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COMPARATIVE INVESTIGATION OF THE ARTHROPOD SUCCESSIONS ON DICHLORVOS-TREATED AND CONTROL CARRIONS IN UBURU, EBONYI STATE, NIGERIA

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Abstract: The study investigated the decomposition pattern and arthropod successions on dichlorvos-treated and control carrions for use in post-mortem investigations. Decomposition rate was notably faster in the dichlorvos-treated carrions. The abundance of arthropod species on dichlorvos-treated carrions 1444 ($t = 6.276$; $p < 0.05$) was less than that of the control carrions 1,928 ($t = 6.637$; $p < 0.05$). The arthropods of the dichlorvos-treated carrions comprised eight orders; the Diptera, 1187(82.18%), Coleoptera, 214(14.81%), Hymenoptera, 21(1.45%), Isoptera, 6(0.42%); Orthoptera, 5(0.35%), Araneae, 6(0.42%) and Polydesmida, 3(0.21%), Decapoda 2(0.14%) while the control carrions comprised eight orders; the Diptera, 1549(80.34%), Coleoptera, 309(16.03%), Hymenoptera, 28(1.45%), Isoptera, 10(0.52%); Orthoptera, 10(0.52%), Araneae, 9(0.36%) and Polydesmida, 6(0.31%). Both carrion groups showed *Chrysomya albiceps* (Calliphoridae) and *Necrobia rufipes* (Cleridae) as the most abundant dipteran and coleopteran species respectively. Additionally, 11 arthropod species were unique to the control carrions while 8 species were exclusive to the dichlorvos-treated carrions. The study documented over 20 forensically uncommon arthropod species from both carrion groups. It was revealed that dichlorvos exposure disrupts the natural decomposition process and significantly alters arthropod successions on carrion. This has important forensic implications, as it can impact the ability to accurately estimate the post-mortem interval.

Keywords: Arthropods, Carrion, Dichlorvos, Entomotoxicology, Forensic entomology.

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INTRODUCTION

Carrion is a decomposing body cum microhabitat that serves as a rich food source for various invertebrate and vertebrate organisms such as bacteria, fungi, arthropods and other vertebrate scavengers. The ubiquitous status of arthropods particularly the necrophagous insects has made it possible for them to become the first invaders of decomposing carrions (Anderson *et al*., 2001; Odo, 2020; Tembe *et al*., 2021). These arthropod species characteristic of decomposing carrions are utilised in forensic entomology to determine the cause and manner of death, body relocation after death, pathological entomotoxicology, myiasis and most importantly the post mortem interval (PMI) during medico-legal investigations (Ilardi *et al.*, 2021; Fatma *et al.*, 2022; Ahmed and Ayuba, 2023; Saleh *et al.*, 2024).

The arthropods associated with the carrion decomposition stages; the fresh, bloat, active decay, advanced decay and dry decay is categorized into four ecological groups, *namely:* necrophages, parasites and predators of the necrophages, omnivores and opportunists or incidental species (Catts and Goff, 1992; Anderson and Van Laerhoven, 1996). The rate of carrion decomposition, the time of invasion by insects and arthropod species associated with the different stages of carrion decomposition are affected and influenced widely by geographical regions (Anderson, 2000; Joseph *et al.*, 2011), seasons (Richards *et al.*, 2009; Tembe and Mukaratirwa, 2021), environments (Parry *et al.*, 2016), habitats (Matuszewski *et al.,* 2013), other microclimatic factors such as humidity, rainfall, ambient temperature (Smith, 1986; Mann *et al.*, 1990) and the presence of drugs and toxins (Goff and Lord, 1994; Abajue and Ewuim, 2020).

Environmental toxins, such as pesticides and heavy metals, demonstrably affect both the biological makeup of carrions and the speed at which it breaks down (Abd El-Bar *et al.,* 2016; Wallace, 2017; Rezk *et al.,* 2018). The World Health Organization (WHO) has identified pesticides poisoning, including dichlorvos, as a prevalent method of suicide globally (Martin *et al.*, 2020; Musa *et al.,* 2010; Kora *et al.,* 2011). Dichlorvos, commercially known as DDVP, is an organophosphate insecticide widely used for insect control in domestic and products storage environments (USEPA, 2007). In Nigeria, it is often marketed under the name 'Sniper'. Exposure to Sniper can occur through various routes, including oral, nasal, or skin absorption, and may result from suicidal attempts, accidents, or intentional homicide (Owoeye *et al.,* 2012; Razwiedani and Rautenbach, 2017). Dichlorvos poisoning manifests systemically with symptoms such as pallor, nausea, vomiting, diarrhoea, abdominal discomfort, headache, dizziness, ocular pain, impaired vision, pupillary changes, lacrimation, salivation, diaphoresis, and mental confusion. In severe cases, the central nervous system (CNS) is affected, leading to inco-ordination, fatigue, speech difficulties, diminished reflexes, asthenia, myoclonus, fasciculations, tremors, paralysis, involuntary elimination, psychosis, cardiac arrhythmia, coma, loss of consciousness, seizures, and ultimately death due to respiratory or cardiac issues (Michael *et al.*, 2008).

It has been established that the presence of toxins, drugs or other poisonous chemicals in carrions can alter the rate of decomposition, succession pattern and insect development. The reports from previous researches indicate that entomological evidence serves as a good viable alternative in forensic toxicology when traditional biological samples, such as bodily fluids and tissues, are unavailable or compro-mised as result of extensive body decay (Amendt *et al.*, 2011; Rawat, 2020; Fatma *et al.*, 2022).

The incidence of mortality resulting from dichlorvos (sniper) poisoning, whether intentional or accidental is a growing concern in Nigeria and globally. The study explored to understand the effects of dichlorvos-treated carrions on ecological arthropod successions and pattern, its implication on post-mortem interval (PMI) and so furnished crucial baseline data and entomological insights for Uburu, Ohaozara Local Government Area, Ebonyi State, Nigeria. This information will also aid forensic entomologists in addressing medico-legal inquiries, particularly those concerning suicide or fatalities resulting from dichlorvos and other organophosphate pesticide poisoning.

MATERIALS AND METHODS

Study area

The study was carried out on an open farmland in Uburu, a town in Ohaozara Local Government area of Ebonyi State, Nigeria (fig. 1). Uburu shares boundaries with Isu, Okposi, and Onicha communities in Ebonyi State and Nkerefi, Mpu, Oduma and Okpanku communities in Enugu State. Obiozara, Uburu is the administrative headquarter of Ohaozara Local Government area, which comprises the three towns of Uburu, Okposi and Ugwulangwu with an area of 312km^2 and supporting a population of 148,626 residents (NPC, 2006). Uburu is situated within the geographical coordinates of 6°2'48" N and 7°45'18" E, at an elevation of 50 meters (164.04 feet). The town experiences a humid tropical climate characterized by two prominent seasons: a wet season lasting from March to October, with annual rainfall varying between 270mm and 2250mm, and a dry season spanning from November to February. Temperature fluctuates between 25°C and 33°C during the dry season and between 23°C and 27°C during the wet season. Its temperature ranges from 25 °C to 33 °C in the dry season and 23 °C to 27 °C in the wet season. Uburu is a town known for a large salt deposit and most of its dwellers are mostly civil servants, traders, farmers or artisans. The plant biodiversity of the study site consists of trees like mango (*Mangifera indica* L.), oil palm (*Elaeis guineensis* Jacq.), African oil bean tree (*Pentaclethra macrophylla* Benth.) and other shrubs and grasses (Ani and Agoro, 2024).

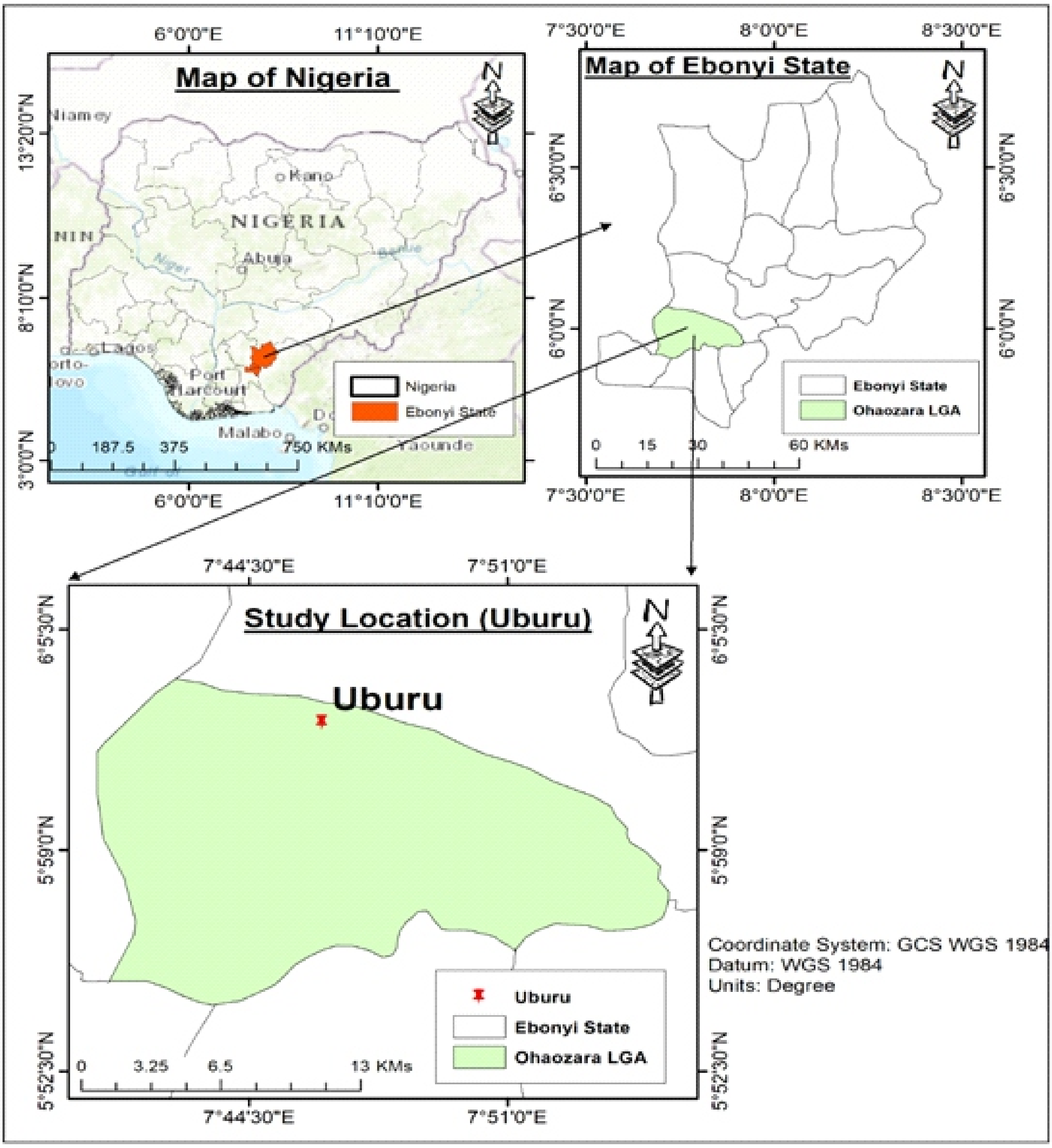

Fig. 1 : Map of the study area (Ani and Ikem, 2025).

Research animal and handling protocols

Domestic pigs (*Sus scrofa* L.) were employed as animal models to simulate human decomposition, following established protocols (Catts and Goff, 1992; Anderson, 2000). The study utilized eight pigs, divided equally into control and dichlorvos-treated groups, each weighing between 23 and 27 kg. These pigs were sourced from a piggery farm in Urobo Uburu, a village near the study site. Two pigs (one control and one treated) were reserved for rearing immature arthropods collected from the remaining six decomposing pigs (three controls and three treated).

Control pigs were euthanized via asphyxiation, while dichlorvos-treated pigs received a lethal oral dose of dichlorvos through gastric tube injection, as described by Abd El-Bar *et al.* (2016), Fatma *et al.* (2022), and Ani and Agoro (2024). Immediately after death, the pigs were transported to the study area and placed at eight distinct locations, spaced ≥100 meters apart to prevent overlapping arthropod attraction, in line with the methods of Tullis and Goff (1987) and Shean *et al.* (1993). The pig carcasses were enclosed in wire mesh cages (60 cm × 45 cm × 30 cm) with a mesh size of 4.45 cm × 4.45 cm. This setup prevented access by vertebrate scavengers while permitting insects and other arthropods to enter freely.

Prior to commencing the study, all ethical guidelines and regulations pertaining to the utilization of porcine subjects in research, as stipulated by the Ethical Board of the Enugu State Ministry of Health (Ref. No: MH/MSD/REC23 /0015, dated May 17th, 2023), were meticulously reviewed and rigorously adhered to (S1).

Ecological and decomposition data collection

Throughout the study, various temperature measurements were recorded using a digital temperature and pH probe (CE-ABS: China). These included the internal temperature of the carrion, the temperature of the maggot mass, the temperature at the interface between the carrion and the soil, and the soil temperature itself. Soil pH was also measured using the same probe. Data regarding ambient temperature, relative humidity, and precipitation were collected daily from the closest weather station, located in Ake Eze, Ivo Local Government Area, Ebonyi State, utilizing a real-time Virtual maze GPS tool.

Collection of adult arthropods and rearing of immature insects

Adult and immature arthropods were collected from the carrions three times daily: in the morning (7:00-8:00 AM), afternoon (12:00-1:00 PM) and evening (6:00-7:00 PM). Flying adult insects were captured using an aerial sweep net, while crawling arthropods were collected with pitfall traps (3 inch tray size) or by direct handpicking using blunt forceps. Adult flies gathered during each decomposition stage were placed in 'killing' jars containing ethyl acetate, a low-toxicity insect killing agent. Arthropod eggs, larva and pupa were collected with brush and forceps and divided into two parts. One part was reared to the adult stage for species identification while the other part was killed with warm water and immediately transferred to vials containing 70 % - 80 % ethanol for preservation as stated by Tabor *et al*. (2004) and Kyerematen *et al*. (2012).

Immature stages collected were reared to the adult stages for confirmatory identification of the species. Rearing was done in plastic rearing chamber half-filled with sawdust to provide a dry condition needed for fly pupation as described by Odo (2020). The chamber was covered with a mesh (1.25cm x 1.25cm) and held tightly in place by rubber bands. The larva were fed with part of the decaying carrion-remains from the control and dichlorvos-treated pigs set apart for rearing the immature stages of the arthropods.

Morphological identification of insects and other arthropods

The immature insects reared to adults and the physically sampled adult insects were prepared, cleaned, soaked in distilled water for 10-15 mins and thereafter air dried for proper identification according to Tembe and Mukaratirwa (2021). The collected arthropods were identified using a stereo microscope (Olympus SZ6-SET, Japan) at the museum of the Institute for Agricultural Research, Ahmadu Bello University, Zaria. Classification into orders, families, genera and species was based on morphological features such as body segmentation, wing patterns, head/mouth structures, and proboscis/tube characteristics, following identification keys from Byrd and Castner (2010), Lutz *et al.* (2018), Lubbe *et al.* (2019), and Bug Guide (2020).

Statistical analysis

Data analysis was conducted using Statistical Package for Social Science Version 26, Microsoft Excel 2016, and Palaeontological Statistics (PAST 4.0.3) software. Arthropod successions and species composition across five decomposition stages (Fresh, Bloat, Active Decay, Advanced Decay, and Dry Decay) were quantified as relative abundances and percentages and presented in tables. T-tests were employed to compare arthropod counts across decomposition stages and total arthropod abundance between control and dichlorvos-treated carrions. Alpha diversity indices, including Shannon-Wiener (H), Dominance, Margalef, Simpson, Evenness, and equitability (J), were calculated to assess arthropod species distribution within each decomposition stage for both control and treated carrions. A significance level of $p < 0.05$ was applied for all statistical tests.

RESULTS

Ecological data and carrion decomposition

During the entire study period, the average environmental conditions were recorded as daily temperature (28.61 ± 0.7 °C), relative humidity (88.75 ± 0.9%), and precipitation (8.11 ± 1.0 mm/day). Decomposition was completed in 50 days for dichlorvos-treated pig carrions and 65 days for the control group. The decomposition process followed five distinct stages: fresh, bloat, active decay, advanced decay, and dry decay. Notably, the control carrions required more days to progress through the fresh, bloat, and active decay stages compared to the treated group. Both groups exhibited similar decomposition rates during the advanced decay stage. However, the control carrions again required more days to complete the dry decay stage (table 1).

Based on the five decay stage decomposition criteria, the control carrions contributed arthropod population of 108(5.60%) for the fresh ($t = 3.745$; $p < 0.05$), bloat 244(12.66%) ($t = 4.780$; $p < 0.05$); active decay, 595(30.86%) ($t = 6.369$; $p < 0.05$); advanced decay, 729 (37.81%) ($t = 6.859$; $p < 0.05$) and the dry decay, 252(13.07%) ($t = 3.719$; $p < 0.05$), while that of the dichlorvos-treated carrion gave a total of 47(3.25%) for the fresh, bloat ($t = 3.626$; $p < 0.05$), 190(13.16%) ($t = 4.887$; $p < 0.05$); active decay, 498(34.49%) ($t = 5.820$; $p < 0.05$); advanced decay 485(33.59%) ($t = 5.993$; $p < 0.05$) and the dry decay 224(15.51%) ($t = 4.760$; $p < 0.05$). The arthropods were more abundant during the active decay stages, followed by the advanced decay stage, the dry decay, the bloat and the fresh decay stages of the two carrion groups (table 1 and fig. 2).

Table 1: Total arthropod abundance and length of decomposition stages of control and dichlorvos-treated carrions.

		FRESH STAGE	BLOAT STAGE	ACTIVE STAGE	ADVANCED DECAY	DRY DECAY	TOTAL
Control	Abundance Degree Days	108 (5.6%) 0-1 (1 day)	244 (12.66%) 2-3 (2 days)	595 (30.86%) 4-5 (2 days)	729 (37.81%) 6-10 (5 days)	252 (13.07%) 11-65 (55 days)	1928 (100.00%) 65 days
Dichlorvos Treated	Abundance Degree Days	47 (3.25%) 0-1 (1 day)	190 (13.16%) 3-6 (4 days)	498 (34.49%) 7-10 (4 days)	485 (33.59%) 11-15 (5 days)	224 (15.51%) 16-50 (36 days)	1444 (100.00%) 50 days

Arthropod Successions and Abundance

The control carrions attracted a significantly greater number of arthropods compared to those treated with dichlorvos (figure 2). A total of 1,928 arthropods ($t = 6.637$; $p < 0.05$) which comprised three classes; the Insecta 1913 (99.22%), the Arachnida 9(0.47%) and the Diplopoda 6(0.31%); eight orders; the Diptera, 1549(80.34%), Coleoptera, 309(16.03%), Hymenoptera, 28(1.45%), Isoptera, 10(0.52%); Orthoptera, 10(0.52%), Araneae, 9(0.36%) and Polydesmida, 6(0.31%); twenty five families and forty four species were recorded for the control carrions at the five different stages of decomposition while the dichlorvos-treated carrions recorded a total of 1,444 arthropods ($t = 6.276$; $p < 0.05$), which made up of four classes; the Insecta, 1433 (99.23%), Arachnida, 6(0.42%); Diplopoda 3(0.21%) and Crustacean, 2(0.14%) eight orders; Diptera, 1187(82.18%), Coleoptera, 214(14.81%), Hymenoptera, 21(1.45%), Isoptera, 6(0.42%); Orthoptera, 5(0.35%), Araneae, 6(0.42%) and Polydesmida, 3(0.21%), Decapoda, 2(0.14%), twenty three families and forty species (table 2 and table 3).

The class Insecta had the highest abundance which included the dipteran order that showed the highest abundance for both carrion groups followed by coleopterans, hymenopterans, the hemipterans, isopterans, orthopterans, the araneae, the polydesmids and decapods. The records of the dipterans from both the dichlorvos-treated and control carrions consisted of different insect species of the families, Calliphoridae, Sarcophagidae, Muscidae, Stratiomyiidae, Piophilidae, Phoridae and Cullicidae. The calliphorids, the muscids and the sarcophagids were more abundant for both carrion groups. Within the Calliphoridae family, the genus *Chrysomya* exhibited the highest prevalence. Specifically, *Chrysomya albiceps* demonstrated the greatest abundance across all arthropod species documented in both carrion groups (table 2 and 3). The dipteran insects of the family Tephrittidae and species (*Pterandrus rosa)* were seen from the dichlorvos-treated carrions but not from the control carrions (table 4).

The order Coleoptera, was the second most abundant arthropod groups from the study. Nine different families of the Coleoptera were recorded with six of them common to both carrion groups. The Elateridae (*Pachyderes* sp.) was only seen on the dichlorvos-treated carrions while the Histeridae (*Hister monotor*) and Carabaidae (*Scarites gagatinus*) were attracted to the untreated carrions. The other Coleoptera families were the Cleridae with the most abundant species (*Necrobia rufipes*), the Demestidae (*Dermestes maculatus*), the Staphylinidae (*Creophilius maxillosus*), Tenebrionidae (*Curimosphena epitragoides*), the Scarabeidae (*Gymnopleurus fulgidus*) and the Chrysomelidae (*Buphonella nigroviolacea*). Their different abundances can be seen in (table 4). The order Hymenoptera, though, it contributed five different families and species to the arthropod successions of the dichlorvos-treated and control carrions it was however, lesser in abundance alongside the other orders (Hemiptera, Isoptera, Orthoptera, Araneae, Polydesmida and Decapoda).

The species of the families; Tephritidae (Diptera), Histeridae (Coleoptera), Carabaidae (Coleoptera), (Coleoptera), Chalcidae (Hymenoptera), Lygaeidae (Hemiptera) and the Reduviidae (Hemiptera) were only attracted to the dichlorvos-treated carrions while the species of the families of the Elateridae (Coleoptera), Apidae (Hymenoptera), Ichneumonidae (Hymenoptera) and the Portunidae (Decapoda) were only attracted to the dichlorvos-treated carrions (table 4). These species only attracted to the dichlorvos-treated carrions were *Isomyia dubiosa*, *Stomorhina rugose, Gonocephalum simplex, Apogonia nitidula, Apogonia moseri, Pachyderes* sp., *Apis mellifera, Scylla serrate* while the species that were only attracted to the control carrions include; *Rhinia apicalis, Ortehelia dubia, Pterandrus rosa, Anermia brevicollis, Gymnopleurus fulgidus, Hister monotor Hister monitor, Nisotra dilecta, Lilioceris livida, Scarites gagatinus, Paltothyreus tarsatus, Antrocephalus* sp., *Lophoraglius* sp., *Pseudophonactonus* sp. (table 5).

The work identified some quite forensically uncommon arthropod species from the study location such as *Termitocalliphora* sp. and *Ortehelia dubia* of the family Calliphoridae and order Diptera; *Pterandrus rosa, Gonocephalum simplex, Curimosphena epitragoides, Anermia brevicollis* of the family Tenebrionidae and order Coleoptera; *Apogonia nitidula, Apogonia moseri* and *Gymnopleurus fulgidus* of the family Scarabeidae and order Coleoptera; *Nisotra dilecta* and *Lilioceris livida* of the Chrysomelidae and the order Coleoptera; *Scarites gagatinus* (Carabidae) and *Pachyderes* sp., (Elateridae) of the order

Coleoptera *Camponotus perrisi* (Formicidae), *Paltothyreus tarsatus* (Formicidae), *Ctenochares* sp., (Ichneumonidae) *Epyris* sp., (Bethylidae) and *Antrocephalus* sp., (Chalcididae) of the order hymenoptera; *Lophoraglius* sp. (Lygaeidae) and *Pseudophonactonus* sp. (Reduviidae) of the order Hemiptera.

Arthropod diversity, as measured by several alpha diversity indices, was demonstrably affected by dichlorvos treatment. Specifically, control carrions exhibited a higher Shannon-Wiener diversity index (3.32) compared to dichlorvos-treated carrions (3.19). A similar trend was observed for Equitability (control: 0.88; treated: 0.86) and Margalef richness (control: 5.69; treated: 5.36). Conversely, the dominance index was elevated in dichlorvos-treated carrions (0.05) relative to control carrions (0.04). The Simpson index was also higher in control carrions (0.96) than in treated carrions (0.95), and the Evenness index followed the same pattern (control: 0.63; treated: 0.61). These results indicated that dichlorvos treatment reduces arthropod diversity and evenness while increasing dominance within carrion ecosystems (table 6).

DISCUSSION

The utility of insects and their other related arthropods as vital forensic marker for post mortem interval estimation during death investigations has been demonstrated by several carrion decomposition and toxicological studies (Amendt *et al*., 2011; Abd El-Bar *et al*., 2016; Odo, 2020; Tembe *et al*., 2021; *Fatma et al*., 2022; Khalil *et al.,* 2023). Carrion decomposition in this study followed a five stage process; the fresh, bloat, active decay, advance decay and dry decay stages in agreement with previous works of (Feugang *et al.*, 2012; Mabika *et al*., 2014; Odo. 2020; Onyishi *et al*., 2020; Saleh *et al.,* 2024). The dry decay stage recorded the longest degree days while the fresh stage was shortest for all the carrion groups. In terms of arthropod presence, the advanced decay stage had the highest number of arthropods for the control while the fresh stage had minimum for both carrions groups (Ekrakene and Odo, 2017).

Table 2: Species abundance of arthropods on control carrions.

CLASS	ORDER	FAMILY	SPECIES	A	B	C	D	E	TOTAL	(%)
Insecta	Diptera	Calliphoridae	*Chrysomya putoria*	10	16	39	40	7	112	5.81
			Chrysomya marginalis	14	19	35	47	5	120	6.22
			Chrysomya albiceps	11	22	49	50	11	143	7.42
			Chrysomya chloropyga	13	24	40	32	5	114	5.91
			Chrysomya regalis	2	13	21	18	2	56	2.90
			Chrysomya inclinata	5	17	26	20	3	71	3.68
			Chrysomya ruffacies	7	12	23	32	4	78	4.05
			Lucilia sericata	13	15	30	32	5	95	4.93
			Lucilia cuprina	6	21	44	53	7	131	6.79
			Termitocalliphora sp.	0	7	22	17	0	46	2.39
			Rhinia apicalis	0	5	13	9	1	28	1.45
		Sarcophagidae	*Sarcophaga tibialis*	1	9	18	14	2	44	2.28
			Sarcophaga exuberans	1	6	16	23	1	47	2.44
			Sarcophaga haemorrhoidalis	3	11	21	15	4	54	2.80
		Muscidae	*Musca domestica*	12	23	36	40	17	128	6.64
			Fannia scalaris	0	2	9	16	1	28	1.45
			Musca sorbens	2	8	24	39	2	75	3.89
			Ortehelia dubia	0	2	13	24	2	41	2.13
		Stratiomyiidae	*Hermetia illucens*	0	0	13	27	7	47	2.44
		Piophilidae	*Piophila casei*	0	0	9	13	0	22	1.14
		Phoridae	*Megaselia scalaris*	0	3	9	16	1	29	1.51

		Culicidea	*Culex pipiens*	7	4	2	0	0	13	0.67
		Tephritidae	*Pterandrus rosa*	1	4	9	13	0	27	1.40
	Coleoptera	Demestidae	*Dermestesmaculatus*	0	0	21	34	46	101	5.24
		Cleridae	*Necrobia rufipes*	0	0	25	47	53	125	6.48
		Staphylinidae	*Creophilius maxillosus*	0	0	3	9	4	16	0.83
		Tenebrionidae	*Curimosphena epitragoides*	0	0	0	5	5	10	0.52
			Anermia brevicollis	0	0	2	3	10	15	0.78
		Scarabaeidae	*Gymnopleurus fulgidus*	0	0	2	4	2	8	0.41
		Histeridae	*Hister monotor*	0	0	0	0	5	5	0.26
		Chrysomelidae	*Buphonella nigroviolacea*	0	0	1	2	4	7	0.36
			Nisotra dilecta	0	0	2	4	3	9	0.47
			Lilioceris livida	0	0	1	3	6	10	0.52
		Carabidae	*Scarites gagatinus*	0	0	0	1	2	3	0.16
	Hymenoptera	Formicidae	*Camponotus perrisi*	0	0	3	5	1	9	0.47
			Paltothyreus tarsatus	0	1	1	2	4	8	0.41
		Bethylidae	*Epyris* sp.	0	0	0	3	2	5	0.26
		Chalcididae	*Antrocephalus* sp.	0	0	1	3	2	6	0.31
	Hemiptera	Lygaeidae	*Lophoraglius* sp.	0	0	0	1	3	4	0.21
		Reduviidae	*Pseudophonactonus* sp.	0	0	1	2	3	6	0.31
	Isoptera	Blattodea	*Reticulitermes flavipes*	0	0	2	3	5	10	0.52
	Orthoptera	Gryllidae	*Acheta domesticus*	0	0	3	2	2	7	0.36
				108	244	589	723	249	1913	99.22
Arachnida	Araneae	Araneidae	*Aranea* sp.	0	0	4	3	2	9	0.47
Diplopoda	Polydesmida	Eurymerodesmidae	*Eurymerodesmus* sp.	0	0	2	3	1	6	0.31
			TOTAL	**108**	**244**	**595**	**729**	**252**	**1928**	**100.00**
			(%)	5.60	12.66	30.86	37.81	13.07	100.00	–

A = Fresh, B = Bloat, C = Active Decay, D = Advanced Decay, E = Dry Decay

Table 3: Species abundance of arthropods on dichlorvos-treated carrions.

CLASS	ORDER	FAMILY	SPECIES	A	B	C	D	E	TOTAL	(%)
Insecta	Diptera	Calliphoridae	*Chrysomya putoria*	2	13	31	25	8	79	5.47
			Chrysomya marginalis	3	14	36	30	11	94	6.51
			Chrysomya albiceps	7	18	41	38	15	119	8.24
			Chrysomya chloropyga	5	15	35	26	9	90	6.23
			Chrysomya regalis	0	4	24	16	3	47	3.25
			Chrysomya inclinata	3	11	21	14	4	53	3.67
			Chrysomya ruffacies	1	9	23	13	5	51	3.53
			Lucilia sericata	2	12	36	24	7	81	5.61
			Lucilia cuprina	3	15	43	32	3	96	6.65
			Isomyia dubiosa	0	8	26	21	5	60	4.16
			Stomorhina rugosa	2	7	19	14	9	51	3.53
			Termitocalliphora sp.	0	6	15	12	6	39	2.70
		Sarcophagidae	*Sarcophaga tibialis*	1	4	13	8	2	28	1.94
			Sarcophaga exuberans	1	7	21	16	1	46	3.19
			Sarcophaga haemorrhoidalis	3	9	17	13	5	47	3.25

		Muscidae	*Musca domestica*	9	22	27	30	15	103	7.13
			Fannia scalaris	0	0	6	12	3	21	1.45
			Musca sorbens	2	9	15	11	4	41	2.84
		Stratiomyiidae	*Hermetia illucens*	0	0	3	7	5	15	1.04
		Piophilidae	*Piophila casei*	0	0	5	2	1	8	0.55
		Phoridae	*Megaselia scalaris*	0	0	3	6	3	12	0.83
		Culicidea	*Culex pipiens*	3	2	1	0	0	6	0.42
	Coleoptera	Demestidae	*Dermestesmaculatus*	0	1	10	40	30	81	5.61
		Cleridae	*Necrobia rufipes*	0	3	13	47	37	100	6.93
		Staphylinidae	*Creophilius maxillosus*	0	0	0	3	5	8	0.55
		Tenebrionidae	*Gonocephalum simplex*	0	0	0	2	3	5	0.35
			Curimosphena epitragoides	0	0	1	1	2	4	0.28
		Scarabaeidae	*Apogonia nitidula*	0	0	0	2	3	5	0.35
			Apogonia moseri	0	0	1	1	2	4	0.28
		Chrysomelidae	*Buphonella nigroviolacea*	0	0	1	1	1	3	0.21
		Elateridae	*Pachyderes* sp.	0	0	0	2	2	4	0.28
	Hymenoptera	Apidae	*Apis mellifera*	0	0	2	5	2	9	0.62
		Formicidae	*Camponotus perrisi*	0	0	1	2	1	4	0.28
		Ichneumonidae	*Ctenochares* sp.	0	0	1	1	3	5	0.35
		Bethylidae	*Epyris* sp.	0	0	0	1	2	3	0.21
	Isoptera	Blattodea	*Reticulitermes flavipes*	0	0	2	1	3	6	0.42
	Orthoptera	Gryllidae	*Acheta domesticus*	0	1	1	1	2	5	0.35
				47	190	494	480	222	1433	99.23
Arachnida	Araneae	Araneidae	*Aranea* sp.	0	0	2	3	1	6	0.42
Diplopoda	Polydesmida	Eurymerodesmidae	*Eurymerodesmus* sp.	0	0	1	1	1	3	0.21
Crustacean	Decapoda	Portunidae	*Scylla serrate*	0	0	1	1	0	2	0.14
			TOTAL	**47**	**190**	**498**	**485**	**224**	**1444**	**100.00**
			(%)	3.25	13.16	34.49	33.59	15.51	100.00	

A = Fresh, B = Bloat, C = Active Decay, D = Advanced Decay, E = Dry Decay

Table 4: Species of arthropods specific to dichlorvos-treated and control carrions.

CONTROL			DICHLORVOS TREATED		
ORDER	**FAMILY**	**SPECIES**	**ORDER**	**FAMILY**	**SPECIES**
Diptera	Calliphoridae	*Rhinia apicalis*	Diptera	Calliphoridae	*Isomyia dubiosa*
	Muscidae	*Ortehelia dubia*			*Stomorhina rugosa*
	Tephritidae	*Pterandrus rosa*	Coleoptera	Tenebrionidae	*Gonocephalum simplex*
Coleoptera	Tenebrionidae	*Anermia brevicollis*		Scarabaeidae	*Apogonia nitidula*
	Scarabaeidae	*Gymnopleurus fulgidus*			*Apogonia moseri*
	Histeridae	*Hister monotor*		Elateridae	*Pachyderes* sp.
	Chrysomelidae	*Nisotra dilecta*	Hymenoptera	Apidae	*Apis mellifera*
		Lilioceris livida	Diplopoda	Portunidae	*Scylla serrate*
	Carabidae	*Scarites gagatinus*			
Hymenoptera	Formicidae	*Paltothyreus tarsatus*			
	Chalcididae	*Antrocephalus* sp.			
Hemiptera	Lygaeidae	*Lophoraglius* sp.			
	Reduviidae	*Pseudophonactonus* sp.			

Table 5: Family abundance of arthropods on dichlorvos-treated and control carrions.

		CONTROL		DICHLORVOS TREATED	
ORDER	**FAMILY**	**ABUNDANCE**		**ABUNDANCE**	
Diptera	Calliphoridae	994	51.55%	860	59.56%
	Sarcophagidae	145	7.52%	121	8.36%
	Muscidae	272	14.11%	165	11.42%
	Stratiomyiidae	47	2.44%	15	1.04%
	Piophilidae	22	1.14%	8	0.55%
	Phoridae	29	1.51%	12	0.83%
	Cullicidae	13	0.67%	6	0.42%
	Tephritidae	27	1.43%	0	0.00%
	Total	**1549**	**80.34%**	**1187**	**82.18%**
Coleoptera	Demestidae	101	5.24%	81	5.61%
	Cleridae	125	6.48%	100	6.93%
	Staphylinidae	16	0.83%	8	0.55%
	Tenebrionidae	25	1.30%	9	0.62%
	Scarabaeidae	8	0.41%	9	0.62%
	Chrysomidae	26	1.35%	3	0.21%
	Histeridae	5	0.26%	0	0.00%
	Carabidae	3	0.16%	0	0.00%
	Elateridae	0	0.00%	4	0.28%
	Total	**309**	**16.03%**	**214**	**14.82%**
Hymenoptera	Apidae	0	0.00%	9	0.62%
	Formicidae	17	0.88%	4	0.28%
	Ichneumonidae	0	0.00%	5	0.35%
	Bethylidae	5	0.26%	3	0.21%
	Chalcididae	6	0.31%	0	0.00%
	Total	**28**	**1.45%**	**21**	**1.46%**
Hemiptera	Lygaeidae	4	0.21%	0	0.00%
	Reduviidae	6	0.31%	0	0.00%
	Total	**10**	**0.52%**	**0**	**0.00%**
Isoptera	Blattoidea	10	0.52%	6	0.42%
Orthoptera	Gryllidae	7	0.36%	5	0.35%
Araneae	Araneidae	9	0.47%	6	0.42%
Polydesmida	Eurymerodesmidae	6	0.31%	3	0.21%
Decapoda	Portunidae	0	0.00%	2	0.14%
	GRAND TOTAL	**1928**	**100.00%**	**1444**	**100.00%**

Table 6: Species diversity indices of arthropods on dichlorvos-treated and control carrions.

	FRESH STAGE		BLOAT STAGE		ACTIVE DECAY		ADVANCED DECAY		DRY DECAY		TOTAL	
	C	T	C	T	C	T	C	T	C	T	C	T
Taxa	16	15	22	21	39	35	42	39	40	38	44	40
Individuals	108	47	244	190	595	498	729	485	252	224	1928	1444
Dominance D	0.09	0.10	0.07	0.07	0.05	0.05	0.04	0.05	0.09	0.07	0.04	0.05
Simpson	0.91	0.90	0.93	0.93	0.95	0.95	0.96	0.95	0.91	0.93	0.96	0.95
Shannon H	2.51	2.50	2.85	2.84	3.24	3.08	3.32	3.16	3.00	3.13	3.32	3.19
Evenness	0.77	0.81	0.79	0.81	0.65	0.62	0.66	0.61	0.50	0.60	0.63	0.61
Margalef	3.20	3.64	3.82	3.81	5.95	5.48	6.22	6.15	7.05	6.84	5.69	5.36
Equitability J	0.90	0.92	0.92	0.93	0.88	0.87	0.89	0.86	0.81	0.86	0.88	0.86

C = Control, T = Dichlorvos-treated

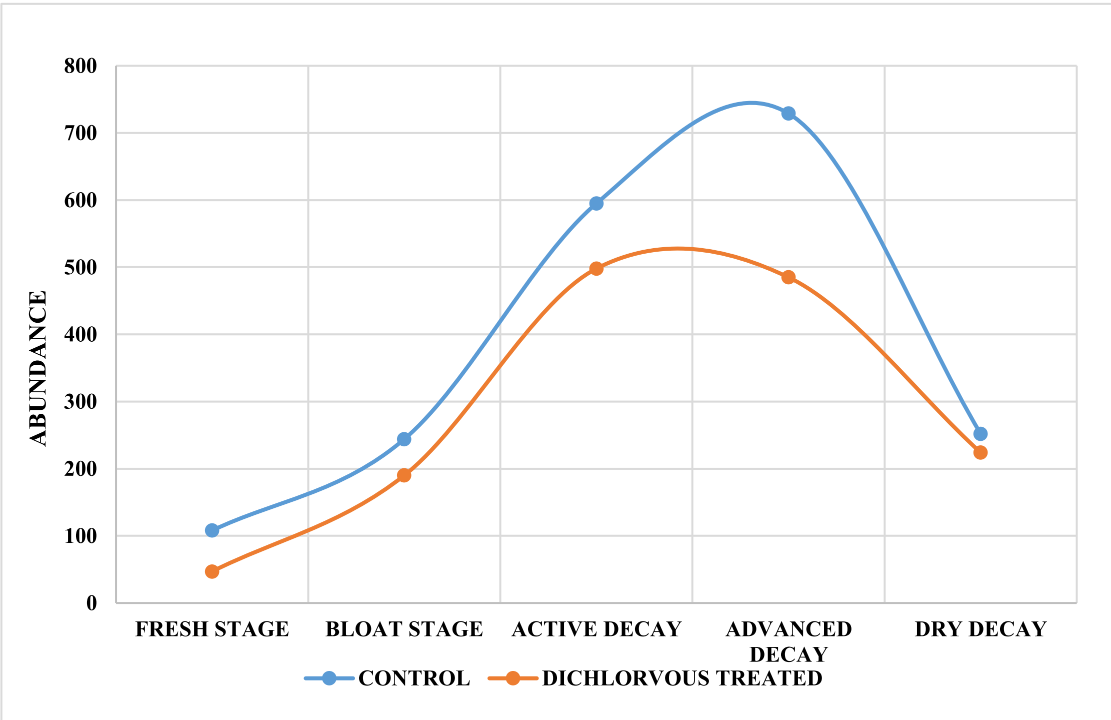

Fig. 2: Abundance plot of arthropods on dichlorvos-treated and control carrions by decomposition stages.

However, the dichlorvos-treated carrions unlike the control recorded its maximum arthropod presence at the active decay stage. This was as result of increased degree days, more insects' activity and effects of decomposition.

The study found that carrions treated with the pesticide dichlorvos experienced an initial delay in decomposition. This was likely due to the toxic effects of dichlorvos deterring fly invasion and activity. Abdollahi *et al.* (2004) and Abd El-Bar *et al.* (2016) had earlier indicated that drugs and toxins may alter the rate of arthropods invasion, development and carrion decomposition rates. However, the overall decomposition rate was faster in the dichlorvos-treated carrions compared to the controls in agreement with the reports of Khalil *et al.* (2023) and Saleh *et al.* (2024).The total decomposition time was 65 days for the controls and only 50 days for the dichlorvos-treated carrions. This accelerated final decomposition in the treated carrions may have been a result of increased internal putrefaction during the delayed early stages, leading to reduced time needed for the final dry decay stage. Some previous studies recorded lesser number of days (Chin *et al*., 2007; Rosina *et al*., 2013) while more days were recorded for complete decomposition by Martinez *et al*. (2007). The variability in reported decomposition timelines across studies can be attributed to differences in environmental factors like temperature, humidity, rainfall, as well as the presence of toxins or other substances that can impact the arthropod community and their role in decomposition (Sharanowski *et al*., 2008; Rosina *et al*., 2013 and Abd El-Bar *et al*., 2016).

The successions and number of arthropods that visited the control carrions (1928) was more than that of the dichlorvos-treated carrion (1444), however, there was no significant difference between the arthropod successions and patterns similar to previous reports of Keshavarzi *et al.* (2021); El-Samad *et al.* (2021); Saleh *et al.* (2024). The higher abundance of arthropods on the control carrions could be due to effect of the increased degree days for decomposition that gave room for more insects' presence and activity similar to previous reports of Rosa *et al*. (2011) and De Faria *et al*. (2018). Also, arthropod invasion and fly activities were delayed in the dichlorvos-treated carrions, similar to the effects, other toxins have on carrions, the effect of parasitic and predative actions of the parasites and predators on the necrophagous species as well as the early shortage of resources due to the loss of carrion biomass that caused the early arrivers to vacate (Abdollahi *et al*., 2004; Abd El-Bar *et al*., 2016). The Insecta class was more abundant in the study and this could be due the ubiquity and necrophagous habit of insects (Anderson *et al*., 2001; Verma and Prakash, 2020).

The arthropod invasion followed the regular succession pattern marked with the arrival of the dipterans, coleopterans and other arthropod orders. The succession of the Diptera order indicated that the family Calliphoridae, Sarcophagidae and Muscidae were the early arrivers and most abundant organisms attracted to both carrion groups. This is in agreement with the works of Al-Mesbah *et al*. (2012) and Abd El-Bar *et al*. (2016). The predictable pattern of succession and early arrival time of the species of these families to the carrion have been shown by Mabika *et al*. (2014) and Tembe and Mukaratirwa (2020) to be of utmost utility in forensic entomology for PMI estimation during criminal investigations. These insects have the ability to detect minute necrotic odours and so get attracted to the carrion immediately after death for feeding and oviposition if the bio-geoclimatic conditions are favourable (Koffi *et al*., 2017; Dao *et al*., 2019; Kpama-Yapo *et al*., 2020; Tembe and Mukaratirwa, 2021). The genus *Chrysoma* and species *Chrysomya albiceps* of the family Calliphoridae was the most abundant arthropod species of the early arrivers in this study. This agreed with previous works that had noted that the genus *Chrysomya* can easily adapt to changing and harsh environmental conditions and can be seen on the carrion at every stage of decomposition (Souza *et al*., 2008; De Faria *et al*., 2018; Odo, 2020).

The Coleoptera ranked the second most abundant arthropod order recorded by this study and they were unevenly distributed between the control and dichlorvos-treated carrions. It included different species from the family; Dermestidae, Cleridae, Staphylinidae, Tenebrionidae, Scarabaeidae, Histeridae, Chrysomelidae, Carabidae and Elateridae. These coleopterans feed on the carrion and get it skeletonised and they can also serve as entomological evidence for PMI estimation in forensic investigation (Kulshrestha and Satpathy, 2001; Schroeder *et al*., 2002). The presence and activities of the coleopteran beetles were seen during the advanced stages of decomposition on both carrion groups in accordance with the works of Rosina *et al*. (2013), but it started earlier in the dichlorvos-treated carrion at the bloat stage which may be due to delay in the bloat stage decay time. In this study the *Necrobia rufipes* of the family Cleridae showed the highest abundance in both the control and dichlorvos-treated carrions and this could be due to its adaptability and reproducibility.

The study also revealed other species of arthropods of different orders and families from both carrions groups such as the Hymenoptera

(Apidae, Formicidae, Ichneumonidae, Bethylidae and Chalcidae), Hemiptera (Lygaeidae and Reduviidae), Isoptera (Battoidae), Orthoptera (Gryllidae), Araneae (Araneidae), Polydemida (Eurymerodesmidae) and Decapoda (Portunidae). Except for some hymenoptrans species of the Formicidae family that can contribute to carrion decomposition and perhaps serve as potential forensic indicator of PMI (Rosina *et al*., 2013), other species from the other orders and families were usually adventitious and opportunistic or were predators of the necrophagous species that were part of the faunal indices of the study geolocation (Abajue *et al*., 2015). The attraction of some arthropod species specifically to the dichlorvos-treated and control carrions respectively could be as a result of the immediate micro conditions of the carrions in relation to the presence of the toxin dichlorvos in the dichlorvos-treated carrions and its absence in the control carrions.

In conclusion, the predictability of arthropod successions on carrion has remained useful in forensic entomology for the determination of post mortem interval (PMI) during criminal investigations. The result of this study showed disparities in the decomposition characteristics as well as the successions and abundance of arthropod species from dichlorvos-treated and control carrions. Due to the implication of dichlorvos in many poisonous and suicidal deaths in Nigeria, this work has provided lead entomo-toxicological information that can be useful in the determination of medico-legal cases relating to dichlorvos and other chemical intoxications. Considering the large geographical sketch of Nigeria, the knowledge of carrion arthropod succession and its use in the criminal justice system is still scanty, therefore, more research works in entomotoxicology and other aspects of entomology should be explored and taken beyond morphological to molecular level across different geographical locations in the country.

CONFLICT OF INTEREST

The authors declare that there is no potential conflict of interest in relation to the article.

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