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Diversity, spatial and temporal distribution of above-ground arthropods associated with watermelon in the Nigerian southern guinea savanna

Okrikata Emmanuel[1*], Ogunwolu Emmanuel Oludele[2] and Ukwela Monday Unwabunne[2]

1 *Department of Biological Sciences, Federal University Wukari, Taraba State, Nigeria.*
2 *Department of Crop and Environmental Protection, Federal University of Agriculture, Makurdi, Benue State, Nigeria.*

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ABSTRACT. Arthropods were sampled on an early- and late-season crop of watermelon in the 2016 cropping season using motorized suction sampler swept along 5m length of the middle row of 20 experimental plots at Federal University Wukari. Specimens were sorted to morphotypes, feeding guilds and as dominant based on percentage relative abundance (RA) and frequency of occurrence (FO). Different species diversity indices were computed. The collections made on the early- and late-sown crops were compared using Jaccard's Similarity index (C_j). Spatial distribution pattern of the dominant arthropods were determined using Taylor's power law and Iwao's patchiness regression. Results showed that collections on both crops were similar (C_j= 0.83). A total of 14,466 specimens sorted to 1 order (Araneae) in the class Arachnida and 64 species in 41 families and 8 orders in the class Hexapoda were collected. Data showed moderately high species diversity (H = 2.8-3.0), richness (R = 6.0-7.2), but low evenness (E = 0.26-0.39). Coleopterous insects (22 species), dominated by chrysomelids, were the most diverse and species-rich followed by hymenopterans, mainly formicids. Dominant arthropods (RA≥1.0 and FO≥25.0%) included *Asbecesta nigripennis, Aulacophora africana, Philanthus triangulum* (parasitoid of bee), *Pheidole* sp., *Camponotus* sp., *Rhynocoris nitidulus* and spiders. Most dominant arthropods were aggregated; dispersion varied with model used and crop season. Only 27.3% of the diverse and rich arthropods on watermelon at Wukari require pest management intervention and validation of their dispersion pattern in large-scale watermelon production.

Key words: Buzas and Gibson's Evenness, Iwao's patchiness regression, Shannon-Weiner index, Taylor's power law, Variance to mean ratio

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Introduction

Watermelon, *Citrullus lanatus* Thunb. (Cucurbitaceae), accounts for 6.8% of the world area devoted to vegetable production (Goreta et al., 2005; Gichimu et al., 2008) and its global consumption is greater than that of any other cucurbit. The crop is gaining a foothold in fruit-based food production across diverse agro-

Corresponding author: Okrikata Emmanuel, E-mail: *eokrikata@gmail.com*
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ecological zones of Nigeria driven by its nutritional, health, and profitable returns to production and marketing investments (Perkins-Veazie & Collins, 2004; Sabo et al., 2013; Ajewole, 2015; Alao & Adebayo, 2015, Okrikata et al., 2019). Economic incentive is fueling proclivity for year-round production with the consequence of organization and stabilization of a community structure of diverse animals. Knowledge of the diversity and richness of organisms in the community is vital to identification of negatively-impacting pest species, the dynamics of their populations, the concomitant effective pest management and safe guarding of human and environmental health as well as to detection of new species, and the rates of species extinction in the habitat (Sisk et al., 1994; Humphries et al., 1995; Mirab-balou et al., 2017).

Entomofaunal studies in watermelon producing areas in Nigeria (Ogunlana, 1996; Bamaiyi et al., 2010; Burabai et al., 2011; Alao and Adebayo, 2015; Malik et al., 2015) had been purposively for pest identification and control. Hardly did any focus on species diversity, richness and dispersion of pest and beneficial organisms. Spatial distribution is an important ecological attribute of arthropod populations and a behavioral response of individuals of a species to the interactions of the complex biological and environmental factors in a given habitat (Sevacherian & Stern, 1972; Steffy, 1979; Arbab & Bakry, 2016). The spatial structure of arthropod populations differs among species (Soemargono et al., 2011); it is influenced by resource availability (Pedigo & Buntin, 1994) and it is important in developing efficient and precise field sampling programs, field monitoring plans, density estimation strategies, population models and ultimately pest management decisions (Khaing et al., 2002; Arbab & Backry, 2016). In this paper, we provide a comprehensive list of the guilds of insects infesting watermelon, their diversity, richness and evenness at a Southern Guinea Savanna location in Nigeria.

Material and methods

Location and study design

The study was conducted at teaching and research farm of Federal University Wukari, Taraba State, Nigeria (Latitude 7° 51′ N and Longitude 9° 47′ E) characterized by warm tropical climate with distinct wet and dry seasons, an annual average temperature of 26.8°C and 1205 mm of rainfall. The crop was established from treated seeds of Kaolack variety of watermelon spaced 1 m within a row and 2 m between rows of plots that were 5 m long and 8 m wide during the early- and late- cropping season of 2016. The plots were hoe-weeded and soil nutrient supplemented with NPK (15:15:15) fertilizer applied at the rate of 200kg/ha.

Sampling of arthropod species commenced at 70 % emergence stage [2 weeks after planting (WAP)] and proceeded at weekly intervals until fruit maturity. A motorized suction sampler with 10 cm diameter inlet cone was used to collect arthropods on plants along the 5 m length of the middle row of each plot (at an approximate walking speed of 1 m/second ≈5 seconds/5 m middle-row/plot) between 1600 and 1800 h. However, to ensure effective sampling of pollinators, collections were made between 0700 and 0900 h during the flowering stage of the crop. Visual observation complemented suction sampling.

Before suction sampling, plants were visually examined to document the parts attacked by dominant insect pests as well as the insects attacked by natural enemies. The specimens collected were killed in ethyl acetate and transported in labeled bags to the laboratory for sorting; the immature stages were reared to adult stage in the laboratory on appropriate food resource. While butterflies and moths were mounted on pins, dried and kept in air-tight boxes containing silica gel, other arthropods were preserved in 70 % ethanol. Insects were identified to species at the Insect Museum of Ahmadu Bello University, Zaria, and then grouped into feeding guilds (Wardhaugh et al., 2012).

Data analysis

The diversity and number of arthropod taxa/species and orders collected and their frequency of occurrence (FO) and relative abundance (RA) were computed for both the early-and late-sown crops. Taxa/species with FO ≥ 25 % and RA ≥ 1 % were regarded as dominant while, those with FO < 25 % and/or, RA < 1 % were regarded as rare following the scale outlined by Zaime & Gautier (1989) and Dajoz (2000) cited in Adja et al. (2016) and Ajayi et al. (2018). The dominant taxa/species were used to compute the natural enemies to pests' ratio (calculated as the sum of natural enemies divided by sum of the pests) for both the early- and late-sown crops. Temporal spread and weekly fluctuations of dominant arthropods were graphically illustrated.

Diversity indices (Shannon-Weiner diversity index, Margalef's species richness index and, Buzas and Gibson's Evenness index) were computed using the Paleantological Statistical Tool –Past3 (Hammer et al., 2001). Similarity between the arthropod taxa collected on the early- and late-sown crops was computed using the Jaccard's similarity index (Ogbeibu, 2014);

Shannon index (H) = $-\Sigma\, Pi \times \ln(Pi)$
Where;
Pi = n/N
n = Number of individuals of one species
N = Total number of all individuals in the sample
ln = Natural logarithm

Margalef's Richness (R) = (S-1)/ln(n)
Where;
S = Number of species
n = Number of individuals
ln = Natural logarithm

Buzas and Gibson's Evenness (E) = e^H/S
Where;
e = Natural logarithm base
H = Shannon index
S = Number of species

Jaccard's index (C_j) = a/a+b+c
Where;
a – No. of taxa/species found on both the early and late sown crops
b – No. of taxa/species found on early and not on late sown crops
c – No. of taxa/species found on the late and not on the early sown crops

Dispersion indices

The variance to mean ratio (S^2/m) proposed by Myers, 1978 in which S^2/m = 1, <1 and >1 indicates random, regular and aggregated dispersion, respectively was used to form a tentative opinion on dispersion patterns of the dominant arthropod taxa/species. It was computed in relation to the stages of growth of the crop.

Linear regression models

Taylor's power law states that the variance (S^2) of a population is proportional to the fractional power of the arithmetic mean (m): $S^2 = am^b$.

To estimate a and b, the values of $\log(S^2)$ were regressed against $\log(m)$ using the formula;

$$\log(S^2) = \log(a) + b\log(m)$$

Where the intercept (*a*) is the sampling/computing factor which changes with sampling unit and, the slope (*b*) is an index of aggregation that indicates a uniform, random or aggregated dispersion when *b* <1, =1 or >1, respectively (Southwood, 1978).

The Iwao's patchiness regression method quantifies the relationship between the mean crowding (m^*) and the mean (m) using the formula;

$$m^* = \alpha + \beta m$$

Where m^* is the mean crowding (Lloyd, 1967). The intercept (α) is the index of basic contagion of a population.

Where;
$\alpha = 0$ [the basic unit of a population is a single individual (a tendency to random dispersion)].
$\alpha > 0$ [there is a positive association between individuals (a tendency to aggregated dispersion)].
$\alpha < 0$ [there is a negative/repulsive association between individuals (a tendency to regular dispersion)].

The slope (β) is the density contagiousness coefficient interpreted in the same manner as *b* of Taylor's regression both of which were computed at 95 % confidence interval (Iwao & Kuno, 1968).

Results

Diversity, abundance and dispersion of arthropods on watermelon

A total of 14,466 specimens sorted into 1 order (Araneae) of the class Arachnida and into 64 species in 41 families and 8 orders of the class Insecta for the early-sown crop and 1 order (Araneae), 53 species in 36 families and 8 orders of insects for the late-sown crop were collected (Tables 1, 2 and 3). Colonization of the early- and late-sown crops was comparable (Jaccard's Similarity Index=0.83). The results show moderately high species diversity (Shannon-Wiener's Index of 2.8–3.0), species richness (Margalef's Richness Index of 6.0–7.2), but low evenness (Buzas and Gibson's Evenness Index of 0.26–0.39) of the arthropods (Table 2).

The insect order Coleoptera was the most diverse (22 species) and numerically dominant with members of the family Chrysomelidae (RA = 8.02–16.04 %, FO = 45.56–80.0 %) being highly abundant and species-rich. Next was the order Hymenoptera (10 species) with members of the family Formicidae (RA = 1.43–6.55%, FO = 27.78–65.00 %) being most abundant and species-rich (Table 3). Coleopterous insects were 4x more abundant than hymenopterans on the early-sown crop but on the late-sown crop the magnitude of difference was 2.2-fold. However, the former order had the lowest species evenness value.

The dominant arthropod species (RA ≥ 1.0 % and FO ≥ 25.0 %) included *Asbecesta nigripennis* Weise, *A. transversa* Allard, *Aulacophora africana* Weise, *Monolepta nigeriae* Bryant, *Epilachna chrysomelina* Fab, *Bemisia tabaci* Genn., *Aphis gossypii* Glove., *Bactrocera cucurbitae* Coq., *Heliothis armigera* Hub., *Cheilomenes sulphurea* Oliv., *Philanthus triangulum* Fab., *Apis mellifera* L., *Crematogaster* sp., *Pheidole* sp., *Camponotus* sp., *Cardiochiles niger* H. & W., *Rhynocoris nitidulus* Fab., and spiders. All others (72.3 % of the collection) were rare or scarce (RA < 1.0 % and/or FO < 25.0 %).

Five feeding guilds were recognized: herbivores (26 taxa), carnivores comprising 17 taxa of predators and 6 taxa of parasitoids, detrivores (6 taxa), pollinators (3 taxa), multi-category and opportunistic feeders (7 taxa). The dominant herbivores constituted 62.6–68.5 % of the collections compared with 15.1–23.4 % for the dominant carnivores giving on the average a ratio of 0.3 carnivore to 1 herbivore. *Apis mellifera* was the main pollinator species (Table 4).

Table 1. Diversity, richness, and evenness of the taxa collected on watermelon at Wukari in 2016 Cropping Season.

Arachnid/ insect order	Early-sown					Late-sown				
	S[1]	*N*[2]	H[3]	R[4]	E[5]	S	*N*	H	R	E
Araneae*	1	86	0.000	0.000	1	1	79	0.000	0.000	1
Blattodea	2	28	0.257	0.300	0.647	1	39	0.000	0.000	1
Coleoptera	22	5195	1.867	2.445	0.294	19	3500	1.879	2.206	0.345
Diptera	8	280	1.149	1.242	0.395	4	232	0.726	0.551	0.517
Hemiptera	8	482	1.46	1.385	0.539	7	996	1.305	0.869	0.527
Hymenoptera	10	1288	1.832	1.257	0.624	10	1557	1.804	1.224	0.607
Lepidoptera	5	81	1.517	0.910	0.912	5	373	0.894	0.676	0.489
Mantodea	2	49	0.688	0.257	0.995	2	42	0.675	0.268	0.982
Orthoptera	7	76	1.804	1.385	0.868	5	83	1.558	0.905	0.950

* All species of spiders were treated as a taxon; [1]**S** Number of species; [2]***N*** Number of individuals/specimens; [3]**H** Shannon-Weiner diversity index; [4]**R** Margalef's species richness index; [5]**E** Buzas and Gibson's evenness.

Table 2. Diversity indices of arthropods collected from watermelon field plots at Wukari in 2016 Cropping Season.

Diversity indices	Early-sown[1]	Late-sown[2]	Inference
Shannon-Weiner Index (H)	2.825	3.040	High species diversity
Margalef's Richness Index (R)	7.166	5.996	Species richness is high. Higher on the early than late-sown crop
Buzas and Gibson's Evenness Index (E)	0.259	0.387	Even distribution of individuals among species is low/few sampled species dominates
Jaccard's Similarity Index (C_j)	0.83		Similarity of species is high between early and late-sown crops

[1] 7565 arthropods in 65 species were collected; [2] 6901 arthropods in 54 species were collected.

Table 3. Relative abundance and frequency of occurrence of arthropod specimens collected on watermelon at Wukari in 2016 cropping season.

Arachnid/ insect order	Family	Species	Early-sown		Late-sown	
			FO (%)[1]	RA (%)[2]	FO (%)[1]	RA (%)[2]
Araneae		Spiders*	30.00	1.14	31.11	1.14
Blattodea	Blaberidae	*Gyna costalis* Walker	1.11	0.03	-	-
	Termitidae	*Odontotermes* sp.	4.44	0.34	9.44	0.57
Coleoptera	Carabidae	*Cicindela melancholica* F.	5.00	0.16	3.89	0.13
		Megacephala denticollis Chd.	2.78	0.08	1.67	0.06
		Platymetopus vestitus Dej.	3.33	0.20	3.89	0.26
	Cerambycidae	*Derobrachus geminatus* Leconte	1.11	0.07	1.67	0.07
	Chrysomelidae	*Asbecesta nigripennis* Weise	80.00	16.04	66.22	14.24
		Asbecesta transversa Allard	75.56	12.86	51.11	8.47
		Aulacophora africana Weise	60.56	12.70	45.56	8.02
		Monolepta nigeriae Bryant	68.89	13.82	55.56	10.50
	Coccinellidae	*Cheilomenes sulphurea* Oliv.	40.56	4.37	50.00	3.87
		Epilachna chrysomelina Fab.	67.22	6.91	43.89	3.62
		Exochomus flavipes Thunb.	8.89	0.49	9.44	0.45
	Curculionidae	*Diaecoderus* sp.	1.67	0.07	1.11	0.03
		Omotrachelus togoanus Mshl.	2.78	0.13	2.78	0.14
	Lycidae	*Lycus corniger* Dalm.	1.11	0.04	1.67	0.07
	Nitidulidae	*Carpophilus dimidiatus* F.	1.67	0.16	2.22	0.19
	Passandridae	*Hectarthrum heros* Fab.	1.67	0.11	2.22	0.14
	Scarabaeidae	*Aulacoserica* sp.	1.11	0.04	-	-
		Copris megaceratoides Waterhouse	5.00	0.20	3.89	0.23

Table 3. Continued

Arachnid/ insect order	Family	Species	Early-sown		Late-sown	
			FO (%)[1]	RA (%)[2]	FO (%)[1]	RA (%)[2]
		Heteronychus mossambicus Couple	3.33	0.11	2.78	0.10
		Onthophagus vinctus Er.	2.22	0.09	3.33	0.13
	Tenebrionidae	*Cossyphus senegalensis* Cast.	0.56	0.01	-	-
		Phrynocolus dentatus Sol.	1.11	0.03	-	-
Diptera	Asilidae	*Laxenecera albicincta* Loen.	4.44	0.26	2.78	0.22
	Drosophilidae	*Zaprionus indianus* Gupta	3.89	0.16	-	-
	Hippoboscidae	*Pseudolynchia canariensis* Macq.	1.11	0.03	-	-
	Muscidae	*Lispe leucospila* Wied.	3.33	0.19	-	-
	Muscidae	*Morellia prolectata* Walk.	1.67	0.11	-	-
		Musca domestica L.	2.78	0.16	3.89	0.23
	Syrphididae	*Phytomia incisa* Wied.	4.44	0.20	3.89	0.23
	Tephritidae	*Bactrocera cucurbitae* Coq.	43.89	2.60	33.89	2.74
Hemiptera	Aleyrodidae	*Bemisia tabaci* Genn.	36.11	1.67	46.11	4.98
	Aphididae	*Aphis craccivora* Kock.	2.78	0.23	7.22	0.46
		Aphis gossypii Glove.	38.33	1.88	43.33	5.97
	Aphrophoridae	*Poophilus costalis* Walker	1.67	0.04	1.11	0.03
	Cicadidae	*Trismarcha* sp.	0.56	0.01	-	-
	Pentatomidae	*Aspavia acuminata* Mont.	3.89	0.21	3.89	0.20
	Pyrrhocoridae	*Odontopus nigricornis* Stal.	3.33	0.19	6.11	0.34
	Reduviidae	*Rhynocoris nitidulus* Fab.	25.56	2.15	23.89	2.43
Hymenoptera	Apidae	*Apis mellifera* L.	38.33	4.86	30.56	5.87
	Braconidae	*Apanteles syleptae* Fer.	4.44	0.20	1.67	0.22

Table 3. Continued

Arachnid/ insect order	Family	Species	Early-sown		Late-sown	
			FO (%)[1]	RA (%)[2]	FO (%)[1]	RA (%)[2]
		Cardiochiles niger H. & W.	30.00	2.06	38.88	2.77
	Chrysididae	*Chrysis convexifrons* Mocs.	2.78	0.12	2.78	0.17
	Crabronidae	*Philanthus triangulum* Fab.	36.11	2.21	36.11	2.04
	Formicidae	*Camponotus* sp.	36.11	1.43	36.11	2.09
		Crematogaster sp.	27.78	1.45	35.00	2.46
		Pheidole sp.	58.33	4.29	65.00	6.55
	Ichneumonidae	*Goryphus bunoh* Guald	2.22	0.12	3.33	0.12
	Vespidae	*Polistes spilophorus* Schlett.	2.78	0.24	5.56	0.22
Lepidoptera	Arctiidae	*Creatonotus leucaniodes* Holland	3.89	0.24	8.33	0.23
	Lycaenidae	*Zizeeria* sp.	3.89	0.21	4.44	0.29
	Noctuidae	*Heliothis armigera* Hub.	2.22	0.08	41.46	4.07
	Nymphalidae	*Acraea eponina* Cr.	5.00	0.36	6.67	0.41
Lepidoptera	Thyrididae	*Epaena danista* Whalley	2.78	0.19	4.44	0.75
Mantodea	Mantidae	*Elaea* sp.	3.89	0.29	4.44	0.25
		Miomantis sp.	4.44	0.36	5.56	0.36
Orthoptera	Acrididae	*Gastrimargus amplus* Sjost.	2.22	0.09	-	-
		Oedaleus nigeriensis Ovarov	6.67	0.29	6.11	
	Gryllidae	*Acanthoplistus* sp.	2.22	0.09	4.44	0.26
		Brachytrupes membranaceus Dry.	1.11	0.07	-	-
		Gymnogryllus sp.	1.11	0.08	3.89	0.19
	Pyrgomorphidae	*Atractomorpha acutipennis* Guer.	3.33	0.22	5.00	0.23
		Pyrrgomorpha sp.	3.89	0.16	4.44	0.14

* Jaccard's similarity index = 0.83; ** Spider species were treated as a single taxon; [1] FO – Frequency of occurrence; [2] RA - Relative abundance.

Table 4. Feeding guilds of the dominant arthropods collected on watermelon at Wukari in 2016 cropping season.

Guild*	Species**	Plant part attacked***	Host/prey
Hb	*A. africana*	Le, Fl, Fr	
	A. gossypii	Le, Vi, Fr	
	A. nigripennis	Le, Fl, Fr	
	A. transversa	Le, Fl, Fr	
	B. tabaci	Le, Vi, Fr	
	E. chrysomelina	Le, Fl, Fr	
	H. armigera	Le, Fl, Fr	
	M. nigeriae	Le, Fl, Fr	
Hb/Po	*B. cucurbitae*	Fl, Fr	
Po	*A. mellifera*	–	–
Pa	*C. niger*		Larvae of beetles, flies and lepidopterans [1]
	P. triangulum		Bees [2]
Pr	*C. sulphurea*		Mites, aphids/Soft bodied insects[3]
	Predatory ants+		Aphids, lepidopterous larvae, beetles, termites [4, 5, 6]
	R. nitidulus		Polyphagous [7]
	Spiders		Polyphagous [8]

* Hb – Herbivore (include defoliators, sap suckers, flower and fruit feeders)
Pr – Predator
Pa – Parasitoid
Po – Pollinator

** Arthropod taxa with frequency of occurrence ≥ 25.0 % and relative abundance ≥ 1.0 %.

*** Le – Leaf; Fl – Flower; Fr – Fruit; Vi - Vine

+ *Camponotus* sp., *Crematogaster* sp., *Pheidole* sp.

1. Adja et al., 2016, 2. Gess & Gess, 2014, 3. Mrosso et al., 2013, 4. Richard et al., 2001, 5. Oliveira et al., 2012, 6. El Keroumi et al., 2010, 7. Subramanian & Kitherian, 2012, 8. Riechert & Lawrence, 1997.

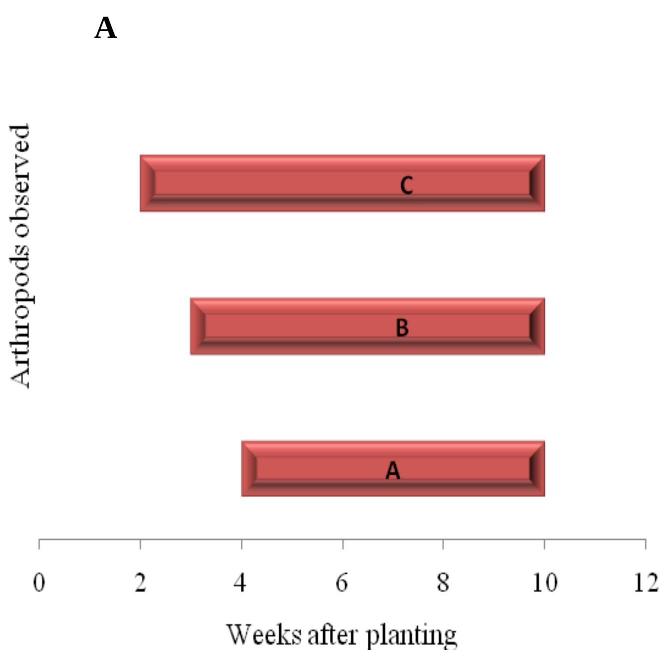
Infestation of the leaf-feeding beetles commenced at the seedling stage and traversed to the fruiting stage; the density peaked at 6 - 7 WAP in the early- and at 5 WAP in the late-sown crop (Figs 1A, B; 2A, B). Among sap-sucking insects, *B. tabaci* was the early colonizer (2 and 4 WAP the early- and late-sown crop, respectively), followed by *A. gossypii* (4 and 3 WAP the early- and late-sown crop, respectively) [Figs 1A, B]. Their infestation persisted to the fruiting stage. The leaf-eating beetles generally occurred at a higher density in the early- than late-sown crop. The reverse was observed with respect to the sap-sucking insects (Figs 2A, B). *Heliothis armigera* was scarce in the early-sown crop but in the late-sown crop infestation commenced at 4 WAP and spanned the fruiting duration. At peak density, there were 3.6 larvae/5 m length of row (Figs 1B, 2B). The fruit fly, *B. cucurbitae*, and bees (*A. mellifera*) colonized the crop at the onset of flowering and persisted through to fruiting stage. Density of the former peaked at 2.7 and 2.0/5 m length of row on the early- and late-sown crop, respectively, while that of the latter peaked at 4.7/5 m and 6.2/5 m length of row on the early- and late-sown crop, respectively (Figs 1A, B; 2A, B). Infestation by ants collectively straddled entire crop growth duration attaining peaks at 6 and 4 WAP in the early- and late-sown crop, respectively (Figs 1A,B; 3A, B). Spiders followed a similar trend but had a bimodal peak on the early crop (4 and 9 WAP) and a single peak (7 WAP) on the late-sown crop (Figs 3A, B).

On the average, densities of pests and beneficial arthropods progressively increased with crop growth attaining a peak at flowering and declining at fruiting stage (Tables 5, 6). Pest density declined 2 weeks earlier on the late- than on the early-sown crop. Beneficial arthropods attained peak density much earlier on the late- than on the early-sown crop. Average density of beetles, predominantly *A. nigripennis*, *A. africana*, and *M. nigeriae*, exceeded the densities of sap-sucking and fruit-feeding insects except on the late-sown crop where average density of *A. gossypii* and *B. tabaci* was higher. Among the beneficial insects, *A. mellifera* had the highest average density on the early-sown crop while on the late-sown crop, *Pheidole* sp. had the highest density.

Taylor's and Iwao's regression models' gave inconsistent dispersion patterns. *Rhynocoris nitidulus* was randomly dispersed using Taylor's model but it was aggregated using Iwao's model (early-sown). On the other hand, *C. sulphurea* was uniformly dispersed with Iwao's regression while it was aggregated with Taylor's regression model late-sown). *Epilachna chrysomelina* was uniformly dispersed on both crops (early- and late-sown). *A. gossypii* and *B. cucurbitae* which were uniformly dispersed on the early-sown crop had aggregated dispersion on the late-sown crop. In the opposite direction, *A. transversa* which were aggregated on the early-sown crop were uniformly dispersed on the late-sown crop (Tables 7, 8). With the same model, dispersion pattern occasionally differed. For example, *C. sulphurea* exhibited uniform dispersion on the early-sown crop but it was aggregated on the late-sown crop (Taylor's power law). *Rhynocoris nitidulus* was aggregated on the early-sown but randomly dispersed on the late-sown crop (Iwao's patchiness regression).

Discussion

The suction sampler has been shown to be efficient in extracting immature and small- to large-sized invertebrates from low vegetation and it gives unbiased density estimates (Grootaert et al., 2010). Though suction samplers have been shown to be less efficient than pitfall traps in collecting spiders and carabid beetles, reasonable success have been recorded in their use for spider and carabid sampling as also observed in the current study (Merrett, 1983; Gibson et al., 1992; Mommertz et al., 1996; Standen, 2000; Brook et al., 2008; McCravy, 2018).



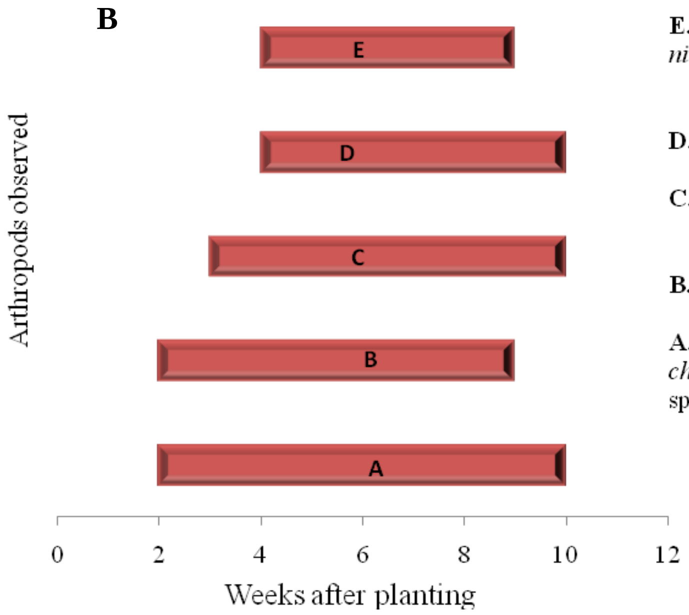


Figure 1. Temporal spread of common arthropods associated with watermelon at Wukari in 2016 cropping season. A) early-sown crop. B) late-sown crop.

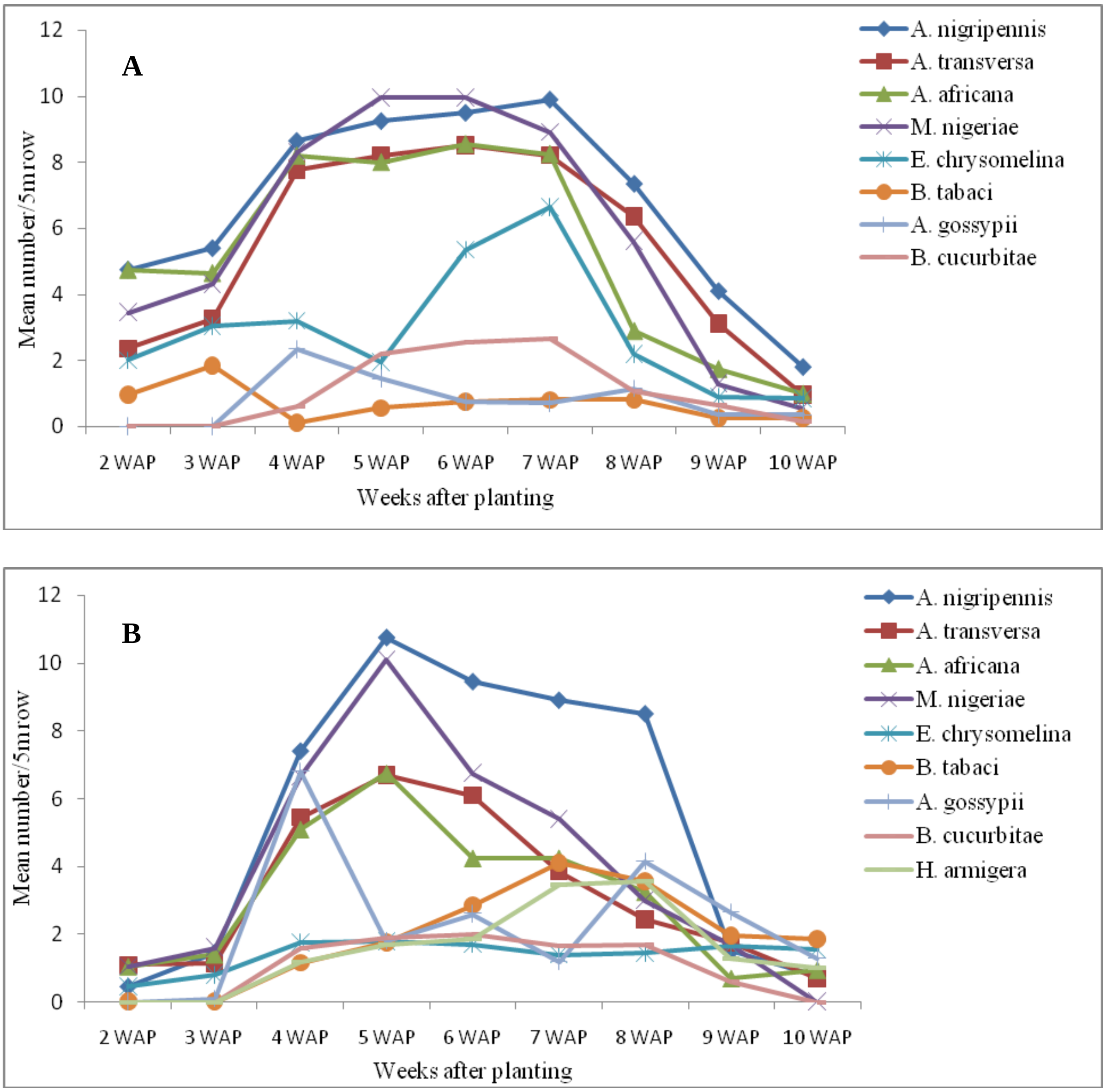


Figure 2. Weekly fluctuations in density of dominant insect pests collected on watermelon at Wukari in 2016 cropping season. A) early-sown crop. B) late-sown crop.

The use of suction sampler in this study accounts for the more comprehensive documentation of arthropods associated with watermelon than those of Ogunlana (1996), Bamaiyi et al. (2010), Burabai et al. (2011), Alao & Adebayo (2015), and Malik et al. (2015). This apart, the authors paid no attention to arthropods whose ecological functions in the community were flower pollination and pest density regulation.

Insect species previously documented but not sighted in this study include: *Copa occidentalis*, *Coccinella septempunctata*, *Diabrotica undecimpunctata*, *Ootheca mutabilis*, *Podagrica* spp., *Phyllotreta cruciferae* [Coleoptera]; *Dacus cucurbitae* [Diptera]; *Zonocerus variegatus* [Orthoptera]; and *Thrips palmi* [Thysanoptera]. Variations in species diversity by geographical location and agroclimatic conditions are well known and reported (Umeozor, 1998; Alao et al., 2016).

Decision which takes no cognizance of the high proportion (72.3 %) of rare species (FO < 25 % and/or, RA < 1 %) which in this study include species belonging the family termitidae, carabidae, curculionidae, tenebrionidae and hippoboscidae etc. and the disproportionate density of carnivores to pest density in controlling pests with synthetic chemicals is bound to be unsustainable, inimical to the optimization of biological control, and negatively impactful on human and environmental health (Okrikata & Ogunwolu, 2017).

Similar to the findings of Tom & Kaippallil (2016), the insect order Coleoptera was the most abundant and diverse. The family Chrysomelidae had high representation probably as a result of co-evolution in which cucurbits' defensive chemical against insect predation equally serves as a chemical cue for host location by chrysomelid beetles of the tribe Luperini (Koul, 2008). In this study, pest infestation was season-long and based on their densities and temporal spread, *A. nigripennis, A. africana,* and *A. transversa* (leaf feeders); *A. gossypii*, and *B. tabaci* (sap-suckers); and *H. armigera*, and *B. cucurbitae* (fruit feeders) are classifiable as the key field pests of watermelon, a designation consistent with the reports by Bamaiyi et al. (2010), Lima et al. (2014), and Alao et al. (2016). *Bactrocera cucurbitae*, a pest of quarantine importance, occurred at a higher density than Malik et al. (2015) documented in their study at Zaria, Nigeria. Concerted effort must be made to curtail its spread and suppress its population in order to avoid restriction of export trading in this commodity. Observation of *A. mellifera*, ants, in particular *Pheidole* and *Crematogaster* sp., as key beneficial organisms in the community confirms previous report by Lima et al. (2014). Given the dearth of research on spider species in Nigeria and especially in the study area, identification of spiders was difficult hence; the spider species collected in this study were treated as a taxon.

Differences found between planting dates for arthropod composition, relative abundance and diversity may relate to weather factors, suitability of host for feeding and oviposition, and density of naturally-occurring biotic agents (Pedigo & Buntin, 1994). Knowledge of pest density and temporal spread is indispensible for pest management decision making (Kumar, 1984). Appropriate and efficient pest sampling protocol, which is instrumental to sound pest management decisions, derives from accurate knowledge of pest dispersion. Results with the different dispersion indices used in this study varied probably on account of insect spatial behaviour's dependence on pest density which itself varies from one cropping season to another (Darbemamieh et al., 2011). The simplest but most unsuitable index was the variance-to-mean ratio (Taylor, 1984). Certain data sets fitted Taylor's regression model better than Iwao's model while others sets fitted Iwao's model better than Taylor's. Mollet et al. (1984) had aptly recommended the use and comparison of different indices to guide decision making.

A rich and diverse species of arthropods colonize watermelon but only a small fraction requires population management interventions. For these, the general clustered dispersion observed in the limited-scale experiment conducted needs to be verified in a larger watermelon production system in order to develop appropriate pest sampling protocol to guide pest management decisions.

Table 5. Population density (*m*±SE)/5m-row and variance to mean ratio (S^2/m) of dominant arthropods collected on early-sown watermelon at Wukari in 2016 cropping season.

	Seedling Stage		**Vegetative stage**		**Flowering stage**		**Fruting stage**	
Species	***m*±SE**	S^2/m	***m*±SE**	S^2/m	***m*±SE**	S^2/m	***m*±SE**	S^2/m
Pest								
A. africana	4.75±0.97	3.985	6.43±0.81	4.110	8.27±0.74	4.041	1.88±0.39	4.744
A. gossypii	-	-	1.18±0.27	2.439	0.95±0.18	2.263	0.62±0.14	1.932
A. nigripennis	4.75±0.98	4.008	6.98±0.87	4.345	9.55±0.88	4.836	4.42±0.58	4.623
A. transversa	2.35±0.58	2.835	5.50±0.77	4.336	8.32±0.68	3.347	3.47±0.53	4.777
B. cucurbitae	-	-	0.30±0.14	2.770	2.47±0.22	1.187	0.62±0.17	2.895
B. tabaci	0.95±0.28	1.600	0.98±0.23	2.171	0.70±0.17	2.484	0.45±0.13	2.442
E. chrysomelina	2.00±0.37	1.370	3.13±0.30	1.135	4.65±0.46	2.682	1.32±0.25	2.923
M. nigeriae	3.45±0.77	3.400	6.30±0.75	3.534	9.58±0.57	2.043	2.48±0.41	4.012
Beneficials								
A. mellifera	-	-	1.43±0.39	4.422	4.12±0.41	2.454	1.07±0.25	3.769
Camponotus sp.	0.10±0.06	0.950	0.53±0.17	2.246	1.25±0.23	2.458	0.17±0.05	1.306
Crematogaster sp.	0.55±0.21	1.618	0.50±0.16	2.052	0.87±0.19	2.707	0.45±0.14	2.669
C. niger	-	-	0.70±0.20	2.433	1.40±0.22	2.209	0.73±0.16	2.362
C. sulphurea	-	-	1.28±0.31	3.005	3.53±0.31	1.608	1.13±0.24	3.164
Pheidole sp.	0.80±0.24	1.525	1.33±0.27	2.183	2.80±0.34	2.419	1.47±0.23	2.216
R. nitidulus	-	-	0.60±0.21	2.975	1.78±0.23	1.830	0.52±0.15	2.823
Spiders	0.25±0.12	1.212	0.60±0.16	1.863	0.32±0.11	2.278	0.63±0.14	1.989

Table 6. Population density (m±SE)/5m-row and variance to mean ratio (S^2/m) of dominant arthropods collected on late-sown watermelon at Wukari in 2016 cropping season.

	Seedling Stage		Vegetative stage		Flowering stage		Fruting stage	
Species	***m*±SE**	***S²/m***	***m*±SE**	***S²/m***	***m*±SE**	***S²/m***	***m*±SE**	***S²/m***
Pest								
A. africana	1.05±0.37	2.648	3.25±0.73	6.575	5.08±0.62	4.606	1.63±0.36	4.779
A. gossypii	-	-	0.65±0.23	3.198	3.73±0.52	4.379	2.70±0.38	3.242
A. nigripennis	0.45±0.24	2.684	4.43±0.62	3.460	9.70±0.62	2.360	3.58±0.61	6.262
A. transversa	1.10±0.39	2.765	3.30±0.55	3.655	5.55±0.54	3.185	1.63±0.30	3.389
B. cucurbitae	-	-	0.80±0.24	3.090	1.78±0.27	2.458	0.77±0.21	3.449
B. tabaci	-	-	0.58±0.26	4.853	2.90±0.39	3.152	2.45±0.32	2.538
E. chrysomelina	0.45±0.25	2.917	1.28±0.28	2.444	1.63±0.25	2.474	1.55±0.23	1.977
H. armigera	-	-	0.60±0.23	3.573	2.33±0.44	4.883	1.95±0.34	3.675
M. nigeriae	1.06±0.38	2.657	4.12±0.63	3.886	7.42±0.60	2.943	1.57±0.34	4.542
Beneficials								
A. mellifera	-	-	0.33±0.23	6.588	5.37±0.60	3.958	1.17±0.31	4.988
Camponotus sp.	0.75±0.28	2.228	1.30±0.34	3.636	0.92±0.23	3.622	0.45±0.14	2.820
Crematogaster sp.	1.00±0.22	1.053	1.73±0.36	2.964	1.13±0.24	3.073	0.23±0.09	1.969
C. niger	-	-	1.23±0.34	3.689	2.07±0.26	1.963	0.27±0.09	1.992
C. sulphurea	0.60±0.21	1.473	1.15±0.25	2.120	2.77±0.25	1.400	0.65±0.16	2.389
Pheidole sp.	1.90±0.42	1.878	3.30±0.47	2.660	3.42±0.40	2.739	1.28±0.21	2.041
R. nitidulus	-	-	0.70±0.30	5.290	1.53±0.27	2.934	0.80±0.21	3.593
Spiders	0.20±0.11	1.370	0.40±0.16	2.667	0.73±0.19	3.244	0.25±0.11	2.932

Table 7. Comparison of dispersion of dominant arthropods collected on early-sown watermelon at Wukari in 2016 cropping season using Taylor's power law and Iwao's regression model.

Species	Taylor's power law				Iwao's patchiness regression			
	A	*b*[1]	SE_b	R^2	α	β[1]	$SE_β$	R^2
Pest								
A. africana	0.461	1.170	0.162	0.882***	2.294	1.114	0.143	0.897***
A. gossypii	0.188	0.981	0.236	0.712**	0.528	1.170	0.348	0.617*
A. nigipennis	0.103	1.605	0.171	0.926***	0.353	1.383	0.104	0.962***
A. transversa	0.239	1.346	0.121	0.942***	0.708	1.251	0.091	0.964***
B. cucurbitae	0.218	0.627	0.153	0.707**	1.143	0.725	0.286	0.478*
B. tabaci	0.276	1.145	0.148	0.896***	0.876	1.134	0.496	0.428NS
E. chrysomelina	0.345	0.766	0.232	0.609*	1.416	0.849	0.148	0.824**
M. nigeriae	0.143	1.254	0.222	0.821**	1.199	1.022	0.092	0.947***
Beneficials								
A. mellifera	0.284	1.243	0.235	0.800*	1.005	1.219	0.215	0.821**
Camponotus sp.	0.222	1.116	0.158	0.877***	0.163	2.233	0.391	0.823**
Crematogaster sp.	0.465	1.420	0.089	0.973***	0.405	2.298	0.581	0.691**
C. niger	0.312	1.106	0.322	0.628*	0.605	1.611	0.440	0.657**
C. sulphurea	0.309	0.898	0.247	0.649**	1.211	0.924	0.254	0.654**
Pheidole sp.	0.231	1.214	0.099	0.956***	0.672	1.125	0.095	0.953***
R. nitidulus	0.232	0.771	0.382	0.368 NS	0.562	1.261	0.311	0.701**
Spiders	0.380	1.406	0.227	0.845***	-0.273	2.927	0.825	0.643**

[1] NS = > 0.05, * = ≤ 0.05, ** = ≤ 0.01, *** = ≤ 0.001

Table 8. Comparison of dispersion of dominant arthropods collected on late-sown watermelon at Wukari in 2016 cropping season using Taylor's power law and Iwao's regression model.

Species	Taylor's power law				Iwao's patchiness regression			
	A	*b*[1]	SE_b	R^2	α	β[1]	$SE_β$	R^2
Pest								
A. africana	0.433	1.371	0.091	0.970***	1.023	1.542	0.235	0.860***
A. gossypii	0.310	1.315	0.116	0.948***	1.374	1.161	0.135	0.913***
A. nigipennis	0.413	0.918	0.090	0.936***	1.659	0.961	0.056	0.977***
A. transversa	0.459	0.979	0.108	0.921***	2.022	0.966	0.166	0.908***
B. cucurbitae	0.064	2.160	0.319	0.868***	0.165	1.711	0.206	0.907***
B. tabaci	0.202	1.475	0.375	0.689**	0.794	1.347	0.313	0.726**
E. chrysomelina	0.363	0.959	0.158	0.841***	1.336	0.994	0.350	0.535*
H. armigera	0.281	1.753	0.399	0.734**	1.026	1.764	0.500	0.640*
M. nigeriae	0.299	1.150	0.190	0.840**	1.437	1.028	0.116	0.919***

Table 8. Continued

Beneficials								
A. mellifera	0.325	1.366	0.313	0.732**	1.417	1.350	0.259	0.796**
Camponotus sp.	0.489	1.405	0.081	0.977***	0.616	2.364	0.506	0.757***
Crematogaster sp.	0.260	1.219	0.101	0.954***	0.108	1.713	0.206	0.908***
C. niger	0.239	1.065	0.251	0.720**	0.540	1.383	0.283	0.773**
C. sulphurea	0.195	1.071	0.066	0.974***	0.616	0.985	0.120	0.906***
Pheidole sp.	0.253	1.306	0.195	0.855***	0.870	1.226	0.188	0.859***
R. nitidulus	0.415	0.695	0.384	0.319NS	1.802	1.309	0.876	0.242NS
Spiders	0.628	1.611	0.087	0.980***	0.223	3.778	0.800	0.761**

[1] NS = > 0.05, * = ≤ 0.05, ** = ≤ 0.01, *** = ≤ 0.001

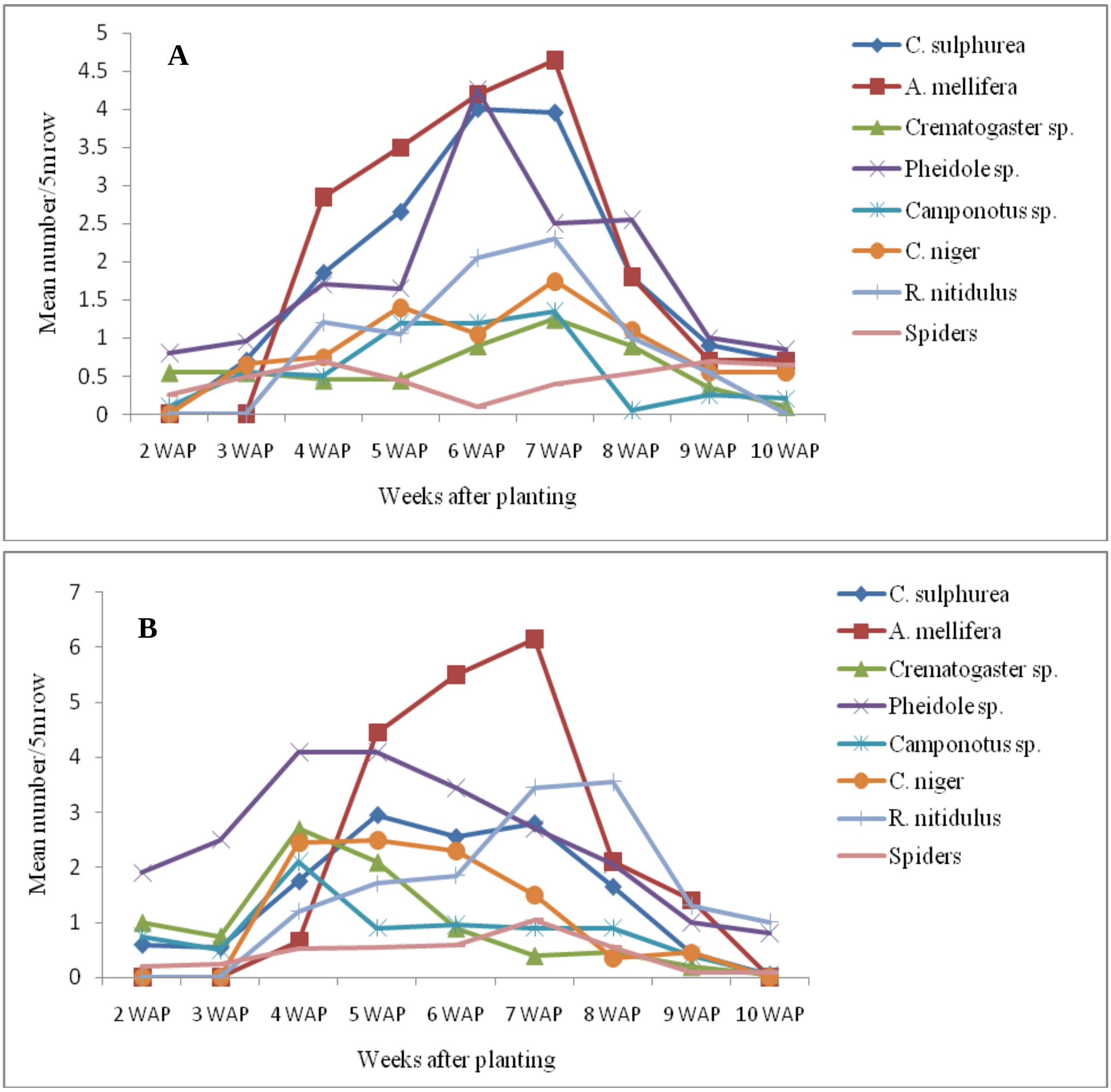


Figure 3. Weekly fluctuations in density of common beneficial arthropods collected on watermelon at Wukari in 2016 cropping season. A) early-sown crop. B) late-sown crop.

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Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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تنوع، توزیع زمانی و مکانی بندپایان مرتبط با هندوانه در منطقه ساوانای جنوبی نیجریه

اوکریکاتا امانوئل[1*]، اوگون ولو امانوئل اولودل[2] و اوکولا ماندی اونوابون[2]

۱ گروه علوم زیستی، دانشگاه فدرال ووکاری، ایالت تارابا، نیجریه.
۲ گروه حفاظت از محصول و محیط زیست، دانشگاه فدرال کشاورزی، مکوردی، ایالت بنو، نیجریه.
* پست الکترونیکی نویسنده مسئول مکـاتبه: *eokrikata@gmail.com*
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چکیـده: نمونه‌های بندپایان مرتبط با هندوانه ابتدا و انتهای فصل در سال ۲۰۱۶ با استفاده از دستگاه نمونه‌بردار مکنده جمع‌آوری شدند. نمونه‌برداری در طول ۵ متر از ردیف‌های میانی ۲۰ کرت آزمایشی واقع در مزرعه تحقیقاتی دانشگاه فدرال وکاری انجام شد. نمونه‌ها بر اساس شکل ظاهری، نوع تغذیه تقسیم بندی شدند. تعیین گونه غالب بر اساس فراوانی نسبی (RA) و فراوانی حضور (FO) انجام شد. شاخص تنوع گونه‌های مختلف نیز محاسبه شد. نمونه‌های جمع‌آوری شده بر اساس الگوی ابتدا و انتهای فصل بر اساس شاخص مشابهت Jaccard (C_j) مقایسه شدند. الگوی توزیع مکانی بندپایان غالب با استفاده از قانونی نمایی تیلور و شاخص رگرسیون آیوائو تعیین شدند. نتایج بدست آمده نشان داد که جمع‌آوری انجام شده روی هر دو محصول مشابه بودند (C_j= 0.83). تعداد کل ۱۴۴۶۶ نمونه متعلق به یک راسته از عنکبوتیان در رده عنکبوت‌مانندها و ۶۴ گونه در ۴۱ خانواده و ۸ راسته از رده شش‌پایان جمع‌آوری شدند. اطلاعات جمع‌آوری شده نشان دهندهٔ بالا بودن نسبی تنوع گونه‌ای (H = 2.8–3.0) و غنای گونه‌ای (R = 6.0–7.2) بود، اما شاخص یکنواختی کم بود (E = 0.26-0.39). در بین حشرات راسته سخت‌بال‌پوشان (۲۲ گونه) سوسک‌های خانواده Chrysomellidae غالب بودند و پس از آنها حشرات راسته بال‌غشاییان، عموماً شامل مورچه‌ها قرار داشتند. بندپایان غالب (RA≥1.0 و FO≥25.0%) شامل *Asbecesta nigripennis*، *Aulacophora africana*، *Philanthus triangulum* (پارازیتویید زنبورهای گرده‌افشان)، *Pheidole* sp.، *Camponotus* sp.، *Rhynocoris nitidulus* و عنکبوت‌ها بودند. اکثر بندپایان غالب دارای توزیع فضایی تجمعی بودند. توزیع بر اساس نحوه و زمان کشت متغیر بود. تنها در مورد ۲۷/۳ درصد از طیف متنوع بندپایان مرتبط با مزرعه هندوانه در وکاری، نیاز به اجرای برنامه‌های مدیریتی بوده و حضور آنها در مناطق تولید با حجم زیاد هندوانه تایید شده است.

واژگان کلیدی: شاخص یکنواختی بوزاس و گیبسون، شاخص رگرسیون آیوائو، شاخص شانون – وینر، قانون نمایی تیلور، نسبت واریانس به میانگین.