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A Scoping Review on Factors Affecting Cadaveric Decomposition Rates

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Abstract

Introduction: The importance of the determination of cadaveric decomposition rate is to enable the forensic pathologist and forensic scientist in estimating the time since death also known as post-mortem interval. There are many factors affecting the cadaveric decomposition rate including environmental factors and non-environmental factors. This scoping review is to explore the relationship between the delaying or accelerating factors and the decomposition rate. Methods: It was conducted using framework suggested by Arksey and O'Maley. Comprehensive search was performed to identify published works and literatures. Inclusion criteria for the search were articles in English published from 2007 to 2016 and related to taphonomic study as well as the decomposition process and/or rate.

Results: A total of 2,893 titles were extracted from electronic databases and other resources and 41 articles were selected based on inclusion criteria. The variables and decomposition rates were generally varied between studies. Accelerating factors were mostly related to higher temperature including the summer season, rainy season, urban and desert area, sun-exposed on ground area, burning effect, enclosed vehicle as well as exposure to insects and scavenger activities. Decelerating factors often relied on the effect of the lower temperature such as winter season, deep coastal marine, underwater, highland and shaded area. It might also depend on the burial effect and other physical barriers by using heavy clothing, wrapping, lime and cement as well as the chemical barrier likewise the organophosphate (OP) pesticide etc.

Conclusion: There were emerging evidences on the affecting factors of the decomposition rate, although it was still very limited in tropical countries including Malaysia. Findings of this scoping review demonstrated that insect activities and temperature were the main factors affecting the overall decomposition rates except in the presence of physical barriers which might have contributed some variations to the decomposition rates.

Keywords: Environmental factor; Non-environmental factor; Taphonomy; Cadaver; Carcass; Decomposition rate

Abbreviations: OP: Organophosphate; MOH: Ministry of Health; IMR: Institute of Medical Research; USIM: University of Science Islamic Malaysia; NMRR: National Medical Research Registry Malaysia; MREC: Medical Research and Ethics Committee; ADD: Accumulated Degree Days; TBS: Total Body Scoring System; ADD: Accumulated Degree Days

Introduction

Post-mortem interval can be estimated using several methods such as entomological study, post mortem changes and taphonomic study, biochemistry of tissues or body fluids from the cadaver etc. The importance of the determination of cadaveric decomposition rate is to enable the forensic pathologist and forensic scientist in estimating the time since death also known as post-mortem interval. With estimation of postmortem interval, the investigating officer could narrow down the search of witness and suspects for a scene of crime or during the death investigation. There are many factors affecting the cadaveric decomposition rate including environmental factors and non-environmental factors. Environmental factors including weather (temperature, humidity etc.), indoor or outdoor, burial or underwater or above ground. Non-environmental factors including body mass/size, wrapping or unwrapped, clothing or unclothed and entomological effects.

There are factors delaying decomposition indicated by M Lee Goff [1] in which divided into physical, chemical and climatic barriers. A body buried in the soil does not decompose as quickly as one exposed on the surface due to the physical barriers. In a similar manner, a body enclosed in a sealed casket or placed into some form of sealed container will also exhibit a delayed decomposition. Embalming process is specifically and chemically designed to prevent the decomposition of the body, with natural body fluids being drained and replaced with various preservative fluids. Insecticides will not permanently delay the colonization of the body by insects. With regards to the climatic factors, at temperatures below 6oC most insect activity ceases but may resume once temperatures rise above this threshold. Wind speed in excess of 16 km/h will inhibit insect flight. Rainfall may also serve as a temporary barrier. Under conditions unfavourable for the colonisation of insects, such as concealment, low temperature or mummification, mites might become the most important or even the only arthropods on a dead body.

Zhou and Byard [2] have also describing the factors accelerating decomposition including exogenous and endogenous factors. Exogenous factors included exposure to elevated environmental temperatures, both outdoors and indoors, exacerbated by increased humidity or fires. Situations indoor involved exposure to central heating, hot water, saunas and electric blankets. Deaths within motor vehicles were also characterized by enhanced decomposition. Failure to quickly or adequately refrigerate bodies may also lead to early decomposition. Endogenous factors included fever, infections, illicit and prescription drugs, obesity and insulin-dependent diabetes mellitus. When these factors or conditions are identified at autopsy less significance should, therefore, be attached to changes of decomposition as markers of time since death. Therefore, the present review will explore the relationship between the delaying or accelerating factors and the decomposition rate. It is hoped that these findings will support future research on the decomposition changes and its affecting factors that might not been well-established to assist in the post-mortem interval estimation especially the homicidal cases.

Review objectives

The authors declared that there was no competing conflict of interests involved in this review. The review objectives were:

i. To identify significant factors affecting cadaveric decomposition rates.

ii. To determine the common indicators used in computing the cadaveric decomposition rates.

iii. To study the relationship between the contributing factors and decomposition rates.

Methods

The design of the study is scoping review. Scoping review aims to map rapidly the key concepts underpinning a research area and the main sources and types of evidence available especially when an area is complex or has not been reviewed comprehensively before. For the purpose of this topic, the scoping review is performed to identify the affecting factors, determine the indicators for decomposition rates and study relationships between both factors and decomposition rates. In this review, cadaver refers to the dead human bodies or animal carcasses that are left to the decomposition process whilst decomposition rate is defined as the time relapse from the first decomposition stage (fresh) to the final decomposition stage (skeletonisation) which based on the TBS scoring system or any of the observational systems. The 5 stages of the scoping review York Framework by Arskey and O'Maley include "Identifying the research questions", "identifying relevant studies", "study selection", "charting the data" and "collating, summarising and reporting the results". Consultation with reviewers from Ministry of Health (MOH), University of Science Islamic Malaysia (USIM) and Institute of Medical Research (IMR) are also conducted to enhance the review work undertaken by the research team members. The study was registered under the National Medical Research Registry Malaysia (NMRR) and the protocol was approved by the Medical Research and Ethics Committee (MREC) Malaysia (ID: NMRR-16-2310-33318).

Identifying the research questions

The review questions were:

i. What are the major factors affecting cadaveric decomposition rates?

ii. How are the indicators used in computing the cadaveric decomposition rates?

iii. How the factors affecting the cadaveric decomposition rates?

Identifying the relevant studies

The purpose of performing the scoping review was to conduct a comprehensive search to identify primary studies (published work) and reviews. The research team members adopted a strategy for searching the evidence using different sources which included electronic databases and relevant research websites such as ProQuest, PubMed and Wiley. The searches also involved online journal articles and books focusing on taphonomic study in Forensic Science and Forensic Medicine. The researchers decided to set the coverage of the review based on the time span and language of the articles. Inclusion criteria for the search were articles in English from year 2007 till 2016 and studies that are consistent with research questions related to taphonomic study as well as the decomposition process and/or rate are studied. The commencement date of 2007 was chosen in order to cover the recent 10 years findings and it was felt that the evidence on the decomposition rate was limited especially in Asian countries including Malaysia. Titles, abstracts and document text for eligibility were examined independently by the researchers. All type of studies were included in the search strategy. Unpublished articles or those written in the language other than English were excluded due to the cost and time that would be required to translate those documents. Studies that were irrelevant such as purely entomological methods and/or biochemical methods used were excluded. Key terms used in the search of articles were shown in Table 1 and Table 2.

Table 1: PICO Table for MeSH term and text word term derivation.

PICO	Initial Term	MeSH Term	Text Word Term
Population	Cadaver	Cadaver	Cadaver, Dead bod*, Animal*, Carcass*, Corpse*, Carrion*
Intervention	Environment	Environment	Weather, Climate, Temperature*, Humid*
	non-Environment	non-Environment	Wrap*, Outdoor, Open area, Indoor, Closed area, Burial, Underground, Underground, Underwater, Under water, Submerge, Immerse Body mass, Body size, Carcass mass, Carcass Size, Cloth*, Cover*, Entomo*, Maggot*
Control	Not applicable	Not applicable	Not applicable
Outcome	Decomposition	Postmortem Changes	Postmortem change*, Postmortem interval*, Putrefact*, Decay*, Taphonom*, Decompos*, Decomposition rate, Decomposition stage*

Table 2: Keywords/Search Terms/Strings.

Strings 1	String 2
decompos* OR postmortem change* OR postmortem interval* OR putrefact* OR decay* OR taphonom* AND cadaver* OR dead bod* OR carcass* OR animal*	decompos* OR postmortem change* OR postmortem interval* OR putrefact* OR decay* OR taphonom* OR cadaver* OR dead bod* OR carcass* OR animal*

Study selection

The study selection is based on the objectives of the study. The review is focused on documents related to the factors including environmental and non-environmental factors affecting cadaveric decomposition rates. Based on the eligible abstracts, copies of full articles were retrieved. The full articles is checked by the researchers as to whether appeared to answer the research questions of the study. Selected full articles were then read by the researchers in order to select the final full articles for the review.

Charting the data

General and specific information about the studies is charted which include authors(s), year of publication, types of affecting factors, objectives or aims of the study, country of study location, study population/sample, sample size including comparison group (if any), methods/instruments and indicators used in the study and findings that were relevant to the objectives of the review.

Collating, summarising and reporting the results

The characteristics of the results from the selected articles from various countries are described based on the design, types and outcomes of each study. The findings of the review were presented in table. Table of evidence on the factors affecting the cadaveric decomposition rates and their relationships with measurements and indicators that are used to describe the various approaches or methods to determine the decomposition rate. Limitation of several studies and research gaps are also identified in order to generate useful knowledge on the taphonomy and post-mortem interval estimation.

Results

Table 3 shoed a total of 2,893 titles were extracted from the selected electronic databases and other resources using the search terms. As portrayed in Figure 1, 59 abstracts were included after the initial screening process and the rest were excluded as they were irrelevant with regards to the decomposition changes or rates, non-English articles, and duplicates. Among these 41 articles met the inclusion criteria in the review, environment factors and non-environmental factors were studied with total of 20 articles and 17 articles respectively. The rest of 4 articles were focus on mixed factors. The studies in this review were equally focus on both environmental factors and non-environmental factors. Most of the environmental aspects surveyed the climate

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factors especially the temperate/tropical climate, dry and wet/rainy seasons, habitats/locations and burial effect. Additionally, researchers emphasize to explore the non-environment factors including the scavenger or insect effect, clothing, wrapping, lime or cement effect, burning effect. Countries of origin of the studies included Malaysia, Europe (United Kingdom, Italy, Germany, Poland, Romania, and Belgium), America (United States, Canada, Colombia, and Brazil), Middle East (Saudi Arabia, Egypt, and Kuwait), South Africa, Australia and China.

Table 3: Search History.

Database / Search Date	Coverage / Search terms (Year 2007 – 2016)	Total search / Total selected
ProQuest (20/11/16 6PM)	Document Text ft(Cadaver, Dead Bod*, Animal*, Carcass*, Corpse*) AND ft((Postmortem change*, Postmortem interval*, Putrefact*, Decay*, Taphonom* OR Decompos*, Decomposition rate, Decomposition stage*))	56 titles / 8 selected
PubMed (20/12/16 6PM)	Title / Abstract ((decompos*[Title/Abstract] OR postmortem change*[Title/Abstract] OR postmortem interval*[Title/Abstract] OR putrefact*[Title/Abstract] OR decay*[Title/Abstract] OR taphonom*[Title/Abstract])) AND (cadaver*[Title/Abstract] OR dead bod*[Title/Abstract] OR carcass*[Title/Abstract] OR animal*[Title/Abstract])	2,236 titles / 37 selected
Wiley (29/12/16 3PM)	Abstract decompos* OR postmortem change* OR postmortem interval* OR putrefact* OR decay* OR taphonom* in Abstract AND cadaver* OR dead bod* OR carcass* OR animal*	601 titles / 15 selected

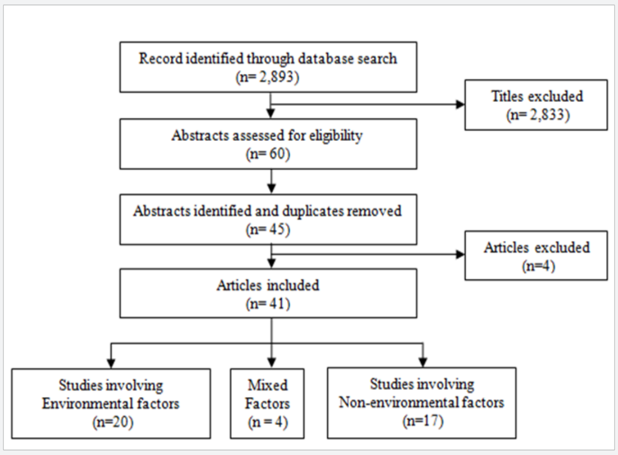

Figure 1: Flow chart of scoping review.

All the articles in this review were using animal carcasses as subjects except Jeong Y et al. [3] using human cadavers to study on scavenger effects during summer season. Majority (26 articles) using swine / pig carcasses as subjects, followed by rabbit carcasses (10 articles) and minority were using monkey and other animal carcasses. The measurement of indicators for each studies were primarily on the comparison of time taken to different decomposition stages, however, some researchers were also using total body scoring (TBS) system in 6 articles as the decomposition scoring methods. Part of the studies utilised different approaches such as decomposition changes by observation, mass/weight loss, first colonisation of insects, insect richness, insect residency time, insect succession patterns and taxa variation. In this review, there were 14 full text articles, out of the 41 selected articles, available online and free for open access. The list of these articles was elucidated in a summary format as shown in the Table 4. In terms of environmental factors focusing on temperate climate variables, the decomposition rate have remarkably slowed down during winter season compared to the other three seasons. According to Meyer J et al. [4], summer season with greater temperature have enhanced the decomposition rate from triple to septuple to reach the dry remains or skeletonisation stage which consistent with the findings by Wang J et al. [5].

Some articles reported an extreme difference between summer and winter seasons whereby pig carcasses reached the dry stage within 8 days but still maintained in bloating stage at Day 133 [6]. Although first insect colonisation started after 15 weeks during winter season, the bacteria activity have actively occurred throughout the first 5 weeks of decomposition at low temperature. However some have reported pig carcasses reached the skeletonised stage at Day 60 in winter season compared to summer season at Day 27 with all the soft tissues completely lost by decomposition. There was no significant difference among spring, summer and fall seasons, yet faster decomposition rate and higher insect richness were encountered during summer season followed by spring and fall seasons for both pig and rabbit

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carcasses. Rabbit carcasses which were in smaller size consumed 21 days and 28 days to reach the dry stage compared to 26 days and 42 days for pig carcasses during summer and spring seasons respectively. In some equatorial or tropical countries [7,8], the wet or rainy season have caused the more rapid decomposition compared to dry season. It showed common decomposition rate for both seasons during the fresh and bloated stage, however the conversion of later decaying stages till the dry stage was relatively faster during the wet or rainy season.

Table 4: Environmental and non-environmental factors affecting the decomposition rates.

No	Authors (Year)	Study Titles	Affecting Factors	Independent Variables	Objectives / Aims	Study Population/ Sample Size/ Comparison	Methods/ Instruments/ Indicators	Relationship to Decomposition Rates/ Findings
1	Iancu L et al. [27]	Using bacterial and *necrophagous* insect dynamics for post-mortem interval estimation during cold season: Novel case study in Romania	Environmental: Season (Winter vs Spring)	Outdoor experiment in temperate climate region of an urban natural environment of Bucharest, Romania. (Nov 2012 - May 2013)	To study succession of *necrophagous* insect species and bacterial communities inhabiting the rectum and mouth cavities	n = 3 2 females and 1 male swine carcasses (*Sus scrofa domesticus*) 15kg each and being about 3 months old, put on ground within cages.	Indicators: Time when first colonizing organism arrived Methods: 1. *Necrophagous* Diptera and Coleoptera identified by morphological and genetic characterization. 2. Bacterial communities identified by denaturing gradient gel electrophoresis (DGGE) and 16S rRNA gene fragment sequencing.	The first colonizing wave, primarily *Calliphoridae*, was observed after 15 weeks when the temperature increased to 13°C. Families belonging to *Coleoptera* Order starting with *Cleridae* and *Silphidae* were observed at week 18 when temperatures raised above 18°C. Metabolic activity of anaerobic bacteria being inhibited by the low temperatures. Three cold-adapted environmental bacteria *P. articus, P. cibarius, P. cryohalolentis* which appeared at the beginning of the freezing period (weeks 1-5) may constitute putative microbial markers for investigations of post-mortem interval during the cold season

2	Barrios M et al. [28]	Initial study of arthropods succession and pig carrion decomposition in two freshwater ecosystems in the Colombian Andes	Environmental: A stream (lotic) vs an artificial lake (lentic)	Freshwater ecosystems in the Colo mbian Andes, at an altitude of 2614m. (Jan - April 2007)	To estimate the post-mortem submersion interval in two fresh water ecosy stems	n = 2 20-kg pig carcasses killed with a bullet wound to the thoracic zone from a 9-mm firearm and pla ced 68m apart within metal cages.	Indicators: Time taken to skeletal remains Stage of decomposition: Submerged fresh, Early Floating, Floating Dec ay, Bloated Deterioration, Floating Remains and Sunken Remains.	Decomposition time to skeletal remains was 80 days in the stream and 74 days in the lake. Submerged Fresh (days 1-8 in the str eam and 1-5 in the lake) Early Floating (days 9-24 in the stream and 6-17 in the lake) Floating decay (days 25-43 in the stream and days 18-40 in the lake) Bloated deterioration (days 44-5 1 in the stream and 41-48 in the lake) Floating remains (days 52-61 in the stream and 49-60 in the lake) Sunken remains (days 62-80 in the stream and 61-74 in the lake)

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3	Segura NA et al. [29]	Succession pattern of cadaverous entomofauna in a semi-rural area of Bogotá, Colombia	Environmental: Climate	Semi-rural area of Bogotá at 2700m above sea-level, average temperature of 14°C (3°C-27°C), RH 73.25% and annual rainfall of 790mm. (Feb 2006 - May 2006)	To examine the succession of insects colonizing cadavers	n = 4 Control = 1 (no arthropod collected) and Samples = 3. 12kg pigs (*Sus scrofa*) were shot and put into metallic mesh cages.	Indicators: Time taken to decomposition stages. Methods: Sampling was done once a day during the first 18 days and then each 2 days until decomposition day 31. It was then carried out twice a week until day 49 and then once a week until decomposition day 97. Arthropods were collected from above, around and below the cadavers to analyse abundance of the all arthropods.	Egg masses and 1st stage *Calliphoridae* larvae were associated with the fresh stage of decomposition (Day 1-3), 1st and 2nd stage larvae of *Calliphoridae* and *Sarcophagidae* during chromatic and emphysematous stages (Day 4-10), immature *Chrysomya albiceps* (Diptera: *Calliphoridae*), *Ophyra sp.* (Diptera: *Muscidae*) and *Oxellytrum discicolle* (*Coleoptera*: *Silphidae*) during the colliquative stage (Day 11-20) and mainly *Coleoptera* during the skeletization phase (Day 21-97). One factor analysis of variance shared that there were no statistically significant differences between the abundance of the all arthropods collected from the three pigs during the decomposition (ANOVA, F =0.13, df=2, n =5981, P >0.05).

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4	Sharan-owski BJ et al. [30]	Insect succession and decomp-osition patterns on shaded and sunlit c arrion in Saskat-chewan in three different seasons	Environ-mental: Season- (spring, summer, fall) and Habitat (sun vs shade)	University of Saskatchewan in Saskatoon, heart of the Moist Mixed Grassland Ecoregion of the Prairie Ecozone of Canada. (May - Oct 2000)	To study insect succession and decomposition patterns for future homicide investigations in Saskat-chewan region	n = 18 Domestic pig carcasses (*Sus scrofa Linnaeus*) weighed 42-79kg	Indicators: Time taken to decomposition stages. Methods: Research was conducted over 25 weeks. For each of the 3 seasons, 3 shaded and 3 fully sunlit sites were selected. Sites for carcass placement were chosen on fringe areas, within shrubs away from the crops (shaded sites), or on the edges of cultivated land (sunlit sites). Each site was 50m away.	Fresh (in Spring days 0-1 for Sunlit and 0-2 for Shaded); (in Summer days 0 for both); (in Fall days 0-2 for Sunlit and 0-3 for Shaded) Bloated (in Spring days 2-12 for Sunlit and 3-15 for Shaded); (in Summer days 1-4 for both); (in Fall days 3-10 for Sunlit and 4-10 for Shaded) Active Decay (in Spring days 13-30 for Sunlit and 16-35 for Shaded); (in Summer days 5-11 for both); (in Fall days 11->54 for both) Advanced Decay (in Spring days 31-42 for Sunlit and 36-45 for Shaded); (in Summer days 12-25 for both) Dry (in Spring days 42->63 for Sunlit and 46->63 for Shaded); (in Summer days 26->43 for both) Results indicated that habitat was only a factor in the decompositional rate of carrion in the spring season. The ambient temperature was the chief factor determining the seasonal variations in decay rate. Carcasses placed in spring and fall att racted a m ore diverse assemblage of insects than summer-placed carrion. Sun-exposed carrion had greater variation in fauna tha n sha ded carrion in spring and fall.

5	Anderson GS et al. [31]	Deep coastal marine taphonomy: investigation into carcass decomposition in the Saanich Inlet, British Columbia using a baited camera.	Environmental: Dissolved oxygen levels	Saanich Inlet, BC, over 3 years utilizing Ocean Network Canada's VENUS observatory	To study the carcass decomposition in deep coastal marine environment	n = 3 Pig carcasses (*Sus scrofa*) Carcass 1 & 2 (tolerable oxygen level) Carcass 3 (extremely anoic)	Indicators: Time taken to skeletonized stage Methods: Each carcass was deployed in late summer/ early fall at 99 m under a remotely controlled camera and observed several times a day	Carcass 1 was rapidly scavenged then dragged from view by Day 22. Carcass 2 was scavenged in a similar fashion. Exposed tissue became covered by *Orchomenella obtusa* (Family *Lysianassidae*) which removed all the internal tissues rapidly. Carcass 3 remaining intact, developing a thick filamentous sulphur bacterial mat, until Day 92, when it was skeletonized by *crustacea*. Carcass 3 was deployed when the water was already extremely anoxic, which prevented larger *crustacea* from accessing the carcass.

6	Simmons T et al. [17]	The influence of insects on decomposition rate in buried and surface remains.	Environmental: Buried vs surface	Preston PR1 2HE, UK (May - July 2008)	To conduct comparative study of decomposition rates	n = 24 Wild rabbit (Oryctolagus cuniculus). 6 for each category (i) to (iv)	Indicators: Total Body Score (TBS) every c. 50 accumulated degree days (ADD) Methods: (i) buried (35 cm depth) after exposure to insect activity, (ii) buried without exposure, (iii) kept above ground behind an insect screen, or (iv) continuously exposed above ground in a field experiment.	Results showed that dipteran oviposition occurred consistently in groups i and iv only. Decomposition rates of rabbits kept behind the screen and those buried without exposure showed no difference ($p = 0.450$). This was significantly slower than those buried after exposure ($p = 0.0016$) which was in turn significantly slower than those continuously exposed ($p << 0.001$). Insect presence is the primary agent affecting decomposition rate via tissue consumption and also the heat they generate. Results showed significant differences ($p << 0.001$) in decomposition rates between carcasses with and without insect access prior to burial. An approximately 30% enhanced decomposition rate with insects was observed.
7	Anderson GS [9]	Impact of Marine Submergence and Season on Faunal Colonization and Decomposition of Pig Carcasses in the Salish Sea.	Environmental: Season (spring vs fall) and Exposed vs caged	Marine Submergence in Strait of Georgia (Feb 2010 - Oct 2013)	To study the impact of marine submergence and season on faunal colonization and decomposition	n = 4 Pig carcasses deployed 2 in spring (exposed + caged) and 2 in fall (exposed + caged)	Indicators: Time taken to skeletonized stage Methods: Placed on the seabed at a depth of 300 m in Ocean Network Canada's Victoria Experimental Network under the sea observatory. One of each category fully exposed, the other covered in a barred cage to protect it from sharks.	Immediately after deployment all carcasses, in both spring and fall, were very rapidly covered in vast numbers of *lyssianassid amphipods*. These studies have shown that in highly oxygenated deeper waters, *amphipods* had skeletonized the carcasses by Day 3 in fall and Day 4 in spring.

8	Vanin S et al. [24]	Decomposition and entomological colonization of charred bodies - a pilot study.	Environmental: Seasons (winter and summer) Non-environmental: Burning	Field in the outskirts of Milan, in winter and summer 2007.	To apply forensic entomological approach to estimate the post mortem interval (PMI) in burnt remains.	n = 4 Control = 2 (unburnt) and Subject = 2 (burnt) 60-kg pig carcasses (Sus scrofa)	Indicators: Decomposition changes and first colonisation period Methods: Two for each experiment. One pig carcass was burnt until it reached the level 2-3 of the Glassman-Crow scale, and unburnt as the control.	In the Winter part of the experiment, the first insect activity on the burnt carcass began in the Day 18 (*Calliphora vomitoria*). On Day 26, a clear reduction of the tissues in several body regions (head, thorax, and abdomen) was observed. Two months after the exposure (Day 60), the bones were clean and only a few remains of burnt skin and muscles were still present. Control pigs with initial putrefactive stage was detected at the end of the second week. In third week, a moderate emphysematic phase in the head region and discharge of decomposition fluids from the mouth was observed. In the abdominal region, the beginning of a colliquative phase was observed. In the Summer part, adult flies and first instar maggots (*Phormia regina*) appeared a few minutes/hours. First colonization wave (*Calliphoridae*) appeared on burnt and control pigs at the same time. After one week (Day 6), the carrion showed some clear skeletonized areas (head, thorax). After the first week, the rate of skeletonisation and the exposure of bones slowed down. In the fourth week (Day 27), soft tissues were almost completely lost, except for large fragments of dry or burnt skin. After 6 weeks, the control pig showed about 40% skeletonisation.

9	Teo CH et al. [15]	Post mortem changes in relation to different types of clothing	Environmental: Ground vs Burial at 30 cm depth graves Non-environmental: Type of clothing (No clothing, light clothing and heavy clothing)	Location at Universiti Kebangsan Malaysia, Bangi, Selangor	To study the effect of burial and type of clothing on rate of decomposition, which can contribute to estimating PMI for victims	n = 12 Controls = 3 (ground) and Subjects = 9 (buried) for each clothing groups. Rabbits (Oryctolagus cuniculus) weighing 2-3kg.	Indicators: Total Body Score (TBS). Methods: Buried subjects were exhumed at 2nd week (reburied), 4th week (reburied) and 6th week.	Control: Day 3 and 4: colonized by ants. (i) Head and Neck region - Day 5: Caving in appearance; Day 6: Bone exposure. (ii) Body Trunk region Day 4: Bloated; Day 6: Fur detachment; Day 8: Caving in appearance; Day 9 (score to stop at 8/35): the skin underwent mummification with dark brown colour slowly fading into light brown by the end of the study. Full skeletonisation of the body trunk under the mummified skin with no internal organ. (iii) Forelimb and Hindlimb region, Day 5: Bone exposure and small amounts of hardened skin still could be observed at the joints by the end of study; Day 10: TBS score was 30/35. Subject: After six week to reach average score of over 30/35. SPSS analysis showed that the burial factor was significant in affecting the TBS score, $F(l,ll)=12.991$, $p<0.05$ with observed power of Day*Burial factor was 0.906 or 90.6%. However type of clothing did not show significant differences among types of clothing, $F(2,9)=0.022$, $p=0.978$ and combination of burial and type of clothing factors also was not significant, $F(2,3)=0.429$, $p=0.686$.

10	Schot-smans EM et al. [32]	Long-term effects of hydrated lime and quicklime on the decay of human remains using pig cadavers as human body analogues: Field experiments	Non-environmental: Lime (Ca(OH)2) vs quicklime (CaO)	Buried micro-environment of shallow graves in sandy-loam soil in Belgium (Feb 2008 - Aug 2011)	To study the effects of lime on the decay of human remains in laboratory conditions and 6 months of field experiments	n = 6 Control = 2 (unlimed) and Subjects = 4. Pig carcasses (*Sus scrofa*) aged between 10 and 12 weeks.	Indicators: Decomposition stages upon exhumation Methods: 1st set (time since death 2 days) was buried in Feb 2008. Excavated in Aug 2011 (after 42 months). 2nd set (time since death 24h) was buried in Mar 2010. Excavated in Aug 2011 (after 17 months).	The extent of decomposition is slowed down by burial with both hydrated lime and quicklime. The limed and unlimed pigs of the burials recovered after 42 months were totally skeletonised without any fragments of soft tissue left. The carcasses recovered after 17 months of burial were in an advanced stage of decay. Unlimed carcass A21 exhibited disintegration of soft tissue on the torso and skeletonised extremities and skull. Both limed pigs, B21 and C21, displayed liquefying soft tissue at the torso and head with skeletonised extremities. The internal organs were no longer distinguishable. The upper surface of both limed pigs displayed a dark brown colour. Unlike the 6 month burials, the skin was neither intact nor recognisable anymore.

11	Abd El-bar MM [26]	A preliminary investigation of insect colonization and succession on remains of rabbits treated with an organophosphate insecticide in El-Qalyubiya Governorate of Egypt	Non-environmental: Organophosphate (OP) pesticide pirimiphos-methyl (test)	Summer in a rural village (uninhabited house) in El-Qalyubiya Governorate (Egypt) (August to Sept 2008)	To compare the *necrophagous* insects colonizing the cadavers	n = 4 Control = 2 (killed by asphyxia); Test Subject = 2 (poisoned by OP) Male rabbits (*Oryctolagus cunicullus domesticus L.*), each weighting 15Kg.	Indicators: Time taken to decomposition stages. Method: Administration of 10ml pure dose of an *anticholinesterase* OP pesticide directly injected into the apex of the heart. Within 10min of death, the four carcasses were transferred into four separate cages welded with wire mesh (1cm). They were then placed 1m apart.	Fresh (days 0-1 for Test Subject and 0-1 for Control) Bloat (days 1-3 for Test Subject and 1-2 for Control) Wet Decomposition (days 4-10 for Test Subject and 2-7 for Control) Dry Decomposition (days 10-40 for Test Subject and 7-19 for Control) Skeletal (defined by complete loss of soft tissues with only bones, cartilage and hair remains present) Control remains reached the skeletal stage by 19 days post-killing. Test subjects had undergone only partial decay even 40 days following OP poisoning with only the lower parts of the test carcasses obviously decayed, whilst their upper parts remained unchanged.

12	Matusz-ewski S et al. [33]	Effect of body mass and clothing on carrion entomofauna.	Non-environmental: Body mass and Clothing	Grassland habitat of Western Poland (May 2012 - Nov 2012)	To study simultaneous effects of carcass mass and clothing	n = 24 Domestic pig carcasses (*Sus scrofa domestica L.*) grouped into 10.5-24.9°C for spring, from 16.5-28.3°C for early summer, and from 9.1-22.0°C for late summer	Indicators: Number of taxa, abundance and residency period of insects Methods: Factorial block experiment with 4 levels of carcass mass (small carcasses 5-15 kg, medium carcasses 15.1-30 kg, medium/large carcasses 35-50 kg, large carcasses 55-70 kg) and 2 levels of carcass clothing (clothed and unclothed)	Results demonstrate that insect assemblages are more complex, abundant, and long-lasting on larger carcasses, whereas clothing is of minor importance in this respect. Only large or medium/large carcasses were colonized by all guilds of carrion insects, while small or medium carcasses revealed high underrepresentation of late-colonizing insects. Residencies of all forensically relevant insects were distinctly prolonged (atleast three times longer) on larger carcasses, indicating that cadaver mass is a factor of great importance.
13	Heo CC et al. [34]	Study of insect succession and rate of decomposition on a partially burned pig carcass in an oil palm plantation in Malaysia.	Non-environmental: Partially burning	Oil palm plantation near a pig farm in Tanjung Sepat, Selangor	To compare the stages of decomposition and faunal succession of partially burnt pig with control	n = 2 Young pigs weighed approximately 10 kg died from pneumonia.	Indicators: Time taken to decomposition stages Methods: One pig was partially burnt by 1-liter petrol while the other served as control. Visited twice per day for the first week and once thereafter.	Fresh (Day 1-2), Bloated (Day 3), Active Decay (Day 4-6), Advanced Decay (7-8), Dry remains (9-16) Results showed that there was no significant difference between the rate of decomposition and sequence of faunal succession on both pig carcasses. Both carcasses were completely decomposed to remain stage after 9 days. The only difference noted was in the number of adult flies, whereby more flies were seen in the control carcass.

14	Benbow ME et al. [35]	Delayed insect access alters carrion decomposition and *necrophagous* insect community assembly	Non-environmental: Delayed insect access to carrion for 5 days	Midwestern temperate forest habitat surrounded by agricultural fields in Xenia, Ohio, USA during two summer seasons, 2010 and 2011	To study the effect of delayed insect access	n = 6 Swine carcasses. 3 random carcasses exposed to insect access (ACC). 3 carcasses were enclosed in Lumite screen cages to exclude *necrophagous* insect	Indicators: Time taken to dry stage Methods: In 2010, six male carcasses ranging from 10.4 - 30.1 kg, euthanized by cranial blunt force. In 2011, using the same methods, six carcasses (three females and three males) euthanized from 5.0–7.3 kg	During the first 5 days of decomposition, insect exclusion carcasses remained in bloat stage while those naturally colonized were well advanced in active decomposition. In 2010 the insect access carcasses were approaching the dry stage with *calliphorid* larval masses covering two carcasses, while for carcass there had already been a larval dispersal event by the end of day 5. Meanwhile, insect exclusion carcasses were in the bloat stage of decomposition on the Day 5. In 2010, insect access carcasses decomposed to the dry stage between the Day 6 and 7 of decomposition; however, in 2011 these carcasses were in the dry stage within 5 days. During both 2010 and 2011, insect exclusion carcasses were in dry stage by the Day 9 of decomposition, which corresponded with the 4 days of post-exclusion insect activity. This suggests that once insects were allowed to colonize the resource it had an accelerated decomposition process.

Animal carcasses subjected to different habitats and localities would present different decomposition changes and insect colonisation. Although there was no significant difference of decomposition in a lake and a stream area, time taken to reach skeletonised stage of pig carcasses was three times longer (61 days) compared to in semi-rural area (21 days) according to the Colombian locality located over 2600 m above sea level. Canadian articles have reported that anoxic condition (very low oxygen level) under deep coastal marine environment would delay the skeletonisation as much as five times compared to moderately low oxygen level (22 days), however, it has taken only 4 days under submergence sea environment in the Strait of Georgia [9-11]. Also there would be a delay of 5 days in insect colonisation causing the delay of skeletonisation in indoor condition compared to outdoor environment. Voss SC et al. [12,13] have investigated into the enclosed vehicle environment in which they found that the higher temperature inside the vehicle have enhanced the decomposition rate by 3 to 4 days. In the Middle East taphonomic study of rabbit carcasses, researchers have reported that decomposition rate in urban area and desert area was double up. It has taken 5 days to reach the dry stage compared to coastal area and agricultural area (13 days). Silahuddin SA et al. [14] has encountered the similar results whereby rabbit carcasses undergone faster decomposition rate in rural or pasture area compared to jungle area and highland area.

Faria LS et al. [7] has also complied with their findings by using pig carcasses whereby insects bred more abundantly in the pasture area compared to forest area. Furthermore, sun-exposed carcasses underwent greater variation in fauna compared to shaded carcasses whilst more abundant on meadow compared to on the floor. From the burial factor perspective by using the total body scoring system, time taken to reach skeletonised stage with score of 30/35 TBS was within 42 days compared to period of 10 days for the ground control rabbit carcasses [15]. It was four times slower decomposition rate due to the burial factor and the SPSS analysis showed that the burial factor was significant in affecting the TBS score. Troutman L et al. [16] reported that deep and core buried subjects of burial were even more significantly slower than those of the shallow and mid-outer buried subjects. According to Simmons T et al. [17] stated that ground and buried rabbit carcasses that have been accessed by insects activity were scored 26/30 TBS after 300 and 400 accumulated degree days (ADD) respectively. In terms of non-environmental approaches, rabbit carcasses did not show significant difference among types of clothing. Combination of burial and type of clothing factors also was not significant.

However, pig carcasses have shown unclothed carcasses decomposing faster than clothed carcasses and presence of clothing markedly prolonged the wet decay stage as well as had larger visible maggot masses which moved more freely and took longer to be dried out. Clothing was the minor importance compared to the insect assemblages and body mass factor. Spicka A et al. [18] mentioned that animal carcasses of a mass less than 20 kg decomposed more rapidly than larger carcasses. Insect exclusion carcasses were delayed at least two times to reach dry stage of decomposition (10 days) compared to the exposed carcasses (26 days). It was reported similarly with the presence of scavenging effects by King KA et al [19]. Nevertheless, physical barriers such as usage of wrapping, lime and cement had significantly more important than clothing effect. Ahmad A et al. [20] had reported that wrapping delayed the arrival of all fly species encountered the monkey carcasses, with the delay up to maximum 13 days. Cemented pig carcasses showed areas of mummification at the abdomen within a general context of initial putrefaction at the third month and showed wide adipocere formation after 6 months [21]. After 17 months of burial, unlimed carcass exhibited disintegration of soft tissue on the torso and skeletonised extremities and skull whilst limed pigs displayed liquefying soft tissue at the torso and head with skeletonised extremities [22].

Moreover, application of quicklime instigated an initial acceleration of decay. Microscopic changes may be delayed in presence of concrete and lime but not totally eliminates all the aerobic bacteria. On the other hand, burning pig carcasses greatly accelerated decomposition in contrast to unburnt carcasses. Physical modifications following burning such as skin discolouration, splitting of abdominal tissue and leathery consolidation of skin eliminated evidence of bloat and altered micro ambient temperatures [23]. It was supported by Vanin S et al. [24] whereby burning effect doubled up the decomposition rate compared to unburnt carcasses. In contrary, burning effect was still not statistically significant as examined by four of local and foreign researchers for both pig and rabbit carcasses. In certain rare condition which happened occasionally, Lynch-Aird J et al. [25] reported that hanging pigs reached advanced decomposition stages sooner, but lagged behind during the early stages. This delay is believed to result from lower variety and quantity of insects. Pig carcasses had undergone only partial decay even 40 days following organophosphate (OP) pesticide pirimiphos-methyl poisoning whilst the control remains reached the skeletal stage by 19 days post-killing [26]. They stated that only the lower parts of the test carcasses were obviously decayed, whilst their upper parts remained unchanged.

Discussion

Based on the evidence in this review, there were emerging literatures for the past 10 years reporting the factors, including environmental and non-environmental, affecting the cadaveric decomposition rates by using animal carcasses in which majority were pigs and rabbits. Several important aspects of these affecting factors within animal carcasses have been identified: Firstly, the affecting factors on the decomposition rate could be further classified into enhancing or accelerating and delaying or decelerating factors which were regularly reported by the published studies [36]. Accelerating factors were mostly related

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to higher temperature including the summer season (triple to septuple), rainy season, urban and desert area (double), sun-exposed on ground area, burning effect (double), enclosed vehicle as well as exposure to insects (at least double) and scavenger activities (double). Decelerating factors, on the other hands, often relied on the effect of the lower temperature such as winter season (3 - 7 times), deep coastal marine (5 times), underwater (3 times), highland and shaded area. It might also depend on the burial effect (4 times) and other physical barriers to prevent the access of insect activities by using heavy clothing, wrapping, lime and cement as well as the chemical barrier likewise the organophosphate (OP) pesticide etc. However, the variables and decomposition rates were generally varied between studies. There are several reasons for these inconsistent findings including the differences in the study design, sample size, sample type, location of study, choice of comparison groups and methods used to assess the relationship between the affecting factors and decomposition rate.

Some of these studies have implied combination of affecting factors which have made the analysis and comparison more complicated. Secondly, it appeared that the techniques of measurements used to evaluate the decomposition rate were also varied depending on the objectives of the respective studies in this review. Most of the researchers observed and recorded the time taken to reach each of the categorised decomposition stages which was also varied from one another. However, the start point (fresh stage) and the ending point (dry or skeletonised stage) of the decomposition changes were often similar among the studies and permit immediate comparison. Nonetheless, some researchers used different approaches such as time taken for first colonisation of insects, insect richness, insect residency time, insect succession patterns and taxa variation. Moreover, more systematic approaches such as total body scoring system (TBS), accumulated degree days (ADD) system and percentage of weight loss of the carcasses were also used to determine the decomposition rate. Again these were also varied from one another, for example, the maximum scores might be different from each articles and the measurements made at different period or by different point of time or at different ADD values [37-40]. The comparison, hence, might be very complex to certain extend in making inference and conclusion from this review.

Thirdly, findings from this scoping review have demonstrated that insect activities and temperature were the main factors affecting the overall decomposition rates except in the presence of physical barriers which might have contributed some variations to the decomposition rates. Apart from that, Simmons T et al. [17] have collected data from previous studies and recent experiments in which were then compared using simple conversions across multiple environments. The major effector of change in decomposition rate was the insect presence, regardless of depositional environment, species, or season. Body size of the animal carcasses chosen was only significant when carcasses were accessed by insects. When insects were excluded, while bodies were indoors, submerged, or buried, then decomposition progresses at the same rate regardless of body size. Therefore, early differentiation of the carcass type and body size used by the researchers would definitely make the scoping review more applicable for comparison as the analogue to the human cadavers. This is due to the limitation of the ethics issues which have been extensively discussed for any taphonomic study using human cadavers [41].

To overcome this problem, researcher are recommended to compute the degree of the affecting factors and report the decomposition rate of animal carcasses in terms of either percentage or tuple order of the delaying effect or enhancing power. It could be also in the form of average TBS per day or ADD per day to tolerate for the application in any carcass type and body size used as the analogue to human cadavers. Finally, this scoping review also found that there was no extensive evidence on the decomposition rate in equatorial or tropical countries including Malaysia. Only a few taphonomy studies in Malaysia was identified which mainly focus in Kedah and Selangor area. However, there were in fact many other studies have been excluded owing to researchers reported only the entomological findings and biochemistry details of the carcasses without correlating with the decomposition rate. The limitation of this study was that the data was collected from certain selected resources without considering unpublished articles especially those minor studies conducted by undergraduate students. Some of the finite values of decomposition rate for each affecting factors were not fully concluded in this study due to the limitation of their study period whereby some of the carcasses might not be fully skeletonised. Therefore, future researches need to be conducted in a systematic ways in order to address the significant factors affecting the decomposition rate and more accurately estimate the postmortem interval in any of the death investigation [42].

Collaborative research effort between the Ministry of Health, universities and other international agencies is one of the strategies that need to be implemented to provide evidence on the relationship between the affecting factors and the decomposition rate which could be recognised world-widely later on. Trained professionals are also encouraged to conduct proper extensive studies and actively discuss with their international networking especially during any platform of research presentations. In conclusion, there were emerging evidences on the affecting factors of the decomposition rate, although it was still very limited in tropical countries including Malaysia. Findings of this scoping review demonstrated that insect activities and temperature were the main factors affecting the overall decomposition rates except in the presence of physical barriers which might have contributed some variations to the decomposition rates. It is hoped that these findings will support the planning of future researches in a more systematic and extensive way to enable more accurate estimation of postmortem interval based on the delaying effects and enhancing factors on the decomposition rates [43].

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