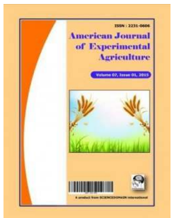


American Journal of Experimental Agriculture
13(2): 1-18, 2016, Article no.AJEA.26238
ISSN: 2231-0606

SCIENCEDOMAIN *international*
www.sciencedomain.org

Abundance and Diversity of Insects Associated with Citrus Orchards in Two Different Agroecological Zones of Ghana

Owusu Fordjour Aidoo[1,2*], Rosina Kyerematen[1,3], Clement Akotsen-Mensah[1,4] and Kwame Afreh-Nuamah[1,4]

[1]African Regional Postgraduate Programme in Insect Science, University of Ghana, Legon, Accra, Ghana.
[2]International Center of Insect Physiology and Ecology (ICIPE), Box 30772-00100, Nairobi, Kenya.
[3]Department of Animal Biology and Conservation Science, University of Ghana, Legon, Accra, Ghana.
[4]Forest and Horticultural Crops Research Centre, School of Agriculture, College of Basic and Applied Sciences, University of Ghana, Legon, Accra, Ghana.

Authors' contributions

This work was carried out in collaboration between all authors. Author OFA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors CAM and RK managed the analyses of the study. Author KAN managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJEA/2016/26238
Editor(s):
(1) Marco Aurelio Cristancho, National Center for Coffee Research, CENICAFÉ, Colombia.
(2) Daniele De Wrachien, State University of Milan, Italy.
(3) Vincenzo Tufarelli, Department of DETO - Section of Veterinary Science and Animal Production, University of Bari "Aldo Moro", Italy.
Reviewers:
(1) Anibal Condor Golec, MSc Organic Plant Production, Lima, Peru.
(2) Barbara Carolina Garcia Gimenez, Federal University of Paraná (UFPR), Brazil.
(3) James Kehinde Omifolaji, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, China.
Complete Peer review History: http://sciencedomain.org/review-history/15293

Original Research Article

Received 6th April 2016
Accepted 13th June 2016
Published 7th July 2016

ABSTRACT

We investigated the abundance and diversity of entomofauna associated with citrus orchards in two different agroecological zones of Ghana. Malaise traps, flight interception traps, pitfall traps, chemical ‟knock down'' and visual observation were used for data collection. We recorded a total of 20, 285 individual insects belonging to 387 species from 107 families and 13 orders. Although, several species of insects were common to both agroecological zones, some were more specific to

**Corresponding author: E-mail: fowusu@icipe.org;*

an orchard of a particular zone. Diversity indices such as Shannon-Wiener index, Pielou's evenness and Margalef index were higher in the Coastal Savannah zone than the Semi-Deciduous Rainforest zone during both the wet and the dry seasons. *Oecophylla longinoda* Latreille was the most dominant insect species in each agroecological zone, however, they were more abundant in the semi-deciduous rainforest than the Coastal Savannah zone. Our study shows that only 9% of all the 387 insects collected were pests of citrus. This indicates that citrus orchards are potential habitats for insect biodiversity conservation. We therefore recommend that management tactics which have less or no negative effects on natural enemies, pollinators among others but can effectively suppress insect pest populations (such as the use of biological control agents, restriction of herbicides and pesticides) should be adopted. Our study has also provided the first comprehensive inventory of insect species associated with citrus agroecosystems serving as a baseline data for further studies to encourage adoption of economically sound integrated pest management approach for citrus production in Ghana.

Keywords: Insect diversity; abundance; integrated pest management; Oecophylla longinoda; citrus.

1. INTRODUCTION

Insects constitute the most dominant component of terrestrial and freshwater biodiversity in terms of species richness, animal biomass and critical ecological functions [1]. They have invaded every niche, except the oceanic benthic zone [2]. Estimates of species richness of insects have been reported to vary from 2 million to as many as 50 million [3]. Insects are very sensitive to human-mediated disturbances, habitat loss, pollution and climate change, and because of their sensitivity several insect taxa are used as indicators of global change [4]. The majority of insects on earth are important to humans: A few are harmful such as agriculture pests and disease vectors whereas others are beneficial such as decomposers, seed dispersers, pollinators and natural enemies of pests [5].

Pesticides are used in conventional farming to suppress pest populations below economic threshold levels and research has shown that more arthropod taxa were found in non-sprayed fields together with greater numbers of predators such as Coccinellids than in fields treated with broad-spectrum insecticides and herbicides [6]. Reduction in bumblebees and butterflies has been observed in farms with higher pesticide application than those with no or lower pesticide application [7]. In Ghana, control of major pests of citrus relies on pesticide application [8] and herbicide application is one of the weed management practices adopted by farmers [9]. These herbicides do not only deprive insects of their source of food but also directly kill them.

After citrus establishment, insect species colonize and over time progressively increase in diversity and abundance. Insects which were previously considered as minor pests are emerging as key pests in many agroecosystems. There is also evidence that honeybees and other pollinators, such as flies, butterflies and major bioindicators such as ants and beetles are in decline across the globe [10]. Anthropogenic climate change threats to insect biodiversity are global. The quickened rate of environmental deterioration could lead to a loss of whole taxonomic groups. In Ghana, [11] reported an annotated list of insects associated with citrus plantations at Kade in the Semi-Deciduous Rainforest zone, however, knowledge of diversity and abundance of insects associated with citrus agroecosystems in different agroecological zones is poorly understood.

To manage natural resources, restore disturbed habitats or conserve valuable species of concern, the biodiversity of insects of specific areas or target habitats needs to be assessed. However, this requires a comprehensive but efficient inventory of the organisms and perhaps their role in the ecosystem [12]. This underscores the critical necessity of this biodiversity study to gain an in-depth knowledge of diversity and abundance of insects associated with citrus agroecosystems to help implement measures that ensure the conservation of biodiversity and the maintenance of agricultural lands to enhance agricultural productivity and sustainability in Ghana.

The aim of this study was to determine the diversity and abundance of entomofauna associated with citrus plantations in two different agroecological zones of Ghana.

2. MATERIALS AND METHODS

2.1 Sampling Zone

We conducted our study in citrus orchards (monoculture) in the Semi-Deciduous Rainforest and Coastal Savannah agroecological zones. In both orchards, weed management was by the use of machetes, and both farms were wholly organic with the citrus variety being Late Valencia. In the Semi-Deciduous Rainforest zone, the research was carried out in a citrus plantation (CI. 25) of the Forest and Horticultural Crops Research Centre (FOHCREC) at Okumaning, Kade in the Kwaebibirem District of the Eastern Region of Ghana. This area experiences an annual bimodal rainfall pattern ranging between 1200-1300 mm, temperature range of 25-38℃ [13]. The coordinates of the site were N 06°09.473', W 000 54.550' and E: 552ft. The orchard was established 20 years ago with a triangular planting distance of 6m x 6m. The vegetation in the study site consisted mainly of *Panicum maximum and Pueraria phaseoloides*. In the Coastal Savannah zone, the research was carried out in a farmer's plot at Asuansi Agriculture Research Station in the Abura/Aseibu/Kwamankesse District of the Central Region of Ghana. The area experiences a mean annual rainfall of 980 mm and the rainfall pattern follows the bimodal distribution. Mean monthly temperature is about 26.90℃ [14] and the coordinates of the study site were N 05° 18.654', W 001° 15.667' and E: 363ft. The citrus orchard was established 15 years ago with a triangular planting distance of 7 m x 7 m. The predominant vegetation of the study area consisted mainly of *Chromolaena odorata* and *Panicum maximum*.

2.2 Insect Collection

Our study was carried out from September 2013 to March 2014. There were eleven main sampling methods used for the insect collection. Sweep net to Sample the topmost part of the vegetation of the understory to collect vegetation-dwelling insects; Aerial nets were used for flying insects such as dragonflies, butterflies and members belonging to the family Cetoniidae; in each agroecological zone, 10 pitfall traps were randomly set to collect ground crawling insects; 10 coloured pan traps (yellow, blue and orange) were randomly set to collect insects which are attracted to a particular colour; and 5 yellow sticky traps were set up to collect flying insects. One malaise trap was set in each zone to collect mainly flying nocturnal insects; one flight interception trap was used for both ground crawling insects and flying insects by intercepting their flights. Hand picking was used for collecting specifically slow moving insects and those which play dead when the vegetation is disturbed. Chemical knockdown was used to collect insects in the canopy of the citrus trees: 10 trees were randomly selected during each sampling period and sprayed with CYDIM super (an emulsifiable concentrate containing 36 g cypermethrin and 400 g dimethoate active ingredient/L) at a rate of 120 ml insecticide/ha using a motorized mist blower early in the morning between 6:00-10:00 am. Pieces of vinyl sheets measuring 2.8 m × 8 m were placed beneath the selected trees to collect any insect that fell from the trees during and after spraying.

2.3 Identification of Insects

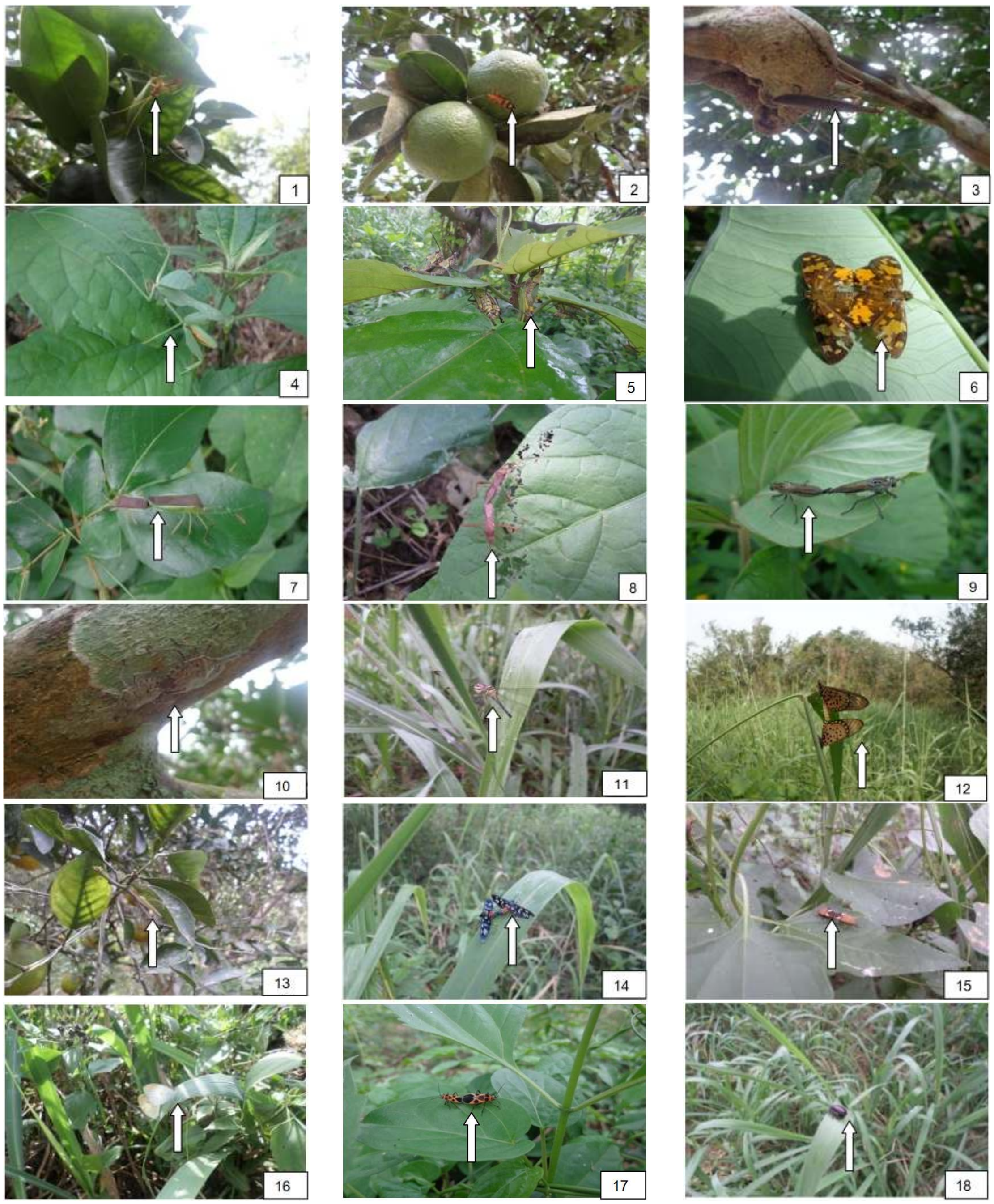
Insects were preserved in 70% ethanol, sorted, identified to the lowest taxonomic rank possible and counted. Identification of insects was done with reference to collection in the museum of the Department of Animal Biology and Conservation Science (DBCS), University of Ghana, as well as with reference to Gullan and Cranston [15-21]. Dr. Maxwell K. Billah of DABCS helped in the identification of the fruit flies. The voucher specimens were deposited at the African Regional Postgraduate Programme in Insect Science (ARPPIS), West African Sub-Regional Centre.

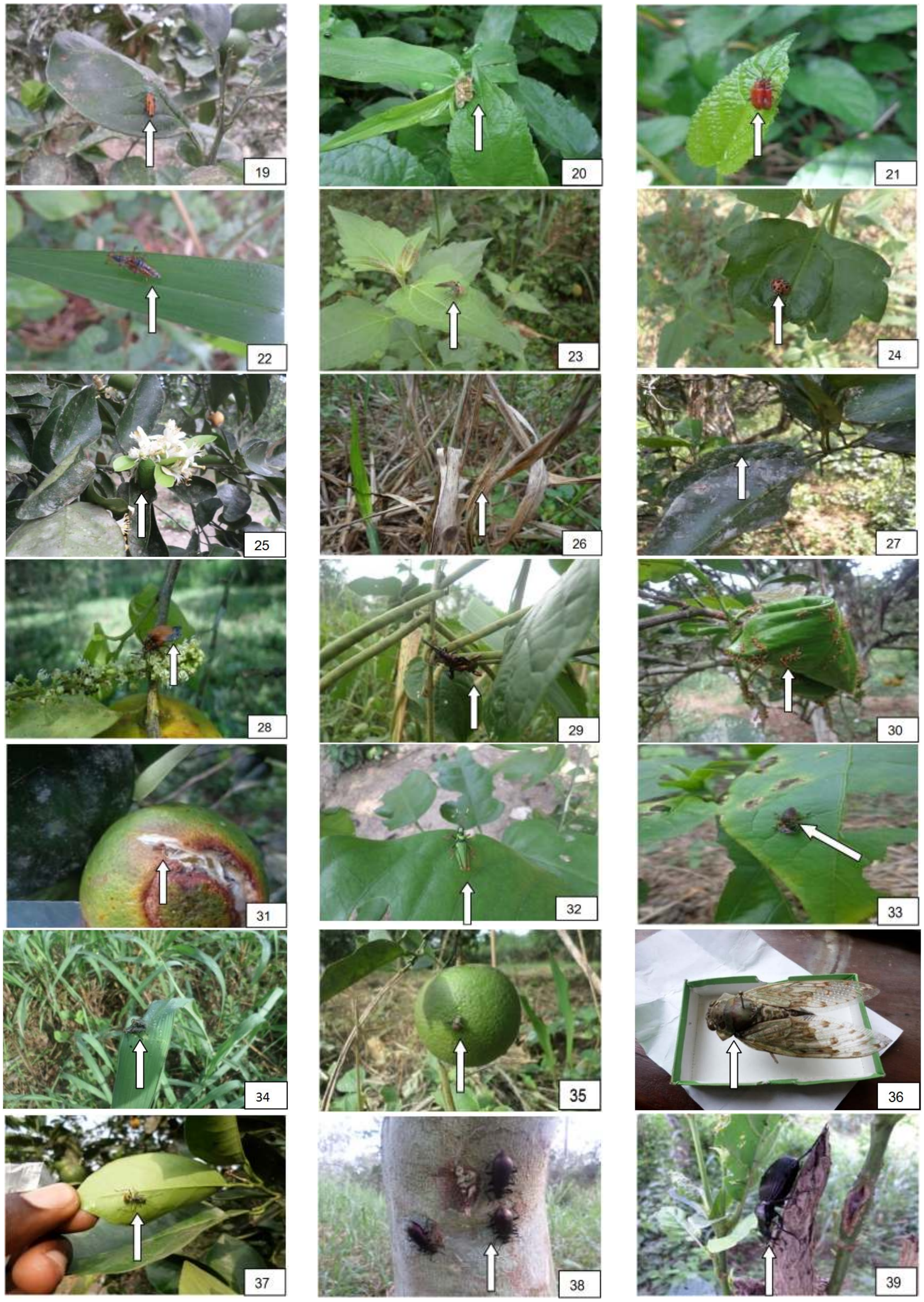
2.4 Data Analysis

Shannon-Wiener diversity index (H') was calculated according to the equation: H'=-Σ(ni/N)log(ni/N), where ni= number of individuals in the ith species and N= total number of individuals sampled. Margalef (d=S-1)/Log (N), is a measure of the number of species present, making some allowance for the number of individuals whiles Pielou's Evenness measures how evenly the individuals are distributed among the different species, both were computed using Past 3.01. To check the completeness of inventory in the orchards, EstimateS (version 9.1.0) was used. The insects were put into two different functional groups; pests and others (pollinators, predators, parasitoids and unknown) based on the authors' long term experience of citrus pests in Ghana.

3. RESULTS

A total of 20,285 individual insects belonging to 387 species from 107 families and 13 orders were collected and identified (Table 1). The total number of entomofauna in the Semi-Deciduous Rain Forest zone was higher than that in the Coastal Savannah zone. 11646 individual insects belonging to 265 species were recorded in the Semi-Deciduous Rain Forest zone compared to 8639 insects from 246 species in the Coastal Savannah zone. The number of citrus pests form both orchards were 35 representing 9% of the total insects collected during the study period. Fig. 1 shows some insects sampled during the study period.




19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39

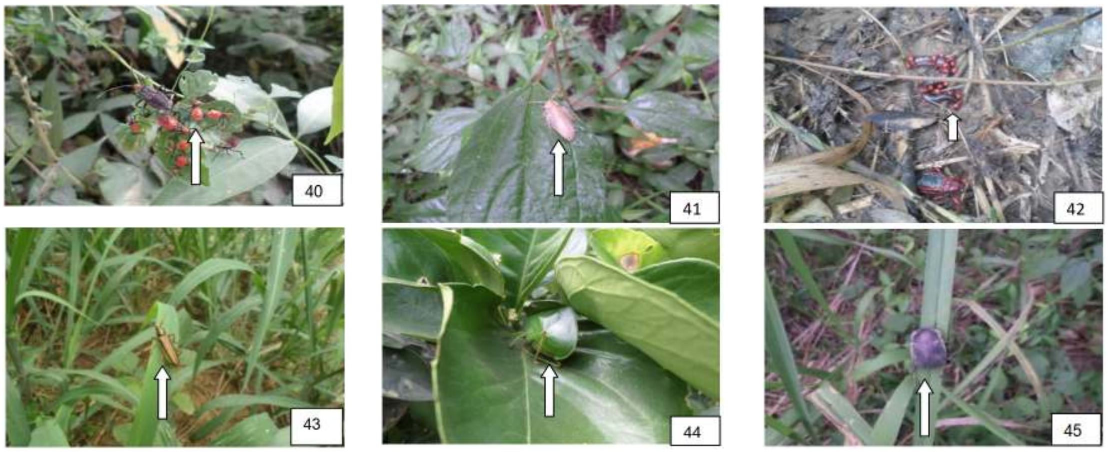


Fig. 1. (1-45) *Ophion leteus* (1), *Brachon* sp. (2) *Mantis religiosa* (3) *Sphodromantis* sp. (4*),* *Z. variagatus* (5), *Celaenorrhinus galenus* (6), *Homoecerus pallens* (7), *Alydus eurinus* (8), *Promachus* sp. (9), *Halyomorpha halys* (10), Dragonfly *(*11), *Acraea* sp. (12), Green lacewing (13), *Zygaena* sp. (14), *Dysdercus* sp. (15) *Mylothris* sp. (16) *Tropidothorax leucopterus* (17), *Lagria villosa* (18), *Rhagonycha fulva* (19), *Lixus* sp. (20), *Lilioceris lilii* (21), *Diopsis longicornis* (22), *Promachus* sp. (23), *Epilachna bifasciata* (24) *Marmylida marginella* (25), *Acrida conica* (26), *Orophus* sp. (27), *Lycus trabeatus* (28), *Sagra femorata* (29), *Oecophylla longinoda* (30) *Drosophilla melanogaster* (31), *Taphronota* sp. (32) *Laphria* sp. (33), *Sarcophaga* sp. (34), *Ceratitis ditissima* (35), *Cicada* sp. (36), *Polyrhachis sulcata* (37), *Coelocnemis lucia* (38), *Tefflus* sp. (39), *Leptoglossus* sp. (40) *Blatella germinica* (41), *Glymmatophora* sp. (42), *Cerambycidae* sp.(43), *Pterophylla camellifolia* (44), *Madateuchus viettei* (45)

Table 1. List of the insect morphospecies and the higher taxonomic ranks of the voucher specimens collected in semi-deciduous rain forest zone (SD) and Coastal Savannah zone (CS) of Ghana

Order	Family	Morphospecies	SD	CS	Economic status
Coleoptera	Scarabaeidae	*Madateuchus viettei*	0	0	others
		Scarabaeus viettei Paulian	1	19	others
		Scarabaeus sp.	2	3	others
		Caccobius schreberi L.	0	1	others
		Onthophagus loalien	0	6	others
		Onthophagus sp.	2	1	others
		Pseudohammus nyrmedonum	0	5	others
		Copris sp.	2	9	others
		Caccobius kelleri	0	3	others
		Alleucosma viridula Kirby	0	5	others
	Cetoniidae	*Pachnoda abyssinica*	0	2	pest
		Marmylida marginella Fab.	5	2	pest
		Thermophilum fornasini	0	3	pest
		Torynorrhina flammea	0	3	pest
		Caelorrrhina barthi	0	1	pest
		Protaetia fusca	0	3	pest
		Pachnoda cordata Dury	0	1	pest
	Carabidae	*Amara ovara*	1	6	others
		Scaphinotus angusticollis	0	1	others
		Amara sp.	2	0	others
		Amara sp 1	1	0	others

Order	Family	Morphospecies	SD	CS	Economic status
		Anomala sp.	0	5	others
		Tefflus mmegerui	0	2	others
		Tefflus sp.	0	4	others
		Harpalus caliginosus Fab.	1	3	others
		Bembidion patruele Dejean	3	0	others
		Tetragonoderus deuvei	4	0	others
	Tenebrionidae	*Tenebrio* sp.1	0	2	others
		Alphitobius sp.	1	0	others
		Tenebrio sp. 2	12	0	others
		Coelocnemis sp.	0	1	others
		Coelocnemis lucia Doyen	1	15	others
		Gonocephalum simplex Fab.	0	10	others
		Eleodes sp.	21	12	others
		Alobates pennsylvanicus DeGeer	0	1	others
	Chrysomelidae	*Chrysochus* sp.	0	4	others
		Lilioceris sp.	13	0	others
		Lilioceris lilii	1	0	others
		Ootheca mutabilis	2	6	others
		Cryptocephalus sp.	0	2	others
		Podagrica uniformis Jac.	0	7	others
		Sagara femorata Drury	5	1	others
		Sagra sp.	4	0	others
		Cassida sp.	4	1	others
		Cassida viridus	4	2	others
		Cassida rubiginosa	1	0	others
		Nsotra uniformis Jac.	11	0	others
	Cerambycidae	*Monochamus* sp.	0	7	pest
		Adynata exilis Borch	0	1	pest
		Elaphidion sp.	8	0	others
	Coccinelidae	*Henosepilachna vigintioctopunctata*	0	36	others
		Exochomus sp.	2	20	others
		Scymnus sp.	0	5	others
		Chilocorus sp.	0	5	others
		Cryptocephalus signaticeps	2	0	others
		Cheilicomus sp.	2	0	others
		Harmonia axyridis	1	0	others
		Epilachna bifaciata	1	0	others
		Epilachna sp.	9	0	others
	Curculionidae	*Lixus* sp.	0	6	others
		Bryochcta pusilla Pasc.	3	0	others
		Eloeidobius kamerunicus	0	5	others
		Sphenophorus maidis Chittenden	0	1	others
	Lagriidae	*Lagria hirta*	0	1	others
		Lagria villosa Fab.	14	6	others
		Cereyonia citri	2	2	others
		Lagria sp.	9	6	others
	Lycidae	*Lycus* sp.	8	5	others
		Calopteron terminale	0	2	others
		Lycus trabeatus	11	3	others
	Anobiidae	*Stegobium paniceum*	0	1	others
	Lampyridae	*Aspisoma* sp.	0	2	others
	Cucujidae	*Silvanus oblitus* Grouv	8	5	others
	Byrrhidae	*Byrrhus fasciatus* Forster	0	2	others
	Trogostidae	*Phloeobius cordiger* Fahrs	0	2	others

Order	Family	Morphospecies	SD	CS	Economic status
	Cicindelidae	*Cicindela leng*	2	0	others
		Cicindella sp.	6	0	others
	Cleridae	*Necrobia* sp.	1	1	others
		Necrobia rufibes DeGeer	0	2	others
	Histeridae	*Saprinus felipae* Lewis	10	0	others
		Saprinus sp.	6	0	others
		Spilodiscus biplagiatus Le Conte	12	0	others
		Platylomalus aequalis Say	3	0	others
	Melolonthidae	*Maladera insanabilis* Brenske	10	1	others
		Serica sp.	8	0	others
		Acantthosternum sp.	0	1	others
	Buprestidae	*Agrilus anxius* Gory	7	0	others
	Anthribidae	*Araecerus fasciculatus* Deg.	3	0	others
	Nitidulidae	*Omosita colon* Linn.	7	0	others
	Prionidae	*Stenodontes* sp.	10	0	others
	Elateridae	*Cardiophorus* sp.	4	0	others
Diptera	Tephritidae	*Ceratitis ditissima* Munro	10	210	pest
		Bactrocera invadens	6	11	pest
		Dacus sp.	0	1	pest
		Ceratitis cosyra.	2	1	pest
		Pterandus sp.	1	0	pest
	Therevidae	*Evansomyia* sp.	1	5	others
	Asilidae	*Stenopogon* sp.	0	9	others
		Stichopogon sp.	8	0	others
		Ommatius sp.	0	8	others
		Laphria sp.	2	0	others
		Machimus sp.	2	0	others
		Promachus sp.	25	0	others
	Syrphidae	*Eumerus* sp.	0	2	others
		Pseudodorus clavatus Fab.	0	16	others
		Melannostoma scalare Fab.	2	0	others
	Bibionidae	*Bibio albipennis* Say	2	1	others
	Drosophilidae	*Drosophila melanogaster*	13	175	pest
	Diospidae	*Diopsis longicornis* Macquart	2	4	others
		Diopsis sp.	3	0	others
	Sarcophagidae	*Sarcophaga* sp.	8	5	others
	Muscidae	*Musca domestica* Linn.	3	18	others
		Musca vicina Macq.	3	0	others
	Caliphoridae	*Caliphora* sp.	2	6	others
		Lucilia sericata Meigen	3	0	others
		Lucilia sp.	5	0	others
	Agromyzidae	*Melanagromyza similis* Lamb	3	10	others
	Tachinidae	*Ramonda spathulata*	4	0	others
	Bombyliidae	*Bombylius* sp.	3	0	others
	Cecidomyiidae	*Mayetiola destructor* Say	8	0	others
Hymenoptera	Syrphidae	*Isodontia mexicana* Saussure	10	0	others
	Mutilidae	*Ephutomorpha* sp.	2	2	others
	Vespidae	*Eumenes smithii*	4	4	others
		Eumenes sp.	4	0	others
		Synagris anali	2	11	others
		Ropalidia cincta Lepeletier	7	0	others
		Synagris cornuta	0	3	others
		Polistes sp.	11	0	others
		Cremnops desertor L.	3	16	others
		Synagris sp.	0	1	others

Order	Family	Morphospecies	SD	CS	Economic status
	Formicidae	*Oecophylla longinoda* Latri.	7598	4996	pest
		Odontomachus haematoda Linn.	54	109	others
		Messor babarus	1	2	others
		Monomorium Pharaonis Linn.	45	135	others
		Atopomyrmex crytoceroides Emery	0	85	pest
		Camponotus pennsylvanicusm	0	15	pest
		Odontomachus sp.	46	55	others
		Messor sp.	4	65	others
		Crematogaster peringueyi Emery	1131	0	pest
		Pachycondyla sp.	9	11	others
		Crematogaster sp.	839	826	pest
		Tetramorium sp.	176	232	pest
		Camponotus sp.	23	94	others
		Phasmomyrmex aberrans Bolton	5	0	others
		Polyrhachis sulcata Bolton	2	5	others
	Sphecidae	*Ammophila* sp.	2	5	others
		Amophila insignis Beauv	8	1	others
		Echilanthus sp.	1	0	others
		Sphex pensylvanicus Linn.	2	2	others
	Ichneumonidae	*Enisoscosphilus* sp.	0	5	others
		Lissonota sp.	2	5	others
		Echthrus sp.	0	2	others
		Ophia sp.	10	8	others
		Anacis sp.	0	2	others
		Priocnemis conformis Smith	0	1	others
	Apidae	*Xylocopa* sp.	22	6	others
		Bombus hortorum L.	0	11	others
		Xylocopa violacea Linn.	22	6	others
		Xylocopa virginica Linn.	3	0	others
	Gasterulidae	*Gasteruption assectator*	4	0	others
	Braconidae	*Euphorius* sp.	1	0	others
		Phanerotoma sp.	0	12	others
		Atanycolus sp.	0	6	others
		Capitonius sp.	20	0	others
	Chalcididae	*Mesocomys pulchriceps* Cam	0	4	others
	Evanidae	*Evania appendigaster* L.	0	4	others
	Melipulidae	*Melipona* sp.	1	0	others
	Pompilidae	*Arachnosphill anceps* Gesson	2	0	others
		Trachypompilus sp.	3	0	others
Hemiptera	Coreidae	*Leptoglossus oppositus*	0	6	others
		Leptoglossus sp.	76	7	pest
		Acanthocephala sp.	0	5	others
		Hypselonotus sp.	3	0	others
		Homoeocerus pallens F.	6	0	others
		Homoeocerus sp.	7	0	others
		Pyrops sp.	2	0	others
		Leptocorisa acuta Thumb	2	0	others
	Lygaeidae	*Spilostethus pandurus*	0	2	others
		Oncopelta fasciatu	0	2	others
		Oncopelta sp.	6	0	others
		Mucanum sp.	4	0	others
		Rhyperochromus sp.	0	2	others
		Neacoryphus sp.	3	0	others
		Neacoryphus bicrucis Say	3	0	others

Order	Family	Morphospecies	SD	CS	Economic status
		Tropidothorax leucoptrerus Goeze	0	6	others
	Pentatomidae	*Oebalus* sp.	0	2	others
		Loxa flavicolis	0	2	others
		Halyomorpha halys	6	8	others
		Pentatoma rufipes Linn	4	0	others
		Euschistus heros	1	4	others
		Aspavia armigera F.	1	5	others
		Pentatoma sp.	4	0	others
		Aspavia albidomaculatus Stall	5	1	others
		Nezera viridula Linn.	11	0	others
	Saldidae	*Pentacora ligata* Say	0	15	others
	Reduviidae	*Glymmatophora* sp.	21	10	others
		Arilus sp.	7	2	others
		Saica sp.	1	0	others
		Zelus sp.	1	0	others
		Rhodius picipes	2	0	others
		Archilestidium sp.	0	2	others
		Rapida sp.	0	1	others
		Tropidothorax leucopterus	0	5	others
		Reduvius sp.	0	2	others
		Cydnocoris sp.	0	5	others
		Nagusta goedeli	0	1	others
		Stenopoda spinulosa	4	0	others
		Rhynocoris sp.	4	0	others
		Triatoma sp.	6	0	others
	Alydidae	*Ormenaria rufifascia*	0	6	others
	Pyrrhocoridae	*Dysdercus superstitious*	9	3	others
		Cenaeus distinguendus Blote	0	12	others
		Dysdercus sp.	6	0	others
	Alydidae	*Leptocorisa acuta*	0	1	others
		Alydus eurinus Say	0	1	others
	Cercopidae	*Neophlaenus* sp.	6	0	others
		Poophilus costalis Walker	1	31	others
		Poophilus sp.	2	4	others
		Neophilaerius sp.	6	0	others
		Plylus grossus L.	0	40	others
	Membracidae	*Oxyrachis lamborni* Dist.	0	3	others
		Oxirachis sp.	1	0	others
		Gargara sp.	2	1	others
	Corixidae	*Hesperocorisa* sp.	1	0	others
	Aphididae	*Aphis gossypii* Glover	32	8	pest
		Toxoptera citricidus Fitch	19	105	pest
		Aphis maides Fitch	6	0	pest
		Toxoptera aurantii Boyer	12	88	pest
	Aradidae	*Aradius acutus* Say	0	10	others
		Protenor sp.	0	7	others
	Gerridae	*Gerris remigis Say*	2	0	others
	Issidae	*Dieuches armipes* Fab.	19	105	others
	Cydnidae	*Sehirus cinctus* Palisot de Beauvois	6	0	others
		Pangaeus bilimeatus Say	4	0	others
	Miridae	*Brycoropsis laticollis* Schum	0	10	others
		Miridae sp	1	0	others
		Chamus boxi China	5	0	others
	Psyllidae	*Mesohomotoma tessmani (*Allum)	6	0	others

Order	Family	Morphospecies	SD	CS	Economic status
	Ricanidae	*Ricanidae* sp.	0	2	others
	Naucoridae	*Ambrysus* sp.	0	6	others
	Scuteridae .	*Diolcus* sp	12	0	others
	Berytidae	*Jalysus spinosus* Say	8	0	others
	Cicadidae	*Cicada orni* Boulard	0	6	others
	Dictyopharidae	*Taosa* sp.	0	3	others
	Coccidae	*Lepidosaphes beckii* Newn	45	51	pest
		Planococcus citri Risso	2	6	pest
Lepidoptera	Danaidae	*Amauris* sp.	0	2	others
		Danaus chryssipus Linn.	11	5	others
		Hypolimnas misippus	2	0	others
		Amauris niavius	7	2	others
		Amauris albimaculata	0	1	others
	Acraeaidae	*Acraea* sp. 1	4	4	others
		Acraea sp. 2	0	2	others
		Acraea pentopolis Ward	0	16	others
		Acraea ancedon	5	0	others
		Acraea perenna	2	0	others
		Acraea alciope	7	0	others
	Hesperiidae	*Calaenorrhinus galenus*	3	2	others
		Pyrrhochelcia iphis	2	0	others
		Pyrrhochalcia iphis Drury	0	3	others
	Zygaenidae	*Zygaena* sp.	0	3	others
		Zygaena ephieltes	2	3	others
		Zygaena sp 1	1	0	others
		Zygaena sp 2	2	0	others
	Noctuidae	*Achaea* sp.	98	28	pest
		Achaea obvia Hmps	0	1	pest
		Anomis leona Schaus	10	3	others
		Ammalo insulata	0	2	others
	Papilionidae	*Papilio demodocus* Linn.	21	9	pest
		Papilio cynorta	2	1	others
		Papilio nireus	1	1	others
		Papilio dardanus	0	3	others
		Papilio conorta	2	1	others
		Papilio menestheus	0	1	others
		Pentila pauli Staudinger	1	0	others
	Nymphalidae	*Acraea johnstoni*	0	1	others
		Eurytela dryopa Edwards	3	0	others
		Hypolinmas debius Linn.	3	0	others
		Hypolimnas misippus Linn.	7	0	others
		Byblia anvatara R&J	2	13	others
		Byblia anvatara Boisd	4	0	others
		Precis pelarga F.	6	2	others
		Salamis temora	0	1	others
		Junonia oenone	14	2	others
		Psuedoacraea sp.	0	3	others
		Mylanitis leda	0	1	others
		Bermastistes epaea	2	2	others
		Achroia sp.	0	1	others
		Neptis laefa Moore	3	0	others
		Neptis laeta Oliv.	0	1	others
		Bicyclus xeneas	2	3	others
		Erytela sp.	1	0	others
	Arctidae	*Arctidae* sp.	0	5	others

Order	Family	Morphospecies	SD	CS	Economic status
		Zale minera	5	0	others
		Spilosoma mundata Walker	0	5	others
	Pieridae	*Dixela doxo*	0	1	others
		Colotis ovagore Klug	1	7	others
		Eurema briggita Stoll	9	1	others
		Mylothris poppea Cr.	1	0	others
		Achiroia sp.	0	1	others
		Mylothris chloris Fab.	1	3	others
		Eurema hecabe Linn.	4	3	others
		Colotis evippe Butler	2	5	others
	Satyridae	*Bicyclus safitza* Hew	5	2	others
		Melanis leda Linn.	1	0	others
		Bicyclus hewitson	1	0	others
	Pyralidae	*Pyralia* sp.	2	0	others
		Homophylotis catori Jord.	7	0	others
	Tinieidae	*Ptilobola inornatella* Wals	2	0	others
	Gracillariidae	*Phyllocnistis citrella* Stainto	0	1	pest
	Saturniidae	*Eacles imperialis* Dury	0	3	others
Orthoptera	Gryllidae	*Gryllus lucens* Walker	28	24	others
		Gryllus pensylvanicus	0	2	others
		Oecanthus nigricornis	1	5	others
		Oecanthus sp.	10	1	others
		Gryllus sp.	5	1	others
		Gymnogryllus lucens Walker	6	0	others
	Tettigonidae	*Atlanticus gibbosus*	0	1	others
		Orophus sp.	5	1	others
		Hyperhomala woodfordi Kirby	0	5	others
		Pterophylla camelifora Fab.	32	8	others
		Conocephalus brevipennis Scudder	9	2	others
		Tetrix undulata (Sow)	6	3	others
		Tetrix sp.	10	0	others
		Tettigonia viridissima Linn	4	0	others
		Arantia rectifolia	0	8	others
		Metrioptera roeselii Hagen	2	0	others
		Conocephalus brevipennis	0	1	others
		Neoconocephalus ensiger	0	1	others
		Zabalus lineolatus Stall	6	0	others
		Scudderia furcata Bruner	1	3	others
		Mustius seralatus Bolivar	1	0	others
	Acrididae	*Neduba carinata*	0	1	others
		Froggaltina sp	0	1	others
		Schistocerca sp.	6	1	others
		Schistocerca cancellata	0	1	others
		Acrida sp.	12	17	others
		Acrida conica	0	2	others
		Melanoplus sp.	5	0	others
		Acanthacris ruficornis Fab.	10	2	others
		Locusta migratoria	0	3	pest
		Abisare viridipennis	3	6	others
		Schistocera albolineata	11	3	others
		Melanoplus femurrubrum	2	0	others
		Heteracris littoralis Rambur	26	2	others
		Gymmobothrus subparallelus	4	0	others
	Pyrgomophidae	*Zonocerus variegatus* Linn.	119	104	pest

Order	Family	Morphospecies	SD	CS	Economic status
		Taphronota sp.	0	9	others
		Attractomorpha similis Bolivar	7	0	others
		Aractomorpha sp.	1	0	others
	Tetrigidae	*Tetrix areuosa* Burmeister	5	0	others
		Pantelia horrenda Walker	0	4	others
		Tetrix undulate (Sow)	0	4	others
	Catantopidae	*Heteracris littoralis* Rambur	3	0	others
		Anacidium sp.	2	0	others
		Catantops sp.	13	0	others
	Raphidophoridae	*Acheta domesticus*	3	0	others
		Ceuthophilus maculatus Harris	0	7	others
		Centhophillus sp.	2	11	others
Odonata	Libellulidae	*Neurothermis* sp.	3	2	others
		Sympetrum corruptum	2	3	others
		Diplecodes lifebvri Rambur	2	3	others
		Sympathrum obstrusum (Hagen)	5	0	others
		Gomphus militaris	3	0	others
		Plathemis lydia	1	0	others
		Platheris sp.	3	0	others
		Libellula quadrimaculata Linn.	3	0	others
		Erythrodiplax umbrata	2	0	others
		Brechmorhoga sp.	4	0	others
	Aeshnidae	*Anax* sp.	1	1	others
		Anax junius	3	0	others
	Coenogrionidae	*Argia apicalis* Hagen	3	0	others
		Agriocnemis fomina fermina Brauer	6	5	others
Dictyoptera	Blattidae	*Blatta orientalis* (Linn.)	8	14	others
		Blattella germanica Linn.	16	23	others
		Blatteria germinica Linn.	2	4	others
	Mantidae	*Mantis religiosa* Linn	13	12	others
		Sphodromantis sp.	17	1	others
Isoptera	Termitidae	*Macrotermes* sp.	50	22	pest
		Microtermis sp.	12	23	pest
Psocoptera	Psyllipsocidae	*Psyllipscoccus ramburi*	0	48	others
Neuroptera	Myrmeleontidae	*Brachynemerus abdominalis*	3	1	pest
		Brachynemuus sackeni Hagen	2	3	others
Dermaptera	Forficulidae	*Forficula auricularia* Linn.	2	15	others
		Doru aculeatum (Scudder)	2	3	others
Thysanura	Lapismatidae	*Lapisma saccharina*	5	93	others

The percentage relative abundance of the entomofaunal families collected from citrus orchards in both zones is given in Fig. 2. In the Semi-Deciduous Rain Forest zone, the four most dominant orders were Hymenoptera (86.34%), Hemiptera (3.48%), Orthoptera (3.12%) and Coleoptera (2.34%) whereas Hymenoptera (77.12%), Hemiptera (5.96%), Diptera (5.56%) and Coleoptera (3.15%) were the four most dominant orders in the Coastal Savannah zone (Fig. 1). *O. longinoda* was the most abundant species recorded in both agro-ecological zones, recording 7598 (65%) and 4996 (58%) individuals for the Semi-Deciduous Rain Forest and Coastal Savannah zone respectively.

The community indices, specifically Shannon-Wiener (H'), Margalef (d) and Pielou's evenness were calculated for the wet season (September-November) and the dry season (January-March) in each agro-ecological zone (Table 2) as well as the two agro-ecological zones (Table 3). In the wet season, the results show that Margalef (d=1.341), Shannon-Wiener diversity (H'=1.011) and evenness (0.229) were higher in the Coastal Savannah zone than in the Semi-Deciduous Rain Forest zone. Margalef (d=1.429) and Shannon-Wiener diversity (H' =0.8613) were also higher in the Coastal Savannah zone in the dry season than the Semi-Deciduous-Rain Forest zone. Evenness of species was relatively low for the two agroecological zones in both seasons (Table 2). The results show that all the diversity indices were higher in the Coastal Savannah zone than the Semi-Deciduous Rain Forest zone (Table 3).

Estimated species richness of insects captured using Incidence-based estimator (Chao 1), Abundance-based estimator (Chao 2), First-order jackknife estimator (Jack 1), Second-order jackknife estimator (Jack 2), Abundance-based coverage Estimator (ACE) and Incidence-based coverage Estimator (ICE) per zone are shown in the species accumulation curves for the Semi-Deciduous Rain Forest zone and Coastal Savannah zone respectively. In both Semi-Deciduous Rain Forest and Coastal Savannah zone, the species accumulation curves were clearly approaching an asymptote showing that species saturation had been reached and sampling effort was adequate (Figs. 3 and 4).

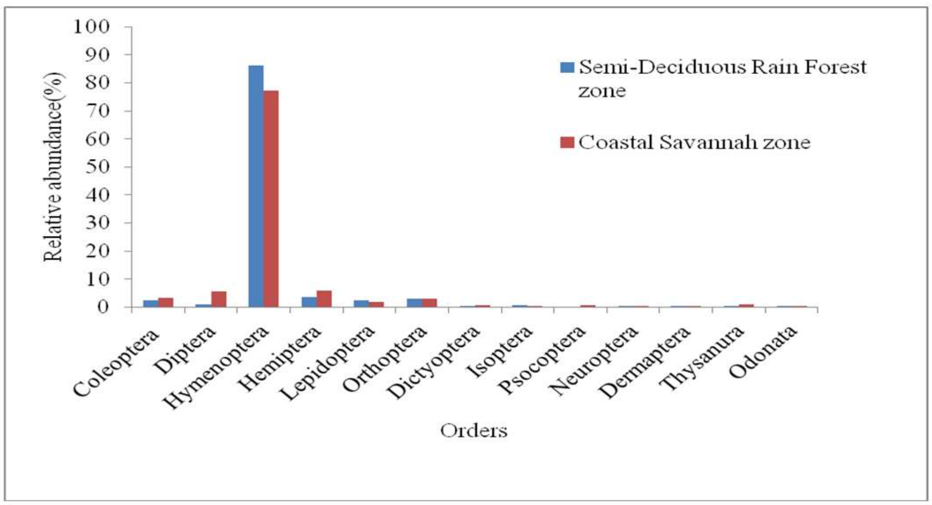


Fig. 2. Relative abundance of insect orders recorded in the study

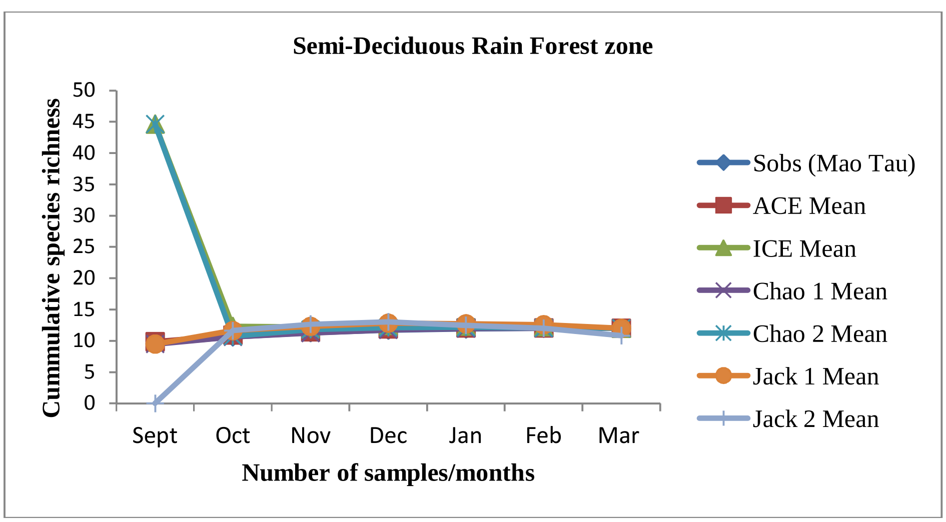


Fig. 3. Species accumulation curve for entomofauna associated with the citrus orchard in the Semi-Deciduous Rain Forest zone and its species richness estimators. Average species richness is based on 50 randomizations [22]

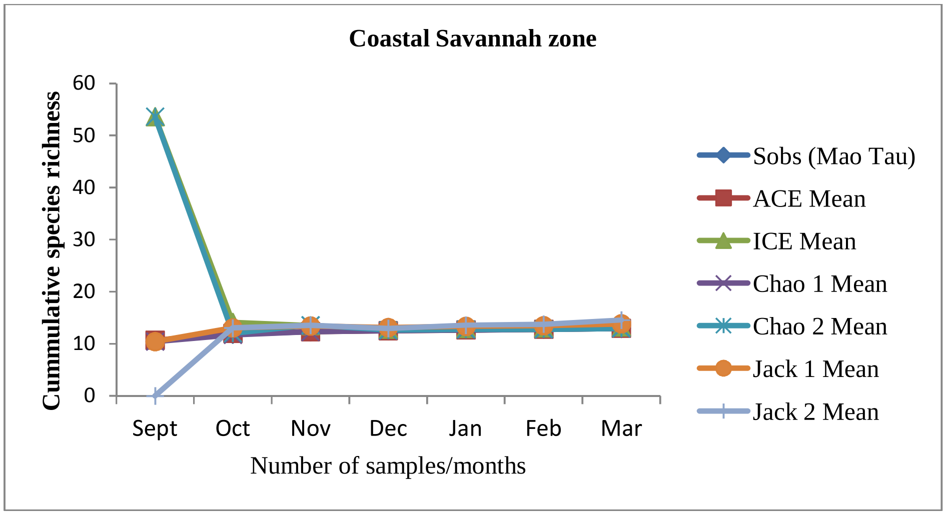


Fig. 4. Species accumulation curve for entomofauna associated with the citrus orchard in the Coastal Savannah zone and its species richness estimators. Average species richness is based on 50 randomizations [22]

Table 2. Diversity indices of the entomofauna for the wet (September-November) and dry (January-March) seasons in the Semi-deciduous rain forest and the Coastal Savannah agro-ecological zones of Ghana

Diversity indices	Semi-deciduous rain forest/wet	Coastal Savannah/wet	Semi-deciduous rain forest/dry	Coastal Savannah/dry
Shannon, H'	0.6086	1.011	0.6309	0.8613
Evenness	0.1671	0.229	0.1566	0.182
Margalef, d	1.184	1.341	1.28	1.429

Table 3. Diversity indices of the entomofauna in the semi-deciduous rain forest and Coastal Savannah agro-ecological zones of Ghana

Diversity indices	Semi-deciduous rain forest	Coastal savannah
Shannon, H'	0.651	0.987
Evenness	0.160	0.204
Margalef, d	1.175	1.327

4. DISCUSSION

Our study reports 387 insects compared to 123 insect species that was earlier reported by [12]. The number of insect species found in this present study shows that citrus agroecosystems provide refugium for a plethora of many insect species in Ghana. Our results show that citrus plantations have high diversity and abundance of entomofauna. Most of the insects collected from each agroecological zone were hymenoptera, probably due to the large number of insects belonging to the family formicidae. They were more in the Semi-Deciduous Rainforest zone than the Coastal Savannah zone because the trees in the latter were comparatively younger. This observation could also probably be attributed to the number of sampling locations, management regimes, sampling techniques and sampling effort in the different studies. This, however, provides the first comprehensive inventory of insects associated with citrus plantations with increasing sampling effort in Ghana.

We found *O. longinoda* to be the most abundant insect species in each agro-ecological zone. This confirms earlier findings of [23] who reported that Weaver ants *O. longinoda* tend to be common over most of their ranges. He further noted that in many localities they are among the most abundant and ecologically dominant elements of the arboreal ant fauna. They were, however, more abundant in the semi-deciduous rain forest zone than in the Coastal Savannah zone, probably due to the age differences in the two orchards, citrus trees in the semi-deciduous rain forest zone being older than those in the Coastal Savannah zone. *O. longinoda* prefers older trees and trees with close canopies [24,25]. Results in the present study are consistent with this earlier observation. The dominance of *O. longinoda* over other insect species could also be attributed to the abundance of honeydew-producing insect species such as citrus aphids (*Toxoptera aurantii, Toxoptera citricidus,* and *Aphis gossypii*), citrus scale insects *Lepidosaphes beckii* and citrus mealy bugs *Planococcus citri* [26,27]. The higher number of *O. longinoda* in the Semi-Deciduous Rainforest zone indicates that citrus trees in this agroecological zone may be better protected from insect pests of citrus than those in the Coastal Savannah zone. It has been earlier noted by [28] that *O. longinoda* protects crops against insect pests, however, the abundance of *O. longinoda* could trigger an outbreak of honeydew-producing hemipterans [29] which are not only pests but also transmit plant pathogens [30]. It was also earlier reported that the association between ants and pests such as aphids and scale insects favours the latter by protecting them from their natural enemies [31], hence could lead to an outbreak of these pests by increasing their abundance and damage.

Our results show that the diversity indices in the Semi-Deciduous Rainforest zone were lower than those in the Coastal Savannah zone. Even though each citrus orchard had several common weeds, some weeds were specific to a particular citrus orchard. The differences could be responsible for variations in abundance and diversity of insect species in each orchard. Variation in the vegetation structure and richness of undergrowth indirectly influence the entomofaunal abundance and diversity [32]. This also confirms the findings of [33] who earlier reported that the structure of vegetation in different zones may influence the diversity of insects in a particular habitat. Similarly, all the diversity indices were higher in the dry season compared to the wet season. During the wet season, from September-November there were no matured citrus fruits, therefore there were few insects in the orchards but during the dry season, from January to March, the fruits were matured and ripened, hence the higher number of insects in the orchards. This could account for the higher diversity in the dry season than the wet season.

In the Semi-deciduous Rain Forest zone, we observed that the abundance of predatory insects belonging to Formicidae (*Crematogaster* sp., *O. longinoda, Tetramorium* sp.) and Asilidae (*Promachus* sp., *Laphria* sp., *Stichnopogon* sp*, Machimus* sp.,) was more than those in the Coastal Savannah zone. This could also account for the low diversity of insects in the Semi-Deciduous Rain Forest zone. This had earlier been reported in several studies where the abundance of predators, parasitoids, and the prevalence of diseases are all involved in insect population control [34,35]. We observed that most of the insects associated with citrus orchards in Ghana are not pest. The majority of the insects found in our study were categorized under “others” (predators, pollinators, parasitoids and unknown species).

5. CONCLUSION

The study has provided a species list of insects in citrus plantations in Ghana. The study shows that citrus orchards have diverse and numerous entomofauna with a small proportion being insect pests of citrus. Our study presents the first comprehensive inventory of insects associated with citrus orchards. This may provide a useful foundation for exploring the integrated production and pest management for citrus production. We recommend that to conserve insect species in citrus orchards, management tactics which have less or no negative effects on natural enemies, pollinators and other insects but can effectively suppress insect pest populations (use of biological control agents, restriction of herbicides and pesticides use) should be adopted.

ACKNOWLEDGEMENTS

This work was funded by the Carnegie Cooperation through the University of Ghana (UG-CCNY ‘Next Generation of Academics Project), the Danish Government through the University of Ghana under BSU-EC, project, the Office of Research Innovation and Development (ORID), and IdeaWild.org. We thank all the staff members of ARPPIS, FOHCREC and the Ministry of Food and Agriculture-Asuansi for their assistance during data collection and identification. We also thank Mr. Henry Davies for helping us in the identification of the fruit flies.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Samways MJ. Insect divers. cons. Cambridge: Cambridge University Press. 2005.

2. Gramaldi D, Engel MS. Evolution of the insects. Cambridge University Press, New York. 2005;755.
3. Stork NE. How many species are there? Biodiversity and Conservation 2. 1993;215-232.
4. Menéndez R. How are insects responding to global warming? Tijdschrift voor Entomologie. 2007;150:355-365.
5. Raina SK, Chauhan TPS, Tayal MK, Pandey RK, Mohan R. Multiple silkworm cocoon cropping in Jammu division. In Proceedings of the Workshop on Recent Trends in Development of Sericulture in Jammu and Kashmir. 2011;63–67.
6. Amalin DM, Peña JE, Duncan R, Leavengood J, Koptur S. Effects of pesticides on the arthropod community in the agricultural areas near the Everglades National Park. Proceedings of the Florida State Horticultural Society 122; 2009.
7. Brittain CA, Vighi M, Bommarco R, Settele J, Potts SG. Impacts of a pesticide on pollinator species richness at different spatial scales. Basic and Applied Ecology. 2010;11(2):106-115.
8. Afreh-Nuamah K. Pests of citrus species-rutaceae. In: Obeng-Ofori D. (edited), Major pests of food and selected fruit and industrial crops in West Africa, The City Publishers Ltd. 2007;119-126.
9. Ministry of Food and Agriculture. Citrus production in Ghana. Horticulture Exports Industry Initiative (HEII). Crop Services Directorate, Ministry of Food and Agriculture. Agriculture information support unit press. Accra, Ghana. 2007;108.
10. Winfree R, Bartomeus I, Cariveau DP. Native pollinators in anthropogenic habitats. Annual review of ecology. Evolution and Systematics. 2011;42:1-22.
11. Afreh-Nuamah K. An annotated list of insects associated with citrus plantations at Kade, Ghana. Ghana Journal of Agriculture Science. 1988;24-27.
12. Kim KC, Byrne LB. Biodiversity loss and the taxonomic bottleneck: Emerging biodiversity science. Ecological Research. 2006;21:794–810.
13. Ofosu-Budu KG. Performance of citrus rootstocks in the forest zone of Ghana. Ghana Journal of Horticulture. 2003;3:1-9.
14. Ministry of Food and Agriculture; 2013. Available:www.mofa.gov.gh/site/?page_id=1436 (Last accessed 30th May, 2016)
15. Gullan PJ, Cranston PS. The insects: An outline of entomology. Blackwell, Malden, Mass, USA; 2005.
16. Gullan PJ, Cranston PS. Insects: An outline of entomology. Chapman and Hall; 2010.
17. Scholtz CH, Holm E. Insects of Southern Africa, Butterworths Professional Publishers; 1989.
18. Crowson RA. Coleoptera: Introduction and Key to Families. HIBI. 1956;4.
19. Ross HH. A textbook of Entomology. Topan Company Ltd. Tokyo. Japan. 1965.
20. McGavin G.C. Insects, Spiders and other Terrestrial Arthropods, Dorling Kindersley. 2002;255.
21. Aidoo OF, Kyerematen R, Akotsen-Mensah C, Afreh-Nuamah K. Effect of some climatic factors on insects associated with citrus agro-ecosystems in Ghana. Journal of Biodiversity and Environmental Sciences. 2014;5(4):428-436.
22. Colwell RK. Estimates- statistical estimation of species richness and shared species from samples. Version 6. User's guide and application; 2000. Available:http://viceroy.eeb.uconn.edu/Estimates
23. Magurran, AE. Ecological diversity and its measurement. New Jersey: Princeton University. 1988;197.
24. Dejean A, Corbara B, Orivel J, Leponce M. Rainforest canopy ants: The implications of territoriality and predatory behaviour. Function Ecosystem Community. 2007;1:105-120.
25. Bawa AS, Yawson GK, Ofori SE, Appiah SO, Afreh-Nuamah K. Relative abundance and diversity of insect species in oil –palm cocoa intercrop at Kusi in the Eastern Region of Ghana. Agriculture Science Research Journal. 2011;1(10):238-247.
26. Blüthgen N, Stork NE, Fiedler K. Bottom-up control and co-occurrence in complex communities: Honeydew and nectar determine a rainforest ant mosaic. Oikos, 2004;106:344-358. DOI: 10.1111/j.0030-1299.2004.12687.x 2015.01.10
27. Tsuji K, Hasyim A, Harlion Nakamura K. Asian weaver ants, *Oecophylla smaragdina* and their repelling of pollinators. Ecological Research. 2004;19: 669-673.
28. Dlussky GM, Wappler T, Wedmann S. New middle Eocene formicid species from

Germany and the evolution of weaver ants. Acta Palaeontologica Polonica. 2008;53(4):615-626.
Available:www.bioone.org/doi/pdf/10.4202/app.2008.04.06
29. Holway DA, Lach L, Suarez VA, Tsutsui ND, Case TJ. The causes and consequences of ant invasions. Annual Review of Ecology & System. 2002;33: 181–233.
30. Delabie JHC. Trophobiosis between formicidae and hemiptera (Sternorrhyncha and auchenorrhyncha): An overview. Neotropical Entomology. 2001;30:501-515.
31. Hill M, Holm K, Vel T, Shah NJ, Matyot P. Impact of the introduced yellow crazy ant *Anoplolepis gracilipes* on Bird Island, Seychelles. Biodiversity and Conservation 2003;12:1969–1984.
32. Khadijah AR, Azidah AA, Meor SR. Diversity and abundance of insect species at Kota Damansara Community Forest Reserve, Selangor. Scientific Research & Essays. 2013;8(9):359-374.
DOI:10.5897/SRE12.481.2015.01.01
33. Abdullah F, Sina I. Rove beetles (Coleoptera: Staphylinidae) of Lanjak Entimau, Sarawak, East Malaysia. International Journal of Zoological Research. 2009;5(3):126-135.
34. Koul O, Dhaliwal GS. (eds). Predators and parasitoids. Taylor and Francis, London. (2003);191
35. Pinheiro F, Diniz IR, Coelho D, Bandeira MPS. Seasonal pattern of insect abundance in the Brizillian Cerrod. Australia Ecology. 2002;27:132-136.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/15293