insect pollinator diversity is important as it gives an indication on the population size of pollinators in agricultural ecosystems and may serve as an indicator of the quality of a particular habitat [11].

C. annuum has a high potential of being an export crop due to its high nutritive value. However, the inadequate supply of the fruit due to low productivity and with poor quality is a challenge in the export market [12]. Between the years 2015 and 2016, *C. annuum* fruits were ranked 4th accounting for 7.1% aromatic vegetables which accounted for 2% of the horticultural value in Kenya. However *C. annuum* yields declined from 7510 MT to 5940 MT leading to a decline in the total value from KES 305 million to KES 238 million in 2015 and 2016 respectively [13].

Therefore, it is important to investigate the possibility of increasing the production of *C. annuum* especially in Machakos, Kenya. Sustainable agricultural intensification practices such as use of ecosystem services like insect pollination can improve yield and quality of Solanaceous crops in Kenya [8] [9]. This can be achieved through an understanding of the diversity and abundance of insect pollinators of *C. annuum* and their influence on fruit quality and quantity especially in semi arid lands of Kenya where poverty, hunger, malnutrition are a major concern. This study aims at providing more information on the seasonal diversity of insect pollinators of *C. annuum* and their influence on yield and quality in Machakos, Kenya.

2. Materials and Methods

2.1. Study Site

The study was conducted in Kitwamba village, Mbiuni location in Mwala Sub County, Machakos County, Kenya. The study site area is located between latitudes S 01.24292˚ and longitudes E 037.47425˚ and an altitude of 1200 m above sea level and is 500 m from Athi River. Mwala Sub County is located in the lower midland Agro-ecological zone IV which is described as a semi-arid land that experiences bimodal rainfall with an average of about 500 mm precipitation with two peaks usually occurring within April to May (long rains) and October to December (Short rains) [14]. The dry seasons are experienced between January to March and August-September. During the sampling period the area experienced temperatures ranging between 13.1˚C to 25.8˚C during the short rains and 11.1˚C to 24.5˚C during the long rains. Mwala Sub County is composed of cumbisol soils that support growth of a variety of vegetables such as tomatoes, cabbages, and pepper among others [13]. *C. annuum* grows best during warm seasons with temperature between 18˚C and 30˚C in areas receiving sufficient sunlight and in a variety of soils with a pH between 6 and 7 [15]. These characteristics make it a suitable vegetable in Kitwamba, Machakos, Kenya.

2.2. Sowing and Weeding

The experiment was conducted between November 2017 and February 2018 and the same procedure was repeated between the months of May 2018 to August 2018. Certified seeds of *C. annuum*, California Wonder variety were sourced from Simlaw Seeds Company Limited in Nairobi. Prior to planting, seed germination test was conducted on a sample of randomly selected seeds to ascertain their viability. The research study was conducted in a farmer field less than 500 m from Athi River. The field was rented and ploughed using a disc harrow to obtain a fine tilth [2]. The seeds were sown in a raised nursery bed at a depth of 1.3 cm in shallow furrows, covered lightly with soil and mulched until germination. *C. annuum* seedlings were hardened off for 1 week before transplanting. Transplanting was done 3 weeks after nursery propagation. Eighty plants of *C. annuum* were transplanted into each treatment plot at the rate of one seedling per hole at a spacing of 30 cm by 60 cm. Field management practices such as gapping, weeding and pest control were adhered to so as to ensure proper vegetable growth. Pest control involved the use of Bio-pesticides and organic pest control methods such as sprinkling wood ash on the soil to control ants on planting holes mainly because synthetic chemicals are threats to insect pollinator populations [10]. Irrigation was done to ensure continuous supply of water for the growing seedling when the top soil was observed to be dry.

2.3. Experimental Plot Layout

The experimental treatments were laid out in Randomized Complete Block Design with each block measuring 16 m by 4 m replicated 3 times. A 5 m buffer lane was left between blocks. Each block was divided into 4 plots measuring 4 m by 4 m [9]. A 1m interval was left between the plots. Four treatments were randomly allocated within the 4 experimental plots (**Table 1**). The randomly allocated treatments were bagged with insect proof netting material at the budding stage. Four levels of treatment were applied: bagged through-out (BT), bagged during daytime (BD), bagged during the night (BN) to prevent insect pollination

Table 1. Experimental layout showing pollination treatments within blocks.

	Block1		
Plot 1 BT	Plot 2 C	Plot 3 BN	Plot 4 BD
	Block 2		
Plot 1 BN	Plot 2 BT	Plot 3 BD	Plot 4 C
	Block 3		
Plot 1 C	Plot 2 BN	Plot 3 BT	Plot 4 BD

and the control/open pollinated (no bagging, C) to allow insect pollination [16] (**Table 1**).

2.4. Quantification of Diversity of *C. annuum* Insect Pollinators during the Study Period

Sampling began in January after the short rain season and in July after the long rain season on the onset of vegetable flowering. Data collection was conducted 3 days a week for a period of one month during each season to minimize disturbance of insect pollinators which would otherwise interfere with pollination. Diurnal flower visitors of *C. annuum* were sampled randomly between 07:00 hours to 12:00 hours, and from 13:00 to 17:40 hours. Dim spotlights were used to observe nocturnal insect pollinators between 18:00 hours to 22:00 hours [16]. In this study, close attention was paid to discriminate between mere flower visitors and pollinators. Only insects that were observed touching the reproductive parts of *C. annuum* flowers were recorded as insect pollinators. Representative specimens of insect pollinators were collected using sweep nets and were killed by transferring them into killing jars containing fumes of ethyl acetate [17] [18]. Voucher specimen collections were deposited and identified at the Invertebrate Zoology Section, Zoology Department-National Museums of Kenya.

2.5. Quantification of Yield and Quality from Pollination Treatments of *C. annuum*

The influence of insect pollinators was determined from fruits harvested from *C. annuum* treatments bagged day and bagged night to test influence of nocturnal and diurnal pollinators respectively and bagged throughout to test the possibility of self pollination. Open pollinated treatments (control) were used to test the influence of both diurnal and nocturnal pollinators on yield. The fruits were harvested at physciological maturity [9] and transported to the Ex-situ Section, Botany Department-National Museums of Kenya. The weight of the fruits was measured to the nearest gram. The fruit length and width were measured to the nearest centimeter. Seeds present in each fruit were extracted counted and their weight measured. Laboratory seed germination test was conducted to test for seed germination potential.

2.6. Data Analysis

Diversity and abundance of insect pollinators

Species abundance and species richness were recorded in the field during the study period. Shannon Weiner diversity index was used to measure insect pollinator diversity, abundance, richness of insect pollinators of *C. annuum*.

This was expressed using the procedures outlined by Morse and Calderone [19],

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

where p_i = proportion of each species

ln = natural logarithm

Data recorded on yield parameters was presented as mean ± standard error of mean. One-way analysis of variance (ANOVA) was used to compare the diversity indices and the mean of the yield parameters. Turkey's honest-significance difference test (Turkey test) was used to compare means. Significance was tested at the 95% level and values less than 0.05 were termed significant. All statistical analysis were done using R software version 2.14.0 [20].

Dependency of *C. annuum* vegetables on insect pollination

Dependency of *C. annuum* on insect pollination was determined by comparing yield from open pollinated plots with those from pollination exclusion treatments (bagged day, bagged night and bagged through-out).

This was expressed using procedures outlined by Morse and Calderone [19],

$$\text{Pda} = \frac{\text{Yub} - \text{Yb}}{\text{Yub}}$$

where Pda = pollinator dependency amount.

Yub = Yield from un-bagged flowers (Open/insect pollinated treatment).

Yb = Yield from bagged flowers (insect pollination exclusion treatments).

The value obtained from the ratio of the yield from un-bagged flowers to that of yield from bagged flowers denotes the amount of yield harvested as a result of insect pollination. This value is called the pollination dependency amount (pda) and is equate to 1. The pollinator dependency amount of the value zero implies that here is no negligible gain from insect pollination while a value of 1 implies that *C. annuum* crop cannot reproduce without insect pollination [2] [16].

3. Results

3.1. Diversity of Insect Pollinator Recorded on *C. annuum* Flowers during the Study Period

During the entire study 13 insect pollinator species (3 orders, 7 families) were recorded on *C. annuum* flowers. Insect pollinator diversity was highest after the long rain season (H' = 1.84) compared to after the short rain season. (H' = 1.58). The most abundant group of insect pollinators recorded after the short rains belonged to the order Hymenoptera (82.9%) followed by Diptera (13.6%) and the least abundant order was Coleoptera (3.5%). The most abundant group of insect pollinators recorded after the long rains belonged to the order Hymenoptera (93.4%) followed by Diptera (3.6%) and Coleoptera (3%). *Apis mellifera* was the most abundant insect pollinator across both seasons. The species richness was highest after the long rain season (13) compared to the short rain season (7) (**Table 2**).

Mean Richness and Abundance of Insect Pollinators of *C. annuum* with Respect to Time of Day during the Study Period

The mean richness of insect pollinator species recorded after the short and long rain season varied significantly (F-statistic = 28.34, p-value < 0.0001) and

Table 2. Diversity of insect pollinators of *C. annuum* during the study period.

Insect pollinators			After short rain Season		After long rain Season	
Order	**Family**	**Species**	**Abundance**	**Proportion (%)**	**Abundance**	**Proportion (%)**
Hymenoptera	Apidae	*Apis mellifera*	806	62.7	593	60.3
	Apidae	*Macrogalea candida*	52	4	48	4.9
	Apidae	*Xylocopa calens*	29	2.3	16	1.6
	Apidae	*Amegilla cymatilis*	-	-	12	1.2
	Apidae	*Amegilla* sp.	-	-	34	3.5
	Halictidae	*Lipotriches* sp.	101	7.9	36	3.7
	Halictidae	*Lasioglossum* sp.	77	6	36	3.7
	Halictidae	*Nomia* sp.	-	-	5	0.5
	Megachilidae	*Megachile* sp.	-	-	3	0.3
	Scoliidae	*Cathimeris* sp.	-	-	16	1.6
	Formicidae	*Camponotus maculutus*	-	-	119	12.1
		Total Hymenoptera	**1065**	**82.9**	**918**	**93.4**
Diptera	Syrphidae	*Phytomia incisa*	174	13.6	35	3.6
		Total Diptera	**174**	**13.6**	**35**	**3.6**
Coleoptera	Coccinellidae	*Coccinella* sp.	45	3.5	29	3
		Total coleoptera	**45**	**3.5**	**29**	**3**
Total abundance			1284	100	982	100
Species richness			7		13	
Shannon index			1.58		1.847	

(F-statistic = 33.19, p-value < 0.0001) respectively across the sampling treatments. The highest insect pollinator richness was observed during the day (treatments bagged night). The least pollinators were observed in the night (treatments bagged day) (Figure 1). The short rain season recorded the highest mean richness of insect pollinators in control treatments when compared to the long rain season (Figure 1).

The mean abundance of insect pollinators recorded after the short and long rain season varied significantly (F-statistic = 28.34, p-value < 0.0001) and (F-statistic = 30.86, p-value < 0.0001) respectively across the sampling treatments while highest insect pollinator abundance was observed during the day (treatments bagged night). The least visitors were observed at night as witnessed by treatments bagged day (Figure 2). The short rain season recorded the highest mean abundance of insect pollinators in control and bagged night treatments when compared to the long rain season (Figure 2).

3.2. Quantification of Pollination Treatments of *C. annuum* Yield in Term of Quality and Quantity

There was a significant difference between the 4 pollination treatments across

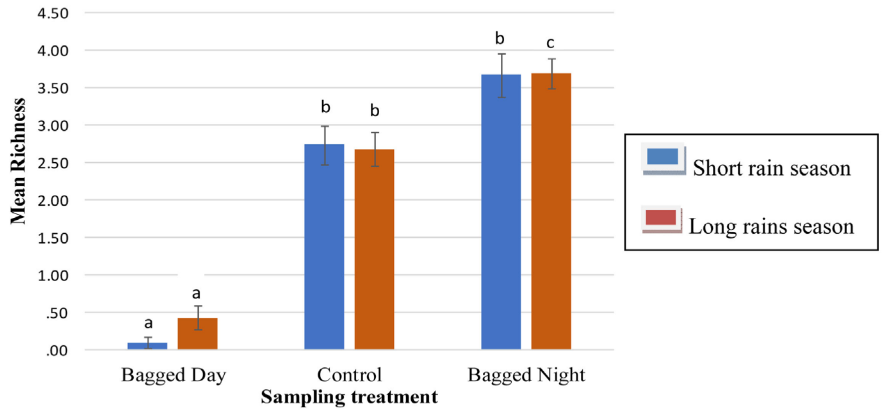

Figure 1. Mean richness of insect pollinators of *C. annuum* after the short rain and long rain season.

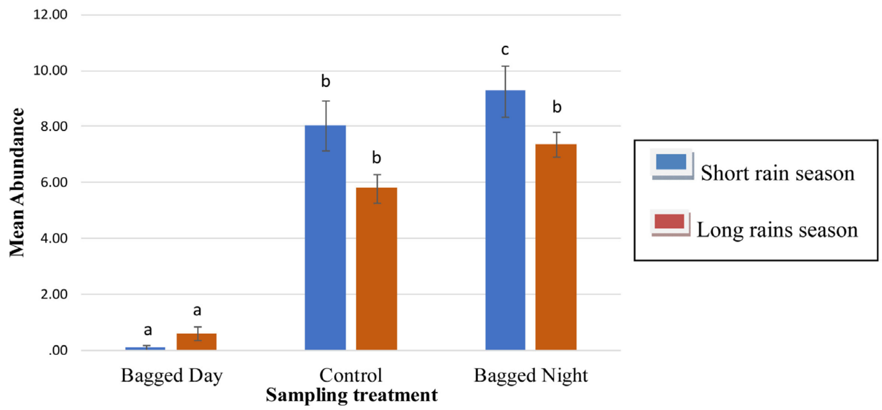

Figure 2. Mean abundance of insect pollinators of *C. annuum* after the short rain and long rains season.

both seasons ($P < 0.05$) in terms of fruit weight, fruit length fruit diameter and numbers of seeds per fruits. However, there was no significant difference on the seed weight ($P = 0.16$) after the long rain season. The highest mean yield and quality parameters were recorded in open pollination (Control) treatments. Treatments bagged night had higher fruit weight, seed weight and seed numbers as compared to treatments bagged day. The lowest mean yield and quality parameters were recorded in treatments bagged through-out across both seasons (Table 3). There was a significant difference in the germination test ($P < 0.05$) across all treatments in both seasons (Table 3). The control plots had the highest mean seed germination followed by treatments bagged night. The lowest mean seed germination rate was recorded in treatments bagged throughout.

Dependency of *C. annuum* to Insect Pollinators

Insect pollination dependancy amount in terms of fruit weight ranged between 0.33 and 0.81 after the short rain season. There was a 67% difference in terms of fruit weight between the treatment bagged throught and control (open pollinated) treatment. A difference in the fruit length (33%), fruit diameter (36%) and seed weight (61%), was noted between the plots bagged through-out and

Table 3. Mean ± S.E yields for the pollination treatments of *C. annuum* during the study period.

After short rain season						
Treatment	Fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	Seed weight (g)	Total seed no/fruit	Germination test
Bagged day	31.73 ± 1.38a	7.05 ± 0.15a	13.53 ± 0.37a	0.90 ± 0.10ab	97.48 ± 9.93a	68.27 ± 3.96a
Bagged night	77.38 ± 2.61b	9.23 ± 0.13b	19.55 ± 0.26b	1.30 ± 0.15bc	181.58 ± 10.36b	79.73 ± 4.23ab
Bagged throughout	31.26 ± 2.03a	6.76 ± 0.22a	13.34 ± 0.21a	0.57 ± 0.15a	80.17 ± 10.51a	65.63 ± 5.24a
Control	95.12 ± 3.07c	10.02 ± 0.16c	20.88 ± 0.31c	1.46 ± 0.19c	196.10 ± 10.50b	90.70 ± 2.94b
F-Value	191.04	90.46	178.88	6.74	32.02	7.61
P-Value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
After long rain season						
Treatments	Fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	Seed weight (g)	Total seed no/fruit	Germination test
Bagged day	51.07 ± 2.60a	10.60 ± 0.32ac	18.60 ± 0.59ac	0.83 ± 0.20a	101.70 ± 17.76a	68.80 ± 5.59a
Bagged night	79.27 ± 3.23b	10.07 ± 0.19a	17.90 ± 0.47a	1.03 ± 0.22a	132.66 ± 16.78a	77.73 ± 4.30b
Bagged throughout	38.67 ± 1.77c	8.73 ± 0.27b	15.37 ± 0.59b	0.63 ± 0.13a	99.15 ± 13.07a	57.23 ± 5.18a
Control	114.17 ± 3.24 d	11.40 ± 0.26c	20.27 ± 0.41c	1.20 ± 0.18a	155.21 ± 15.40a	92.93 ± 2.34c
F-Value	145.77	17.620	15.340	1.707	2.85	12.55
P-Value	<0.001	<0.001	<0.001	0.16	0.04	<0.001

Footnote: Table 3 shows a comparison between the means of the 4 pollination treatments in terms of yield and quality (fruit length and fruit width) of *C. annuum* fruits. Bagged day treatments were allowed access to insect pollination during the night while bagged night treatments were allowed access to insect pollination during the day.

open pollinated plots. The percentage difference also varied between plots bagged day and bagged night with those of the open pollinated plots after the short rain season (Table 4).

The insect pollination dependancy amount in terms of fruit weight ranged between 0.34 and 0.79 after the long rain season. A 66% difference in terms of fruit weight between the treatment bagged throught and control (open pollinated) treatment. A difference in the fruit diameter (24%) fruit length (23%), and seed weight (48%) was noted between the plots bagged through-out and open pollinated plots. The percentage difference also varied between plots bagged and bagged night with those of the open pollinated plots after the long rain season (Table 5).

The average yield parameters from both seasons show that open pollination treatments recorded increased fruit weight (66.5%), seed weight (54.5%) fruit length (28%) and fruit diameter (30%) when compared to treatments bagged throughout.

4. Discussion

Diversity of insect pollinators of *C. annuum* during the study period

This study has shown that insect pollinators vary in terms of diversity and abundance during the short rain and long rain seasons. The long rain season recorded the highest species diversity index ($H' = 1.85$). whis could have been as

Table 4. Dependency of *C. annuum* on insect pollinators after short rain season.

Parameter	Treatment	Mean	Control	Pda	Difference (%)
Fruit weight (g)	Bagged day	31.73	95.12	0.33	67
Fruit weight (g)	Bagged night	77.38	95.12	0.81	19
Fruit weight (g)	Bagged throughout	31.26	95.12	0.33	67
Fruit diameter (cm)	Bagged day	13.53	20.88	0.65	35
Fruit diameter (cm)	Bagged night	19.55	20.88	0.94	6
Fruit diameter (cm)	Bagged throughout	13.34	20.88	0.64	36
Fruit length (cm)	Bagged day	7.05	10.02	0.70	30
Fruit length (cm)	Bagged night	9.23	10.02	0.92	8
Fruit length (cm)	Bagged throughout	6.76	10.02	0.67	33
Seed weight (g)	Bagged day	0.9	1.46	0.62	38
Seed weight	Bagged night	1.3	1.46	0.89	11
Seed weight	Bagged throughout	0.57	1.46	0.39	61

Key: Pda-pollinator dependency amount.

Table 5. Dependency of *C. annuum* on insect pollinators after the long rain season.

Parameter	Treatment	Mean	Control	Pda	Difference (%)
Fruit weight (g)	Bagged day	51.07	114.17	0.45	55
Fruit weight (g)	Bagged night	79.27	114.17	0.69	31
Fruit weight (g)	Bagged throughout	38.67	114.17	0.34	66
Fruit diameter (cm)	Bagged day	18.6	20.27	0.92	8
Fruit diameter (cm)	Bagged night	17.9	20.27	0.88	12
Fruit diameter (cm)	Bagged throughout	15.37	20.27	0.76	24
Fruit length (cm)	Bagged day	10.6	11.4	0.93	7
Fruit length (cm)	Bagged night	10.07	11.4	0.88	12
Fruit length (cm)	Bagged throughout	8.73	11.4	0.77	23
Seed weight (g)	Bagged day	0.83	1.2	0.69	31
Seed weight	Bagged night	1.03	1.2	0.86	14
Seed weight	Bagged throughout	0.63	1.2	0.53	48

Key: Pda-pollinator dependency amount.

a result of high species richness mainly due to the availability of more wild bee species on *C. annuum* flowers and also availability of more natural floral resources in the surrounding habitats as compared to the short rain season. *C. annuum* flowers were pollinated by a diverse group of insect pollinators belonging to the orders Hymenoptera (bees, ants and wasp), Diptera (flies) and Coleoptera (beetles). The results of this study agree with those of a study in Kakamega (Kenya) where *C. annuum* has been reported to rely on feral pollinators such as bees, ants and other biotic organisms [2] [9]. This study realized that highest species richness and abundance was from the bee family Apidae. *Apis mellifera* recorded as the most abundant insect pollinator in both seasons. This could be attributed to their aggressive foraging behavior that out competes that of solitary bee species [21] as well as their perennial large colonies [11]. Despite the low abundance of solitary bee species especially after the short rains, these insect pollinators are important in pollination of *C. annuum* and are promising alternative pollinators for managed pollination in agriculture [9]. Similar to this study, most numerous visitors of *Capsicum frutescens* in New Mexico were reported to be *Apis mellifera*, *Halictus* species and *Megachile* species [22]. *C. annuum* flower visitors reported in the USA were *Halictus* sp., *Apis mellifera*, *Megachile* species among other bee species (Tanskley 1984 cited in [23] while in tropical America, Jamaica and Guadeloupe solitary bee species among other insects were observed [24].

Results from this study reported non-bee species from the order Diptera (syrphidae: *Phytomia incisa*) and Coleoptera (*Coccinella* sp.) as pollinators of *C. annuum* as they were observed touching the reproductive parts of the flowers while foraging. The finding of this study agree with studies done in Southern Quebec which reported that syrphid flies (*Eristalis tenax)* possesses desirable attributes for the pollination of *C. annuum* [25]. This implies that syrphid flies could be potential insect pollinators of *C. annuum* in semi arid lands of Kenya. There is little information on beetle pollination (cantharophily) on flowers of *C. annuum*. Researchers agree that it is difficult and expensive to make direct observation and report on beetle pollination in plants as these insects are nocturnal and may spend many hours inside a flower blossom [26]. However, observation on other plant species provide evidence that more than 184 angiosperm species representing 34 families, are exclusively pollinated by beetles (Coleoptera) [26].

With respect to time of the day, most insect pollinator were recorded during the afternoon and morning hours after the short and long rain seasons respectively. This could be the time when nectar and pollen production is high thus attracting more insect pollinators on *C. annuum* flowers. Previous studies conducted in Brazil reported that *C. annuum* pollination occurs when flowers open in the morning [1]. The foraging period of bee declines in the evening hours due to a decline in the light intensity [9] and this could explain why few bee species and other insect pollinators were recorded during the evening hours in the current study. The flowers of *C. annuum* have been reported to remain open for less than 24 hours and usually close at different times of the day to prevent drying of the stigma [6]. This explains why no nocturnal insect pollinators were recorded between 1900 hours to 22:00 hours during the sampling period.

Influence of insect pollinators on *C. annuum* yield quality and quantity

Insect pollination in this study led to a significant increase in fruit weight seed weight, seed number and fruit size. In terms of fruit weight, this study reported an average of 66.5% increase from yields obtained from open pollinated treatments (control) compared to treatments bagged through out (self-pollinated). This present study is in agreement with a study conducted in Brazil which reported a 65% increase in fruit weight from *C. annuum* flowers pollinated by bees compared to those pollinated by wind [1]. In Kenya a 56% increase in fruit weight from treatments bagged during the day compared to control treatments were reported in Kakamega and the study concluded that insect pollination leads to production of heavier fruits [2]. Which is in agreement with this present study. The results of this experiment reveal that more seeds were obtained from open pollinated treatments and treatments bagged during the night compared to the other pollination treatments. This study suggests that the high insect pollinator diversity foraging on *C. annuum* flowers may have enhanced pollination leading to increased seed production in pollinated flowers. These results are in agreement with previous studies that explain how pollen grain deposition on the stigma influences the number of seeds present in a fruit [27]. Similar results were obtained in *C. annuum* L. (hot pepper variety) that was reported to benefit from increased seed numbers as a result of pollination by *Bombus terrestris* L. [5]. A study conducted in Brazil, reported 85% increase in seed numbers from flowers pollinated by *Melipona subnitida* bees compared to wind pollinated flowers [1]. In the current study, there was no significant difference on seed weight between the pollinator inclusion and exclusion treatments after the long rain season. This implies that the seed weight was influenced by other factors other than insect pollination. Treatments bagged throught (self pollinated) were excluded from insect pollination and had the lowest seed germination potential compared to other treatments. Seed germination tests showed that insect pollination enhance seed germination potential as the highest means were obtained from insect pollinated treatments.

Fruits obtained from self pollinated treatments had the smallest fruits size in terms of fruit length and fruit width compared to fruits from the other treatments. Poorly developed fruits could be as a result of unequal distribution of seeds inside the fruits [1] [9]. A study done in Southern Quebec using *Eristalis tenax* (Syrphidae) as the pollinator *C. annuum* resulted in longer and heavier fruits which is in agreement with the results of the current study [25]. Bee pollination by the use of stingless bees has been reported to enhance the fruit quality of *C. annuum* leading to heavier and bigger fruits with more seeds from bee pollinated treatments compared to self pollinated treatments [9]. Heavier fruits with better quality in terms of the length and width of the fruits influences the market prices of *C. annuum* in Kenya [2] [8]. Farmers and policy makers in Machakos, Kenya should be sensitized to practice intergrated pollinator-pest management practices so as to conserve insect pollinator species for maximum production of *C. annuum*.

5. Conclusion

This study has revealed that seasonality influences the diversity and abundance of insect pollinators during the short rain and long rain seasons. The long rain season recorded the highest species diversity index ($H' = 1.85$). This could have been as a result of high species richness mainly due to the availability of wilder bee species on *C. annuum* flowers as compared to the short rain season. *Apis mellifera* were the most abundant pollinators of *C. annuum* flowers across both seasons. Although *C. annuum* are self pollinated, flowers visitation by insect pollinators belonging to the order Hymenoptera, Diptera and Coleoptera led to improved weight and size of *C. annuum* fruits with more seeds numbers. The average yield parameters from both seasons show that insect pollination increased fruit weight (66.5%), seed weight (54.5%) fruit length (28%) and fruit diameter (30%) when compared to self pollination. However further research is recommended to determine the most efficient pollinators among the three insect orders recorded in the present study. This study shows that insect pollinator diversity has a significant influence on *Capsicum annuum* both in quality and quantity. This calls for the need to conserve insect pollination service for improved vegetable production in semi arid lands of Kenya such as Machakos.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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