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A preliminary study on decomposition and seasonality of insect succession of decomposing rabbit carcasses at El-Sharkia Governorate, Egypt

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Abstract

Background Studying insect succession on carcasses is important in estimating the postmortem interval. This study aims to identify the decomposition stages of decomposing rabbit carcasses and to find out the relationship between seasonal variations and abundance of insects colonizing rabbit carcasses at El-Sharkia Governorate, Egypt.

Methods Three domestic rabbits (weighing 1300 g each) were killed by a sharp knife. The carcasses were exposed to the sun, left to decompose and inspected twice daily at 6-h intervals to collect insects. Maggots were collected and reared.

Results The rabbit carcasses underwent four decomposition stages: fresh, bloat, decay and dry stages. The identified families and their respective collected species included three dipteran families: Calliphoridae (*Lucilia sericata, Chrysomya megacephala,* and *Chrysomya albiceps*), Sarcophagidae (*Sarcophaga argyrostoma*) and Muscidae (*Musca domestica* and *Synthesiomyia nudiseta*), three coleopteran families. Histeridae (*Saprinus semistriatus*), Cleridae (*Necrobia rufipes*) and Dermestidae (*Dermestes frischii* and *Attagenus gloriosus*) and three hymenopteran families: Chalcididae (*Brachymeria femorata*), Vespidae (*Vespa orientalis*) and Formicidae (*Monomorium sp.*). Carrion fauna was dominated by dipteran and coleopteran species, with calliphorid and sarcophagid flies found to play a significant role in carrion consumption process.

Conclusion The succession pattern and decomposition rate were season dependent. The information collected may help establish the basic database for entomological forensic investigations in the future.

Highlights

- Diptera and Coleoptera constitute the major decomposers in the carrion fauna.
- Calliphorid and sarcophagid flies play a significant role in carrion consumption.
- Decomposition rate and succession patterns of necrophagous insects vary across seasons.
- The study provides valuable data concerning arthropod succession on carrions in El- Sharkia governorate where no previous data is available.

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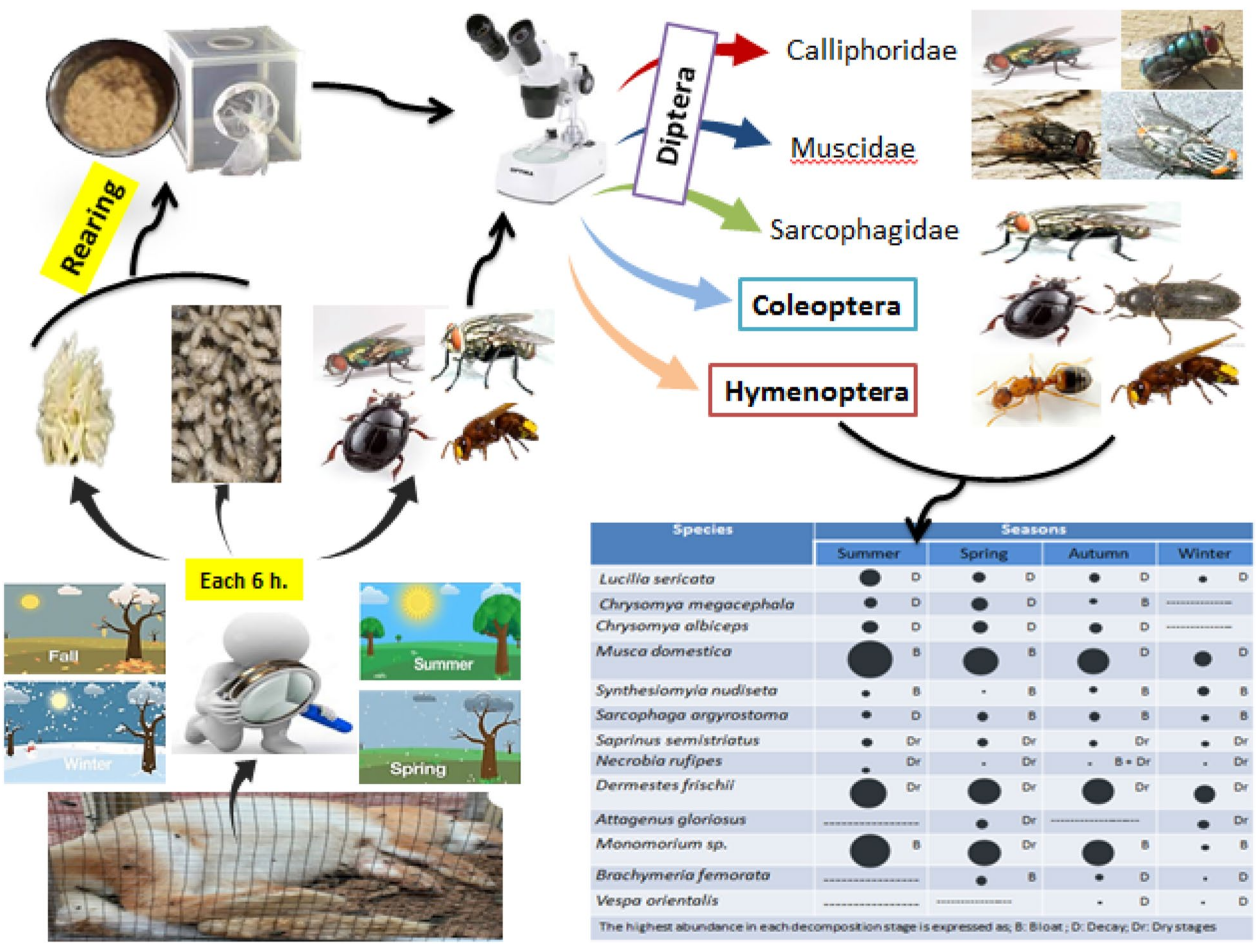
Keywords Insect succession, Decomposition stages, Diptera, Coleoptera, Hymenoptera, Seasons

Graphical abstract



1 Background

The study of insects connected to legal matters is called medico-legal entomology, which is an aspect of forensic entomology [1]. Most importantly, in medico-legal entomology, insects have been identified as a viable tool for calculating the minimum postmortem interval (PMI_{min}), which is the amount of time that passes from the moment of death until the corpse's surface is discovered [2, 3]. The age of the immature stages growing on the cadaver and an examination of the growth and/or succession of insects found on human remains can be used to estimate the PMI_{min} [4].

The decomposition of a cadaver is a complicated biological process that undergoes several stages, including fresh, bloat, active decay, advanced, dry, and skeletal stages (remains) [4]. But because it is so challenging to distinguish between the last two stages, they are frequently combined into dry/remains [5]. The process of cadaver decomposition is linked to several parameters, the most significant of which is the biogeoclimatic zone, such as environmental conditions (habitat, vegetation and soil type), burying conditions (surface or submersion) and climatic conditions (seasonal temperature) [6–8]. Mann et al. [9] reported that one of the key variables influencing the rate of decomposition is the season, most likely as a result of variations in temperature and insect activity. Extrinsic and intrinsic factors are also considered in decomposition, e.g., corpse size, microbiome of gut, reason of death and existence or absence of clothes [1, 10, 11]. These factors synergistically might influence insect species present and their seasonal availability [12]. Thus, the presence or distribution of insect species on a carcass indicates the decomposition stage and death time [13].

Several creatures are drawn to the cadaver throughout the decomposition process for feeding, reproduction (using carcass as an oviposition medium), predation or patriotization on the arthropod fauna occurring on the remains [14]. Insects comprise the majority of the fauna found on the remains, primarily belonging to the Coleoptera order and including calliphorid (blowflies), sarcophagid (flesh flies), muscid (houseflies), and carrion beetles [15].

Some investigations have been performed to assess the pattern of succession of forensically important insects on carrions in Egypt [16–18]. To the best of our knowledge, no studies have been undertaken in Egypt to explore season-insect abundance and succession relationship at El-Sharkia Governorate.

This study aims to identify the decomposition stages of decomposing rabbit carcasses and find out the relationship between seasonal variations and the abundance of insects colonizing rabbit carcasses at El-Sharkia Governorate.

2 Material and methods

2.1 Study site

The work was carried out in the garden inside the University campus, from June 2022 to May 2023, encompassing spring, summer, autumn and winter seasons. Relative humidity (RH) and ambient temperature were noted daily throughout the four seasons of experiments using a portable thermo-hygrometer. Temperature and relative humidity were 25 ± 1 °C and 54–73% RH (for summer), 18 ± 1 °C and 40–60% RH (for spring), 15 ± 1 °C and 51–81% RH (for autumn) and 11 ± 1 °C and 47–82% RH (for winter).

2.2 Carcasses

Since domestic rabbits (*Oryctolagus cuniculus* L.) are known to be an excellent model for human carcasses, they were chosen as the animal model [19, 20]. Three healthy rabbits weighing 1300 g each, obtained from a local farm, were killed for seasonal experiments. In each season, the rabbits were killed by a sharp knife, crucified on a wooden panel and maintained under the above-mentioned ambient conditions. Carcasses were used immediately after killing. So, the exact time of death was known. Each carcass was placed approximately one meter apart. To protect carcasses from birds, carnivores or scavengers; wire cages measuring 60 × 60 × 60 cm were placed over each carcass. The mesh size of cages, measuring 60 × 10 mm, did not add shading; thus, they kept cages exposed to the sun. All experiments carried on animals for this study, were conducted in compliance with the relevant guidelines for animal use (approval number: ZU-IACUC/1/F/422/2023).

2.3 Sampling procedure

Carcasses were examined twice a day, separated by six hours. They were checked once a day when they got to the dry stage. Every kind of arthropod found on, within, and beneath a cadaver was noted. Eggs were collected using a fine wetted paint brush. Tiny spoons and forceps were used to gather larvae and crawling species. A fine artist's paintbrush dampened with 75% ethanol was used to gather small, fragile insects. The carcasses were carefully raised to observe and sample the fauna beneath. In order to minimize carcass disruption and preserve the micro-community's integrity, the manipulation and sampling duration was limited to 15 min.

Ethyl acetate vapor was used to kill adult flies, beetles, wasps, and other insects. After two minutes of killing in hot water, dipterous larvae were placed in vials containing Hood's solution, which consisted of 95 ml of 80% ethanol and 5 ml of glycerin [21]. Fly larvae samples were maintained alive and reared in the laboratory to the adult stage for larval identification, as identification of early instars is much more difficult and inaccurate than identification of adults [22, 23].

2.4 Sample identification

Under a stereo microscope, gathered adult arthropods were morphologically recognized using dichotomous identification keys of flies [24, 25], necrophagous beetles [26–28], and Hymenoptera [29].

2.5 Data analysis

Normality of the data (Shapiro–Wilk test) was tested before statistical analyses. One-way analysis of variance (ANOVA) was conducted to assess significant variations in decomposition stage durations of the rabbit remains among the different seasons. This analysis was then followed by post hoc comparisons between stage durations (Tukey HSD test; $P < 0.05$). The abundance of necrophagous species was compared between decomposition stages and seasons using a generalized linear model (GLM) with negative binomial regression. This approach was selected due to overdispersion in the count data, where the variance exceeded the mean. The negative binomial model serves as a robust alternative to Poisson regression in such cases [30]. Data analyses were carried

Table 1 Insect succession and abundance from a sun-exposed rabbit carcass during decomposition stages in summer season (25 ± 1 °C and 54–73% RH) at El-Sharkia Governorate, Egypt, from June 2022 to May 2023

Order	Family	Genus/Species	Decomposition stages				Total
			Fresh 0–1 d	Bloat 2–4 d	Decay 5–10	Dry 11–29 d	
Diptera	Calliphoridae	*Lucilia sericata*	7	19	29	–	55
		Chrysomya megacephala	4	13	20	–	37
		Chrysomya albiceps	4	21	24	–	49
	Muscidae	*Musca domestica*	5	53	45	–	103
		Synthesiomyia nudiseta	3	8	2	–	13
	Sarcophagidae	*Sarcophaga argyrostoma*	–	3	17	–	20
Coleoptera	Histeridae	*Saprinus semistriatus*	–	–	8	15	23
	Cleridae	*Necrobia rufipes*	–	–	2	11	13
	Dermestidae	*Dermestes frischii*	–	1	23	61	85
		Attagenus gloriosus	–	–	–	–	–
Hymenoptera	Formicidae	*Monomorium sp.*	30	10	36	19	95
	Chalcididae	*Brachymeria femorata*	–	–	–	–	–
	Vespidae	*Vespa orientalis*	–	–	–	–	–

Table 2 Insect succession and abundance from a sun-exposed rabbit carcass during decomposition stages in spring season (18 ± 1 °C and 40–60% RH) at El-Sharkia Governorate, Egypt, from June 2022 to May 2023

Order	Family	Genus/Species	Decomposition stages				Total
			Fresh 0–2 d	Bloat 3–7 d	Decay 8–15 d	Dry 16–37 d	
Diptera	Calliphoridae	*Lucilia sericata*	5	9	12	–	26
		Chrysomya megacephala	1	18	25	–	44
		Chrysomya albiceps	2	16	21	–	39
	Muscidae	*Musca domestica*	3	43	31	4	81
		Synthesiomyia nudiseta	–	5	3	–	8
	Sarcophagidae	*Sarcophaga argyrostoma*	–	14	8	–	22
Coleoptera	Histeridae	*Saprinus semistriatus*	–	–	10	13	23
	Cleridae	*Necrobia rufipes*	–	–	1	7	8
	Dermestidae	*Dermestes frischii*	–	2	19	54	75
		Attagenus gloriosus	–	–	6	19	25
Hymenoptera	Formicidae	*Monomorium sp.*	14	21	10	29	74
	Chalcididae	*Brachymeria femorata*	–	4	9	3	16
	Vespidae	*Vespa orientalis*	–	–	–	–	–

out using IBM SPSS Statistics version 27 software (IBM Corp., Armonk, NY, USA).

3 Results

3.1 Decomposition stages

Tables 1, 2, 3, 4 show that four decomposition stages were identified following the classification of Reed [31]. These were fresh, bloat, decay, and dry stages. Furthermore, Fig. 1 demonstrates statistically significant seasonal variations in the duration of these stages ($P < 0.001$ for each stage). During warmer seasons, the decomposition stages decreased, while they increased during cooler seasons. The fresh stage started at the time of death and persisted until the initial observation of bloating. The duration of this stage varied seasonally: 1 day in summer, 2 days in spring, 3 days in autumn, and 6 days in winter with all pairwise comparisons showing significant differences ($F = 375.8$, $df = 3$, $P < 0.001$). At this point, there are no obvious alterations in morphology or decaying odors. The process of autolysis, or the disintegration of complex proteins and carbohydrate molecules into simpler chemical compounds, occurs during the fresh stage [32],

Table 3 Insect succession and abundance from a sun-exposed rabbit carcass during decomposition stages in autumn season (15 ± 1 °C and 51–81% RH) at El-Sharkia Governorate, Egypt, from June 2022 to May 2023

Order	Family	Genus/Species	Decomposition stages				Total
			Fresh 0–3	Bloat 4–9	Decay 10–19	Dry 20–47 d	
Diptera	Calliphoridae	*Lucilia sericata*	3	7	12	–	22
		Chrysomya megacephala	1	9	–	–	10
		Chrysomya albiceps	2	13	18	–	33
	Muscidae	*Musca domestica*	2	30	41	4	77
		Synthesiomyia nudiseta	1	13	3	–	17
	Sarcophagidae	*Sarcophaga argyrostoma*	–	10	9	–	19
Coleoptera	Histeridae	*Saprinus semistriatus*	–	–	7	9	16
	Cleridae	*Necrobia rufipes*	–	–	1	1	2
	Dermestidae	*Dermestes frischii*	–	1	18	49	68
		Attagenus gloriosus	–	–	–	–	–
Hymenoptera	Formicidae	*Monomorium sp.*	8	25	16	19	68
	Chalcididae	*Brachymeria femorata*	–	3	7	1	11
	Vespidae	*Vespa orientalis*	–	2	3	–	5

Table 4 Insect succession and abundance from a sun-exposed rabbit carcass during decomposition stages in winter season (11 ± 1 °C and 47–82% RH) at El-Sharkia Governorate, Egypt, from June 2022 to May 2023

Order	Family	Genus/Species	Decomposition stages				Total
			Fresh 0–6 d	Bloat 7–12 d	Decay 13–28 d	Dry 29–61 d	
Diptera	Calliphoridae	*Lucilia sericata*	1	5	7	–	13
		Chrysomya megacephala	–	–	–	–	–
		Chrysomya albiceps	–	–	–	–	–
	Muscidae	*Musca domestica*	3	16	21	–	40
		Synthesiomyia nudiseta	1	17	6	–	24
	Sarcophagidae	*Sarcophaga argyrostoma*	–	9	4	–	13
Coleoptera	Histeridae	*Saprinus semistriatus*	–	–	6	8	14
	Cleridae	*Necrobia rufipes*	–	–	1	4	5
	Dermestidae	*Dermestes frischii*	–	1	19	36	56
		Attagenus gloriosus	–	–	3	16	19
Hymenoptera	Formicidae	*Monomorium sp.*	3	5	1	1	10
	Chalcididae	*Brachymeria femorata*	–	1	5	1	7
	Vespidae	*Vespa orientalis*	–	1	2	–	3

mostly as a result of the action of ferments or digestive enzymes [24].

Bloating was observed on Day 2, 3, 4 and 7 postmortems during summer, spring, autumn and winter, respectively. The bloat stage showed a similar pattern ($F = 237.9$, $df = 3$, $P < 0.001$), except there was no significant difference between autumn and winter ($P = 0.593$). When the carcass begins to swell, the bloat stage begins, and it terminates when the carcass deflates. This is the phase when putrefaction, the main process of decomposition, starts. The first obvious symptom is a little inflation of the abdomen brought on by an accumulation of gasses in the intestines as a consequence of anaerobic bacteria's metabolic activity [33]. Hair loss commences, and when fluids begin to escape into the earth from natural body openings, a decaying smell becomes apparent.

The decay stage varied significantly across all seasons ($F = 212.7$, $df = 3$, $P < 0.001$), with the shortest duration observed in summer, followed by spring, autumn, and winter. The fifth, eighth, tenth and thirteenth day marked the decay stage during summer, spring, autumn and winter, respectively. Until the cadaver deflates, the

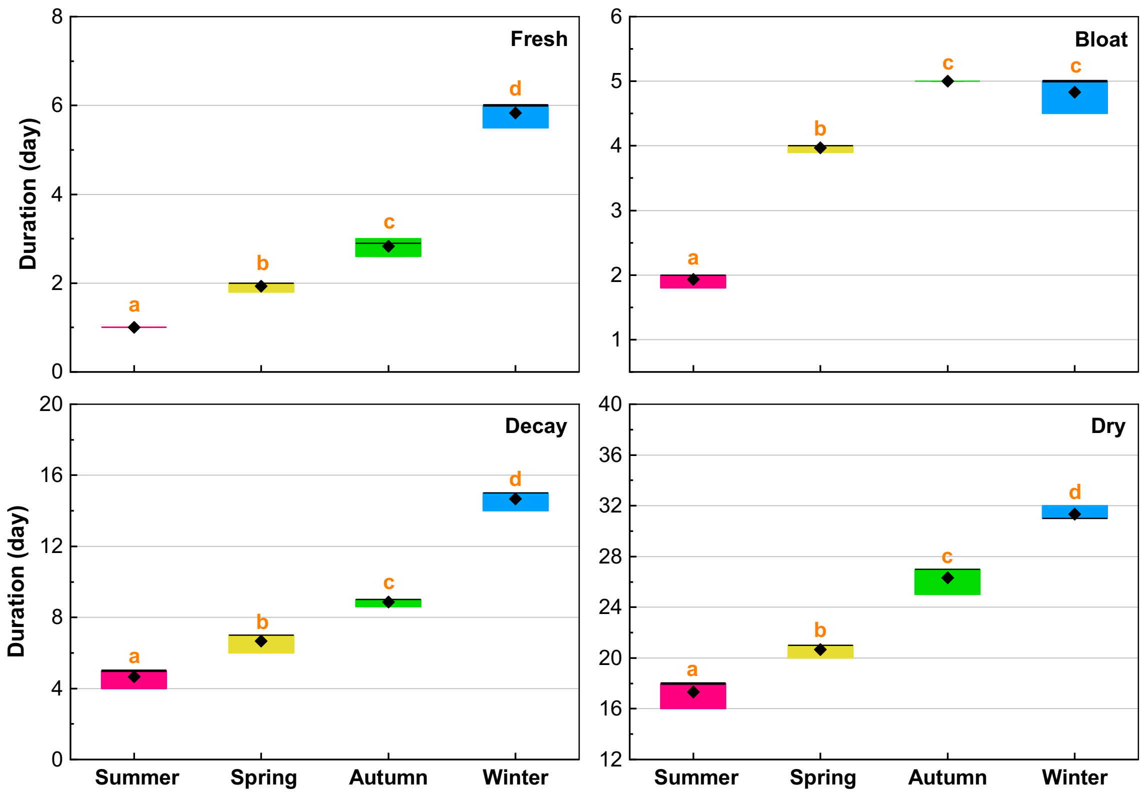


Fig. 1 Seasonal variation in decomposition stage durations of sun-exposed rabbit carcass. Boxes followed by different letters denote significant differences in duration of decomposition stages between the different seasons (analysis of variance [ANOVA]; Tukey HSD test; $P < 0.05$)

decay stage starts, and it ends until the majority of the fragments are somewhat dry. The feeding maggots typically cause one or more cracks in the skin, allowing air to enter and promoting the aerobic protein breakdown process. The loss of hair is noticeable, particularly in places where maggot activity is quite visible. The odor of decay is strong, and most of the carcass biomass was consumed by maggots by the end of this stage. There was a significant difference in appearance between carcasses passing through the decay stage in warm or cold weather. Carcasses in summer and spring were found to blow up slightly, losing their outlines and turning into rounded and the odor was very strong. In autumn and winter, the carcasses retained their normal shapes and only one or two large holes were observed in their bodies. This may be readily caused by the greater temperatures in summer and spring.

By Day 11, 16, 20 and 29 during summer, spring, autumn and winter, respectively, the last stage of decomposition, known as the dry stage, was indicated by the cadaver' drying out. This stage also exhibited significant differences among all seasons ($F = 137.7$, $df = 3$, $P < 0.001$). Only dried skin, hair, cartilage, and bones remain on the cadaver. The longer duration of this stage is attributed to the occurrence of different arthropod species in the carcasses over long periods.

The various decomposition stages were easily marked by the existence, absence or activity of carrion flies and their maggots. In the fresh stage, only adult flies were present. The majority of these flies were observed feeding and ovipositing in natural body openings and abdominal openings which they made, mating, moving on, or hovering around the carcasses. In the bloat stage, early instar larvae were noticed in the mouth, ears, nose and abdominal openings. Third instars occupied the carcasses in the decay stage. The maggots were seen in masses, their rear ends, which carried the two posterior spiracles, projecting above the surface of the carrion, and their pointed anterior ends and bodies submerged in the semi-liquid flesh of decomposing carcasses. The final wave of maggots to infest the body stopped feeding, and their dispersal from the carrion signaled the end of the decay stage and the beginning of the dry stage. Several unopened and empty fly puparia dispersed under and around the bodies indicating the dry stage.

3.2 Seasonality of insect succession

Tables 1, 2, 3, 4 show the seasonal abundance of various insect species gathered from the rabbit cadavers at different decomposition stages. Three dipterous families, namely Calliphoridae, Muscidae and Sarcophagidae, were recorded inhabiting rabbit carcasses. Early colonizers arriving rabbit caraccas in the fresh stage were the calliphorids (*Lucilia sericata, Chrysomya megacephala,* and *Chrysomya albiceps*) and muscids (*Musca domestica and Synthesiomyia nudiseta*). Calliphorids were recorded from the fresh stage and up to the decay stage. *L. sericata* was noticed to breed successfully on carrion during winter, autumn, and spring where it acted as a primary species. During summer, adults of *L. sericata* were found in abundance on carrion but no breeding occurred. *C. megacephala* was entirely absent during the winter season either as adults or larvae. In autumn, it was rare, and adults visited carcasses during the fresh and bloat stages. During summer and spring, *C. megacephala* bred successfully and it was well represented as a secondary species on carcasses. Thus, it appears that this species prefers warmer temperatures. *C. albiceps* was a secondary species on carcasses during summer, autumn and spring, while it was absent during winter. *M. domestica* and *S. nudiseta* were collected from rabbit carcasses, with *S. nudiseta* only bred during the cooler seasons. *S. argyrostoma* was recorded breeding on carcasses during the four seasons. It appeared in both the bloat and decay stages.

The second wave of insect succession on rabbit carcasses was represented by the order Coleopter. Three coleopteran families, namely Histeridae (*Saprinus semistriatus*), Cleridae *(Necrobia rufipes)* and Dermestidae *(Dermestis frischii* and *Attagenus gloriosus*), were abundant and seemed to be a constant component of the faunal succession on corpses. *S. semistriatus* was the first coleopteran species that arrived in carcasses throughout the decay stage and continued up to the dry stage. It was collected during the four seasons of the study. *N. rufipes* was present on cadavers in the decay stage and the early part of the dry stage, with the most abundance in the dry stage. It was frequently observed on carcasses during winter, spring and summer, with a lesser extent during autumn. Generally, dermestids were the most abundant beetles on carcasses. *D. frischii* was observed on carcasses in large numbers during the four seasons from the bloat stage and up to the dry stage, while *A. gloriosus* was frequently observed on carcasses during winter and spring in the decay and dry stages.

Three hymenopteran families were associated with rabbit carcasses, each was represented by only one species. These are Formicidae (*Monomorium* sp.), Chalcididae *(Brachymeria femorata),* and Vespidae *(Vespa orientalis). Monomorium* sp. was observed throughout the decomposition process during the four seasons, with the highest abundance during the warmer seasons. *B. femorata* was collected from rabbit cadavers during winter autumn, and spring starting from the bloat stage. It was entirely absent during summer. *V. orientalis* visited carcasses in the bloat stage and in the early part of the decay stage during autumn and winter. It was observed gnawing at carcasses and feeding on the fluids seeping from them.

Table 5 shows the results of the negative binomial regression analysis. These results indicate that necrophagous insect species abundance varied significantly across decomposition stages and seasons. The decomposition stage had a notably strong impact on species abundance ($\chi2 = 87.4$, $df = 3$, $P < 0.001$). Specifically, the fresh stage exhibited a much lower abundance of species compared to the dry stage (the reference stage),

Table 5 Seasonal and decomposition stage-dependent variations in necrophagous species abundance: negative binomial regression analysis (MLE)

Factor	χ2	Df	*P*	B	95% CI	*P*
Stage of decomposition	87.4	3	< 0.001***			
Fresh stage				–1.408	– 1.803 to – 1.014	< 0.001***
Bloat stage				0.082	– 0.269–0.433	0.646
Decay stage				0.358	0.011–0.706	0.043*
Dry stage				Ref	–	–
Season	29.8	3	< 0.001***			
Summer				0.985	0.612–1.358	< 0.001***
Spring				0.792	0.422–1.162	< 0.001***
Autumn				0.531	0.157–0.905	0.005**
Winter				Ref	–	–

χ^2 = Wald chi-square (tests of model effects), B = estimated Poisson regression coefficient, P = *P* value, significance codes: ****P* < 0.001, ***P* < 0.01, **P* < 0.05

with a regression coefficient (*B*) of −1.408 ($P < 0.001$). The decay stage showed a slight increase in abundance ($B = 0.358$, $P = 0.043$), while no significant change was seen at the bloat stage (compared to the reference dry stage) ($P = 0.646$). Seasonality also significantly affected species abundance ($\chi 2 = 29.8$, $df = 3$, $P < 0.001$), with the highest abundance recorded in summer ($B = 0.985$, $P < 0.001$), followed by spring ($B = 0.792$, $P < 0.001$) and autumn ($B = 0.531$, $P = 0.005$), using winter as the reference season.

4 Discussion

Before being utilized in forensic entomological cases, forensic entomological studies using models of animals could aid in offering an understanding of species prevalent in a particular region. Four distinct stages of decomposition were noted: the fresh, bloat, decay, and dry stages. These results agree with those observed by earlier researchers, who worked on animal models [33–36] and on human cadavers [37]. However, Goff [38] divided the decomposition stages into five stages, known as fresh, swelling, decay, post decay and skeletonization, of which fourth and fifth stages are similar to dry stage in the present study. Several authors [39–42] also described five stages of decomposition: fresh, swelling, active decomposition, advanced decomposition and dry remains stages. The third and fourth stages correspond to the decay stage in the present work. During the dry stage in the present research, the cadavers were revealing dryness signs. Therefore, flies were absent, except a few numbers of *M. domestica* were observed during spring and autumn. The predominant coleopteran species that was being gathered from the decay stage was *D. frischii.* Nevertheless, several investigations have isolated *Dermestes* sp. as soon as the stage of bloat [43]. Van Laerhoven and Anderson [44] speculate that rather than the carcass's state of decomposition, the reason *Dermestes* sp. being present at such an early stage of the decay process could be related to the species' peak seasonal appearance.

The first organisms to inhabit the corpses were Diptera, followed by Coleoptera, which persisted until the very end of the decomposition process. These results are in accord with those of earlier authors [33, 36, 38, 41, 45, 46]. Calliphoridae and Sarcophagidae were found to have the most essential role in the process of carrion degradation.

During winter, spring and autumn, *L. sericata* acted as a primary species where it successfully bred on carcasses. Although adults were observed infesting carcasses in summer, no breeding occurred. Similar observations were noted by Ullyett [47], who observed that adult populations of *L. sericata* reached their highest prevalence during summer while breeding on carrion occurred primarily during winter. Shalaby [48] and Tantawi et al. [34] observed that *L. sericata* colonized and bred successfully on rabbit cadavers in Alexandria during autumn, winter and spring, and were found in abundance during summer. Horenstein et al. [49] also observed that *L. sericata* was exist in winter, autumn, and spring. Martínez-Sanchez et al. [50] showed that *L. sericata* may reflect a lower tolerance to dry and hot conditions than *C. albiceps*. Martin-Vega and Baz [51] observed that *L. sericata* had a lower abundance in meso-Mediterranean habitats during summer. Magni et al. [52] recorded the presence of *L. sericata* during the decomposition process of pig cadavers in Tasmania.

It appears that *C. megacephala* prefers warmer temperatures. These observations agree with those of Shalaby [48] and Tantawi et al. [34], who noticed the existence of *C. megacephala* on rabbit carcasses during spring and summer seasons. Ngoen-Klan et al. [53] collected high numbers of *C. megacephala* in the dry season (March to May), with the peak being in May. They discovered that fly populations quickly declined following the dry season, staying low during the rainy and chilly seasons. However, Horenstein et al. [49] found that *C. megacephala* was mainly abundant in autumn and collected only two adults of this species at the beginning of summer, while Shi et al. [33] found that *C. megacephala* was the only species dominant in the four seasons.

C. albiceps has been reported to occur in Egypt as among the most essential carrion breeding flies [34, 54, 55]. According to descriptions, it is an aggressive predator that feeds on disintegrating tissues and other dipterous larvae found on carrion [34, 56]. This clarifies why, when *C. albiceps* and other fly species existed together on the same carrion, comparatively fewer maggots of other fly species, even Calliphoridae, occurred. *C. albiceps* has been identified by Tantawi et al. [34] and Wolff et al. [41] as a secondary breeder on pig and rabbit cadavers. In the absence of Calliphorinae, it is generally believed that Chrysomyiinae flies can function as main species [57, 58]. *C. albiceps* was a secondary species on the carcasses in autumn, summer, and spring, while it was absent in winter. These observations agree with the findings of Smit [59], who detected that in South Africa, *C. albiceps* do not lay eggs in winter. According to Arnaldos et al. [60], *C. albiceps* was a secondary species that first emerged on the third day and then became dominant in the autumn. According to Martin-Vega and Baz [52], *C. albiceps* represents one of the most common species in supra-Mediterranean environments during the summer and the dominant species in meso-Mediterranean assemblages. Its numbers decreased in autumn, and it was not present in the winter or spring assemblages. The same observations were noted by Martínez-Sanchez et al.

[50] in a Mediterranean holm-oak pasture ecosystem. O'Flynn and Moorhouse [61] found that Chrysomyiinae were primary colonizers in warm seasons. Additionally, it was shown that *C. albiceps* frequently arrived as the first colonist in areas that are Afro-tropical, oriental, central South American, and Southern European [62, 63]. According to Bharti and Singh [64], even in situations where Calliphorinae are also present, individuals of the subfamily Chrysomyiinae can function as main flies.

Although both the muscids *M. domestica* and *S. nudiseta* infested carcasses during the four seasons, the former species did not breed, whereas the latter species bred only in autumn and winter. Similarly, Shalaby [48] and Tantawi et al. [34] demonstrated that adults of *S. nudiseta* frequently visited the rabbit cadavers during all seasons yet they bred only in autumn. Although *S. nudiseta* was found as adults in the early stages of decomposition, Shi et al. [33] showed that they were mostly identified as late invaders in the spring and winter. Voss et al. [1] revealed that adults of *M. domestica* were observed to visit carcasses regularly, however, oviposition was rare. Even though the families Muscidae, Carnidae, Ephydridae, Fanniidae, Periscelididae, Phoridae, Psychodidae, Sphaeroceridae, and Ulidiidae were linked to the rabbit cadavers and occasionally plentiful, none of them were seen to reproduce; instead, it appeared that they were only drawn to the remains for food, according to Al-Mesbah [65]. According to Arnaldos et al. [60], *M. domestica* was the most important muscid species. It was the most common species throughout the summer when it first appeared. In the same way, Horenstein et al. [49] clarified that *M. domestica* was the most common species, occurring frequently in the summer, autumn, and spring but hardly at all in the winter.

S. argyrostoma was the only sarcophagid fly that colonized and bred on rabbit carcasses during the four seasons. However, five sarcophagid species were collected by Shalaby [48] from rabbit carcasses in Alexandria, including *S. argyrostoma, Wohlfahrtia nuba, Sarcophaga aegyptiaca, Sarcophaga crassipalpis and Sarcophaga surcoufi*. In summer and spring, *S. argyrostoma* was observed to be a primary species, while in autumn and winter, it was a secondary species. Galal et al. [66] found that sarcophagids that colonized exposed human tissues in Assiut were *Sarcophaga carnaria* and *Wohlfahrtia* sp. These observations agree with Early and Goff [43] and Payne [67], who reported that flesh flies were the main invaders of carrions in tropical areas and warmer temperate. Martin-Vega and Baz [52] elucidated that *S. argyrostoma* and *Sarcophaga cultellata* seemed to be the primary component of meso-Mediterranean assemblages yet the summer was when they contributed most frequently.

Three families of the order Coleoptera (Histeridae, Cleridae and Dermestidae) were the most abundant during the four seasons. Shalaby [48] recorded 10 coleopteran families from rabbit carcasses in Alexandria. For example, Dermestidae was represented by *D. frischii and Dermestes* maculatus, which colonized the carcasses during the four seasons, except *D. frischii*, which was absent during spring. Cleridae was represented by *N. rufipes and Necrobia ruficolis*. Histeridae was represented by *Saprinus chalcites, Saprinus semipunctatus, and Saprinus tenuistriatus*. Arnaldos et al. [60] collected *D. frischii and D. maculatus* during the early stage of decomposition of chicken carcasses in spring and summer. They observed that their numbers elevated as cadavers started to dry. *N. rufipes* was collected in the advanced stage of decomposition that is similar to the decay stage in the present study. Voss et al. [1] showed that *Dermestes* ater, *D. maculatus, N. rufipes and Saprinus sp*. were observed to breed on cadavers from bloat stage of decomposition onwards. Kyerematen et al. [68] documented that as the ammonia smell from fish, chicken and beef carcasses minimized, coleopteran adults and larvae, mainly *D. frischii* and *N. rufipes* became abundant from the second week onwards feeding on the keratin, accordingly maggots colonized these carcasses.

Three hymenopteran species (*Monomorium* sp., *B. femorata* and *V. orientalis*) frequently visited the rabbit cadavers from the bloat stage of decomposition during the different seasons. In comparison, Shalaby [48] and Tantawi et al. [34] recorded five hymenopteran species (*V. orientalis*, *B. femorata*, *Dirhinus excavates*, *Nasonia vitripennis* and *Muscidifurax raptor*) during the cooler seasons. There didn't seem to be any effect of the hymenopteran species found here on the process of decomposition. This runs counter to the findings of Morreti et al. [69], who found that ants consumed maggots and carcasses.

5 Conclusion

This study demonstrated that Coleoptera and Diptera dominated the carrion fauna, with calliphorid and sarcophagid flies found to have the most significant role in the process of carrion consumption. The rate of decomposition and succession pattern of necrophagous insects on carrions varied across different seasons. Data obtained might be useful to supply an initial database in the future as to the best extent of our comprehension; no prior data were accessible regarding arthropod succession on carrions at El-Sharkia Governorate. Further investigation is required to create a geographic database on Egypt's endemic species of arthropod succession from various settings. This information will support the usefulness of using insect species to determine PMI_{min} in forensic investigations.

Abbreviations

L. sericata	*Lucilia sericata*
C. albiceps	*Chrysomya albiceps*
S. argyrostoma	*Sarcophaga argyrostoma*
M. domestica	*Musca domestica*
S. nudiseta	*Synthesiomyia nudiseta*
S. semistriatus	*Saprinus semistriatus*
N. rufipes	*Necrobia rufipes*
D. frischii	*Dermestes frischii*
A. gloriosus	*Attagenus gloriosus*
B. femorata	*Brachymeria femorata*
V. orientalis	*Vespa orientalis*
PMI_{min}	Minimum post mortem interval
RH	Relative humidity

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AMS and EEZ conceived, designed and wrote the paper. EHS supervised and wrote the paper. The manuscript was read and approved by all authors.

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Declarations

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Consent for publication
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Competing interests
The authors declare no competing interests.

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