Visible Post Mortem Changes as a Tool for Decomposition Timeline Estimation in a Tropical Rainforest Vegetation of Nigeria

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ABSTRACT

Background: Decomposition timeline is the interval from death to complete decay of a carcass. Accuracy in the estimation of this interval helps to confirm the testimony of an alibi or suspect in homicide investigations especially at the law courts. **Objectives:** This study investigated the early and late visible post-mortem changes of porcine analogues on soil surface in order to document a model for post-mortem interval estimation in Tropical rainforest vegetation of Nigeria. **Materials and Methods:** Four (two males and two females) matured domestic pigs (Sus scrofa domestica) were used for this study. Animals were sacrificed; early visible post-mortem changes were investigated in an indoor environment whereas the late visible post-mortem changes were investigated in an outdoor environment after eight hours post mortem. The study lasted for a period of 49 days. Data on climatic readings were collected on-site. **Results:** There was almost a complete skeletonization on all four animals. Adipocere formation was observed on some of the body parts of some of the carrions which delayed the complete skeletonization within the study period. Five stages of decomposition were identified from this study and a timeline drawn from the visible changes of post mortem. The five stages identified were fresh, bloat, active decay, advanced decay and remains stages. **Conclusion:** Visible post-mortem changes of decomposition can be used to estimate the actual time of death of a strangled carcass on clandestine soil surface of a tropical rainforest vegetation of Nigeria.

Keywords: Crime investigation, Post mortem interval estimation, Forensic taphonomy, Stages of decomposition, Visible post mortem changes.

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INTRODUCTION

Over the years, there have been reports from local authorities and security personnel on several cases of clandestine bodies found in Nigeria which were not properly investigated due to lack of taphonomic data.[1] A good example

of such case was verbally reported by one of the locals (indigenes) of Umudim, Ekwulumili, Nnewi south Local Government Area, and the information was verbally confirmed by the central vigilante group (security unit) of the town. According to the indigene, on the 27th of July, 1985; the body of a male indigene of Enugwu community, Umudim village, Ekwulumili was found murdered and hidden in a clandestine location at Enugwu community of Umudim village, Ekwulumili of Anambra State, Nigeria. His brother reported this murder case to the authorities. An investigation was carried out by the law enforcement agencies which led to the arrest of a number of suspects. The suspects were charged to court. Witnesses testified based on assumptions on the actual time of death and the suspects found at that particular time. However, since there was no substantive proof and material evidence related to the time of death of this body found, the jury discharged and acquitted the suspects.

Decomposition is the process of breakdown of the body immediately after death. Immediately after death, the body starts to break down its cellular components (autolysis). This is followed by other external factors that lead to the total putrefaction of the body. The fifth stage of death is putrefaction, which is preceded by pallor, algor, rigor, and livor mortises.[2] In broad terms, putrefaction is the decomposition of body proteins, tissue cohesiveness and the liquefaction of almost all the organs in the body. Payne identified five stages of decomposition which include fresh, bloat, decay, post-decay and skeletal or remains stages.[3] These stages are predominant in temperate regions.[4] However, Goff noted that the most common modification of the stages of decomposition include fresh, bloat, active decay, advanced decay and skeletal stages.[5] These stages make up the post-mortem interval (PMI) of carcasses.

Decomposition timeline vary across different climatic regions because climatic factors such as temperature, humidity, wind, and rainfall aid the survival of microorganisms and / or primary decomposers.[6] In addition, different climate present different floral and faunal communities which influence the rate of decomposition.[7,8] Nigeria is a country located within the tropics with damp and very humid climate. Nigeria is covered by three types of vegetations forests, savannahs and montane land. The montane land is found at the border between Nigeria and Cameroun. The forest and savannah vegetations are sub-divided into three parts. The savannah vegetations include the Guinea forest-savannah, Sudan savannah, and Sahel savannah. The forests vegetations include the Mangrove swamp forest, fresh water swamp forest and the rain forest.[9] The tropical rain forest vegetation is found in a region of Nigeria characterised by tall trees (30m to 70m), high rainfall, high humidity, and a varying temperature across the rainy and dry seasons. In some of the country, the temperature may go as high as 44 °C all through the year except March and April after the harmattan period. The type of soil in this vegetation varies from loamy, sandy, and clayey to humus.[9] Anambra state is found in the tropical rainforest vegetation.

This study is aimed at investigating the early and late visible post mortem changes that occur from time of death to skeletonization; and to document a model account of the timeline of decomposition of Sus scrofa domestica in the tropical rainforest vegetation of Nigeria which will be used to estimate decomposition timeline.

MATERIALS AND METHODS

Ethical consideration and approval for the study

The ethical approval was obtained from the ethical committee of the Faculty of Basic Medical Sciences, University of Calabar, Calabar. The certification number is 079PHY3321 dated 24th March, 2021.

Study location

The research was carried out in a private fenced research facility located at the uplands of Enugwu community, Umudim village, Ekwulumili in Nnewi South Local Government Area of Anambra State, Nigeria

Experimental animals

The experimental animals used for the study were

four (two males and two females) adult domestic pigs (*Sus scrofa domestica*) weighing between 30kg to 40kg. They were procured from a pig farm located very close to the study location.

Experimental procedure

This study was an animal experimental study. The concept used for the research procedure was formulated by the researchers. Data on the observable decomposition changes of the animals were collected by the researchers.

Animal gender and body statistics (recumbent length, pre-mortem weight, and waist and chest circumference) were recorded. The peri-mortem and post-mortem rectal (body) temperatures of all the animals were documented. The animals were sacrificed by strangulation so as ensure its forensic importance. Animal death was confirmed when no heart beat was recorded using stethoscope and observation of the pupillary reflex. The exact time of death was recorded. The early signs of decomposition (algor, pallor, livor and rigor mortises), marking autolysis were documented. The early signs of decomposition were monitored in a controlled environment where the room temperature was taken note of. The body temperatures of the animals were recorded every 10 minutes for up to six times until an hour. Subsequent hourly temperature changes were recorded for 8 hours. Animal post mortem weight (after 8 hours) was recorded. The body parts where decomposition occurred, and when it occurred was documented. This study also noted the insect activities though proper entomological study was not conducted.

Animals were immediately moved to the research site at the end of the 8 hours post mortem observation period. Visible post mortem changes of the animals were observed daily morning, afternoon and evening. The perimeter of the forensic sites (9.39m in length and 3.38m in width) were secured and marked clearly with forensic tape and sign post to avoid any human interference.

Method of data collection for daily climate readings

The thermo-hygrometer was placed in a room (shed), and the wire plug (containing the mercury knob) extended outside the room via its window. The liquid content display (LCD) of the equipment was taken far away from sun rays; then the temperature scale was set to Celsius. The time was also set on the equipment to the Greenwich mean time (GMT) of our location to ensure accuracy in documenting the readings. The lowest atmospheric temperature of the day was recorded between 3am and 7am; and the highest atmospheric temperature of the day recorded between 11am and 3pm. The lowest humidity of the day was recorded between 11am and 3pm; and the highest humidity of the day recorded between 3am and 7am.

The rain gauge display was placed in a dry area free of dirt, dust and sun rays. The display and rain gauge must be within 30m (100ft) of each other. The rain gauge was installed at 0.9m above the ground on a flat level surface so as maximize wireless range communication and to ensure accurate rain measurement. In addition, the display and rain gauge were placed away from large metallic items, thick walls, metal surfaces, or other objects that may limit wireless communication; and both units were placed at least 0.9m away from electronic devices (TV, computer, microwave, radio, etc). We ensured that the rain gauge is not placed in a low spot that could become flooded or in an area where there are obstructions above it. We also ensured that the rain gauge base is fastened on a sturdy surface with screws using hand tools. At the completion of the installation, the rain gauge synchronized with the display and took daily readings daily automatically.

Experimental control / Precautions

We ensured that the experimental animals were healthy and the food they took two weeks before the experiment did not contain any poisonous or alcoholic substances. Animals were procured from nearby farms to the research facility to ensure that there was no change in body thermal condition. Animals were procured very early in the morning between 5am and 6am, and allowed to rest and acclimatize for a period of 1 hour. The mercury part of

the thermometer was cleaned after inserting it inside the anus of the animals with methylated spirit and dry cotton wool so as to ensure accuracy in data collection.

Statistical tool and method of data analysis

Data were analyzed using Statistical Package for Social Science (SPSS) IBM series version 25. The data were descriptively analysed and represented in tables and figures.

Duration of Research

This study lasted for a period of 49 days (from October 2019 to November, 2019).

RESULTS

Peri-mortem body statistics

The recumbent length, chest circumference, waist circumference, peri-mortem body weight, and peri-mortem body temperature of the animals were documented in Table 1. The peri-mortem body statistics revealed that the experimental animals were fully matured, whose body weight ranged between 30 40kg.

Post-mortem body statistics

During the sacrifice, one of the animals (female) struggled for survival (with discharge of faecal matter and urine) which led to elevated body temperatures at death as shown in Table 2. This increase in body temperature sped up autolytic activities for this carrion. The other animals died slowly during the sacrifice which could be a reason the body temperature remained the same as shown in Table 1 and 2.

Body temperatures of animals

The body temperatures recorded six times for the first one hour and subsequently the recorded hourly for seven times (N=13) were analyzed for each pig. Pigs 2 and 4 had the least standard deviation (SD = 2.5) showing that their body temperatures were more consistent and reliable when compared to Pigs 1 and 3 (Table 3). This means that the rate of change in body temperatures in Pigs 1 and 3 were not much when compared to the body temperatures of Pigs 2 and 4. Pigs 2 and 4 had an inconsistent temperature which may have affected its autolytic process.

Visible post-mortem changes

The animals appeared fresh on the first day (Figure 1). However, there were notable events that occurred on the animals few minutes after deaths. The first visible change that was observed from the animals was algor mortis also explained as body cooling (Table 4). Pallor mortis (paleness of skin) and rigor mortis (muscular rigidity) were observed one hour later (Table 5). Livor mortis (blood pull to the dependent side on which the animals were placed) was observed two hours after death (Table 5). These events mark autolysis and chemical breakdown of the bodies with release of putrid gases. These putrid gases attracted houseflies to the orifices of the animals.

The decomposition process of the animals progressed from the fresh stage to the bloat stage; and subsequently to the active decay stage. The active decay stage was characterised by skin discolouration (from white to brown) and slippage of all the body structures, rapid breakdown of the body structures by swarm of maggots, gross hair loss, bone exposure of some of the body structures, release of putrid fluid, and presence of few flies (Figure 2; Table 6). As the active decay stage progressed, the putrid odour became less and the skin of the animals turned dark brown. As the putrid odour became lesser, the fly activity reduced and eventually stopped.

The advanced decay stage of decomposition followed the active decay stage. At this stage, more bones became visible with gross discolouration of the skin to grey; less maggot activity and less putrid odour (Figure 3; Table 7). Adipocere first formed on the head and structures (Figure 4), then progressed to the trunk (Figure 5). However, at this stage, most of the bones of some of the animals were very visible though with greasy body matter. The advanced decay stage progressed at a very slow rate to the dry decay stage.

The dry decay stage was characterised by presence of adipocere formation on the skull, ribs and vertebrae; absence of putrid odour, flies and maggots; and

Table 1: Peri-mortem body statistics of the animals used for the study

Body Statistics	PIG 1	PIG 2	PIG 3	PIG 4
Weight (Kg)	40.0	30.5	40.0	35.0
Rectal Temperature (^{0}C)	37.8	38.3	39.4	38.6
Recumbent Length (cm)	116.8	101.6	111.8	111.8
Chest Circumference (cm)	97.0	72.5	97.0	79.0
Waist Circumference (cm)	87.0	62.0	88.5	76.5

Table 2: Post-mortem statistics of the animals used for the study

Body Statistics	PIG 1	PIG 2	PIG 3	PIG 4
Weight after 8 hours (Kg)	42.5	34.5	42.0	36.5
Rectal Temperature at death (^{0}C)	40.0	38.2	39.5	38.6
Atmospheric Temp. at death (^{0}C)	24.0	24.0	24.0	24.0
Time of Death	10.10	9.10	10.20	9.45

Table 3: Descriptive statistics of the body temperatures of all the animals

Pigs used for the Experiment	Mean	N	Std. Deviation
PIG 1	36.3385	13	2.63361
PIG 2	35.2846	13	2.46267
PIG 3	36.2077	13	2.93526
PIG 4	35.5154	13	2.53372

N = The number of readings observed 6 times (per minute) for the first one hour and 7 times (hourly) for the second seven hou

Table4: Day 1 Visible Changes10 minutes periodic data after death

TIME	BT (^{0}C)	AT (^{0}C)	RT (^{0}C)	Visible Changes	Insect / Fly Activities
10.20am	39.7	24.0	25.8	No pupillary reflex	Nil
10.30am	39.6	24.0	24.9	Algor Mortis starts	Nil
10.40am	38.9	24.0	26.1	Body temperature drops	Nil
10.50am	38.5	24.0	25.8	Body temperature drops	Nil
11.00am	38.3	24.0	26.1	Body temperature drops	Nil
11.10am	38.2	24.0	26.1	Body temperature drops	Nil

BT. Body temperature; AT. Atmospheric temperature; RT. Room temperature

dryness of the exposed bones and complete skeletonization of the limbs (Figure 6; Tables 9 & 10). However, at this stage, two of the animals were completely skeletonized.

Timeline of decomposition

The decomposition timeline was estimated and documented from the observable visible post mortem changes (Table 11). Algor mortis started immediately at death and lasted about eight hours. Pallor and rigor mortises started at about two hours after death. Pallor mortis lasted a period of six hours whereas rigor mortis lasted about 42 hours. Livor mortis started three hours after death and lasted about five hours.

The fresh stage of decomposition started immediately after death and lasted about 11 hours. This was immediately followed by the bloat stage. The bloat stage of decomposition lasted about three days and was immediately followed by the active decay stage. The active decay stage started on the third post mortem day and lasted about 11 days. The advanced decay stage immediately followed the active decay stage and lasted about 15 days. The dry decay stage started on the 21st post mortem day and lasted till the last day of the study.

Table 5: Day 1 Visible changes – Hourly observation

Time	BT (^{0}C)	AT (^{0}C)	RT (^{0}C)	Visible Changes	Insect / Fly Activities
12.10pm	36.0	27.0	26.0	Pallor and Rigor mortises start.	Nil
1.10pm	35.1	27.0	26.0	Body continues to stiffen; Paleness became more visible. Livor mortis starts.	Nil
2.10pm	34.8	27.0	26.0	Livor, Pallor and Rigor mortises progress.	Houseflies on the anal region.
3.10pm	34.6	27.0	26.0	Algor, Pallor, Rigor and Livor mortises continue to progress.	Fly activities increases on the anal region
4.10pm	33.3	26.0	25.0	Body temperature continues to drop; Lividity progresses. Muscular rigidity intensifies.	Houseflies at the oral region.
5.10pm	32.7	26.0	25.0	Temperature continued to drop and lividity progressed.	Houseflies at the ear.
6.10pm	32.7	26.0	25.0	Algor and Livor mortis became fixed. Body completely turns pale. Waning of rigor mortis starts.	Flies at anal, oral and ear body areas

As at 6.10pm, animal body and rectal temperature s were no longer dropping, and hence algor mortis ceased. Animal was moved to the research site and placed on the soil surface by 6.35pm.

BT. Body temperature; AT. Atmospheric temperature; RT. Room temperature

Table 6: Day 7 Visible changes

Time	Head & Neck Visible Changes	Trunk Visible Changes	Limbs Visible Changes
Morning (6:42am)	Skin slippage continued on neck region. Black discolouration continued. Less maggot activity. No fly activity.	Complete skin slippage of the ventral surface of the trunk. Brown to black discolouration on the ventral surface of the trunk. Gradual breakdown of abdominal contents on the soil surface attracting a swarm of maggots. Purging of fluid continued. Putrid odour still persisted.	Skin slippage progressed on the hind limbs. Complete skin slippage of the fore limbs. Black discolouration of hind limb closer to the soil surface. Black discolouration of all aspects of the fore limbs with bone exposure. No fly activity.
Afternoon (1:03pm)	Skin slippage of head region progressed. Bone exposure of upper jaw. Black discolouration spreads on all aspects of head and neck region. Less maggot activity. Increased maggot activities.	Active decay stage progressed. Swarm of maggots present.	Active decay stage progressed. Skin slippage progressed. Swarm of maggots present.
Evening (6:30pm)	Active decay stage progressed. Swarm of maggots present. No fly activity.	Active decomposition progressed. No fly activity. Swarm of maggots on all aspects of the trunk.	Skin slippage progressed. Hind limb bones became more visible. Decreased maggot activity.

Table 7: Day 14 Visible changes

Time	Head & Neck Visible Changes	Trunk Visible Changes	Limbs Visible Changes
Morning (6:34am)	Complete caving in of eye, ear and throat. Tendons and ligaments turned dark-brown. Hair loss of skin over the neck. All bones of the skull completely exposed.	Partial exposure of ribs and pelvic bones. Skin of the dorsal surface of the trunk turned dark-brown. Maggot activity present. Putrid odour still persisted. No fly activity.	Almost all bones of both limbs exposed. Some greasy skin still visible on some bones. Tendons and ligaments continued to discolour as advanced decomposition stage progressed.
Afternoon (12:46pm)	Almost all bones of the head and neck visible. Some greasy skin still visible on the neck. Hair loss of skin over neck continued. Less maggot activity. No fly activity.	Advanced decay of the trunk progressed.	Bones largely dry retaining some grease.
Evening (6:07pm)	Advanced decay of head and neck progressed.	Advanced decay of the trunk progressed.	Advanced decay of all the limbs progressed.

Table 8: Day 21 Visible changes

Time	Head & Neck Visible Changes	Trunk Visible Changes	Limbs Visible Changes
Morning (6:20am)	Bones of the head completely dry. Bones of the neck completely exposed but with greasy skin. Tendons and ligaments of the neck not decomposed. Greyish discolouration of matter surrounding bones. Less maggot activity.	Adipocere formed on the trunk. Lumbar, thoracic and pelvic vertebrae exposed. Advanced decay of body matter surrounding the exposed bines. Hair loss continued. Swarm of maggots present.	Bones completely dry. Greyish discolouration of body matter surrounding the bones. Less maggot activity.
Afternoon (12:26pm)	Advanced decay of body matter progressed. Less maggot activity.	Greyish discolouration of body and bony matter. Swarm of maggots present.	Tendons and ligaments of some bones completely decomposed. Less maggot activity.
Evening (6:30pm)	No visible changes. Less maggot activity.	Advanced decomposition of the trunk progressed. Putrid odour still persisted. Swarm of maggots present.	Decomposition of tendons and ligaments progressed. Less maggot activity.

Table 9: Day 28 Visible changes

Time	Head & Neck Visible Changes	Trunk Visible Changes	Limbs Visible Changes
Morning (6:30am)	All bones appeared dry. Complete decay of tendons and ligaments. No fly and maggot activity.	Adipocere formed on vertebrae slowing the rate of decomposition. All rib bones including tendons remain dry. No fly and maggot activity.	All bones remain dry and completely skeletonized. Complete decay of tendons and ligaments. No fly and maggot activity.
Afternoon (1:00pm)	No visible changes.	No visible changes. No putrid odour.	No visible changes
Evening (6:20pm)	No visible changes.	No visible changes.	No visible changes.

Table 10: Day 49 Visible changes

Time	Head & Neck Visible Changes	Trunk Visible Changes	Limbs Visible Changes
Morning (6:20am)	Dry bones (complete skeletonization).	Adipocere continued to appear on the vertebrae. All other bones appeared dry and completely skeletonized.	Complete skeletonization.
Afternoon (12:56pm)	No visible changes.	No visible changes.	No visible changes.
Evening (6:35pm)	No visible changes.	No visible changes.	No visible changes.

Table 11: Estimated timeline of decomposition

Stage / Period	Timeline	Duration
Algor mortis	00:20 PMI – 08:00 PMI	8 Hours
Pallor mortis	02:00 PMI – 08:00 PMI	6 Hours
Rigor mortis	02:00 PMI – Day 3	42 Hours
Livor mortis	03:00 PMI – 08:00 PMI	5 Hours
Fresh	00:00 PMI – 11:00 PMI	11 Hours
Bloat	11:00 PMI – Day 4	3 Days
Active decay	Day 3 – Day 14	11 Days
Advanced decay	Day 13 – Day 28	15 Days
Dry decay	Day 21 – Day 49	28 Days

Data above represents the timeline of decomposition from autolytic phase to putrefaction phase.

Table 12: Factors that could affect the rate of decomposition

DAY	HAT (^{0}C)	LAT (^{0}C)	HH (%)	LH (%)	PREP (%)
1	27	24	98	83	95
2	28	22	98	86	100
3	31	22	92	78	90
4	29	25	100	86	100
5	31	23	97	81	80
6	31	24	89	75	80
7	31	24	96	81	85
8	29	23	100	83	100
9	30	22	98	79	98
10	28	21	100	84	100
11	27	22	100	86	100
12	29	22	98	82	98
13	31	24	92	81	92
14	27	22	100	78	95
15	29	21	98	84	81
16	27	22	92	81	77
17	28	23	91	84	87
18	30	22	97	78	80
19	29	22	98	82	80
20	28	22	92	80	90
21	28	21	92	81	80
22	28	22	98	78	0
23	27	22	89	71	0
24	27	21	100	81	0
25	30	22	95	83	8
26	30	22	88	74	21
27	31	22	97	80	12
28	33	23	87	61	2
29	29	22	81	72	5
30	32	21	80	71	14
31	33	23	99	80	0
32	32	24	100	78	2
33	33	24	100	77	10
34	29	22	91	82	75
35	30	22	96	70	0
36	33	23	91	73	0
37	32	24	81	72	0
38	34	22	99	50	3
39	32	24	81	75	4
40	29	22	97	51	0
41	33	22	92	73	0
42	34	25	99	71	0
43	34	26	91	78	0
44	33	24	95	77	2
45	31	22	85	73	3
46	32	23	98	81	1
47	34	22	88	67	0
48	36	23	97	62	0
49	38	22	100	63	0

HAT. Highest Ambient Temperature ; LAT. Lowest Ambient Temperature
HH. Highest Humidity; LH. Lowest Humidity; PREP. Precipitation (Rainfall)

Figure 1: *Sus scrofa domesticus* immediately after sacrifice (DAY 1 – Fresh Stage). The animal appeared fresh with no visible decomposition changes.

Figure 2: DAY 7– Active decay stage

Figure 3: DAY 14-Early advanced decay stage

Figure 4: DAY 21–Early dry decay stage / Adipocere formation

Figure 5: DAY 28–Dry decay stage / Adipocere

Figure 6: DAY 49 –Dry decay stage / Adipocere

DISCUSSION

The speedy rate at which algor mortis started and progressed suggests that the strangulation process enhanced the decomposition rate of some of the animals. This is because a study by Hanna and Moyce noted that mode of death (such as strangulation) is a factor that accelerates the rate of decomposition.[10] The speedy rate of rigor and pallor mortises also suggests an early speedy decomposition process. This is in line with report by Hanna and Moyce, which noted that rigor mortis is one of the first signs of autolysis.[10] However, the rate and process of decomposition within the first eight hours would have been different if the animals were immediately exposed to the field and sun. This is because a recent study has shown that carcasses exposed to the sun decompose faster than those in the shade.[11] One of the objectives of this research was to investigate the early visible post mortem changes (especially autolytic activities). But a pilot study we carried out in an outdoor environment to investigate the autolytic activities of domestic pigs showed inconsistency in the results of the algor mortis. This made the researchers carry out the first eight hours investigation in an indoor environment and this yielded consistent algor mortis results. Therefore, this study recommends that further studies on the first eight hours of decomposition be carried out in an outdoor environment to ascertain the effects of environment conditions on the rate and process of decomposition.

The putrefaction phase started after the autolytic phase. There were optimum climatic conditions (though with extreme humidity at certain periods) which positively influenced the decomposition process (Table 12). This condition led to the optimal decomposition of the animals to the skeletonization stage. The extreme humidity initiated adipocere formation on some body parts which delayed decomposition on those areas. Adipocere formed on these body parts contributed insignificantly to the decomposition process because most of the body parts of the carrions skeletonised within the study period. These visible post mortem changes of decomposing domestic pigs corroborate the findings reported by several authors.[7,8,12,13,14]

The decomposition timeline estimated in this study showed that the first sign of autolysis was algor mortis. This report corroborates with the report by Obun et al.,[8] but contradicts the report by Hanna and Moyce whose findings identified pallor mortis as the first sign of decomposition.[10] The timeline for rigor and livor mortises contradicts the reports on decomposition timeline by Payne.[3] Several authors have also reported that these early visible post mortem changes (pallor, algor, rigor and livor mortises) are notable visible changes of the fresh stage of decomposition.[3,10,15]

The timeline of bloat stage of decomposition reported in this study is similar to the reports by Hanna and Moyce and Megyesi et al.[5,9,16] The active decay pattern reported in this study is similar to the reports by Hanna and Moyce, and Megyesi et al. but with different timelines[5,9] However, some of the animals experienced adipocere formation which started at about the 21st day post-mortem and lasted till the end of the study on some of the body structures of the animals. Adipocere formed on the animals due to high humidity (Table 12), and this was one of the factors

that delayed the skeletonization of the animals (Table 12). Adipocere formation has been reported by several authors as a factor that delayed decomposition rate in very humid Climates.[17,18,19,20,21,22,23,24]

The timeline of advanced decay stage is similar to the reports by some authors,[10,14] but contradicts the report by Obun et al which identified a faster advanced decay stage.[8] The delay in the progression of the advanced decay stage could be as a result of the stoppage of rain at the 22nd post mortem day (Table 12). The absence of rain or reduced precipitation level within this period made the fleshy body parts of the animals to dry up resulting to feeding difficulty of the maggots.

The timeline of the dry decay stage conforms with the findings reported by some authors that noted that dry decay stage kicks off at about 4 weeks post-mortem.[25,26] However, a dissimilar report from Hanna and Moyce noted that dry decay or remains stage occurs from 50 to 365 days which may even last for hundreds of years for bodies at the surface of the earth under certain conditions.[5] This study lasted 49 days and there was incomplete skeletonization of some of the animals within the study period because of adipocere formation. Therefore, this study recommends that further studies should be carried out for a longer timeline in order to ascertain the actual time it will take for complete skeletonization of animals on the soil surface in a Tropical rainforest vegetation of Nigeria. In addition, further studies should also be carried out at the dry season when no or poor precipitation level is recorded.

CONCLUSION

The putrefaction phase started after the autolysis phase of decomposition. Five stages of decomposition were identified in this study fresh, bloat, active decay, advanced decay and dry decay stages.

The fresh stage of decomposition lasted for about 11 hours, and the visible post mortem changes characterized by this stage include algor mortis, pallor mortis, rigor mortis, livor mortis, release of putrid odor and presence of house flies. The bloat stage lasted for three days and the visible post mortem changes is characterized by rigor mortis, bloating of body structures, greenish discoloration of body especially the trunk, increase in intra-abdominal pressure, stretching and marbling of skin, release of putrid gases, and increased fly activity. The active decay stage lasted for 11 days and its visible post mortem changes is characterized by brownish skin discoloration, swarm of maggots' activity, purging of body fluid forming cadaver decomposition island, sagging of flesh, skin slippage, hair loses, few bone exposure, putrid odor, and less fly activity. The advanced started at about the 13th day and lasted for 15 days. The visible post mortem changes significant with the advanced decay stage in this vegetative region (during the rainy season) include adipocere formation, gross bone exposure, greyish discoloration of the skin and body matter, less putrid odor compared to the active decay stage, and visibly insignificant maggot and fly activities. The dry decay stage immediately followed the advanced decay stage, and is characterized by the absence of fly and maggot activities, absence of putrid odor, exposure of dry bones, and adipocere formation.

There was incomplete skeletonization of two animals within the study period due to adipocere formation. The visible post mortem changes identified in this study at the stages of decomposition can be used to estimate the decomposition timeline of strangled carcasses on clandestine soil surface in the tropical rainforest vegetation of Nigeria.

Author contributions

This work was carried out in collaboration of all authors; and all authors read and approved the final manuscript.

Author ODN carried out the experiment and wrote the first draft of the manuscript. Author ODN also assisted author EUG to design the study. Author ADC assisted author FVA to review the draft manuscript. Author FVA reviewed the draft manuscript. Author OIM managed the literature searches. Author EEN assisted author OIM to manage the literature searches. Author NKE curated the data. Author OGC assisted author NKE to curate the data. Author OC wrote the experimental protocol. Author OEA

acquired and managed the animals. Author AAE assisted authors NKE and OGC to curate the data. Author EUG conceptualized the study, designed the study, and supervised the experimental study.

Data availability

The data used to support the findings of this study are available from the site publicly.

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