THERMODYNAMIC IN TERMITE MOUND: THE RELATIONSHIP BETWEEN VENTILATORY STRUCTURES AND MOUND SIZES.

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DEPARTMENT OF ANIMAL AND ENVIRONMENTAL BIOLOGY

FACULTY OF LIFE SCIENCES

UNIVERSITY OF BENIN

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A PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF ANIMAL AND ENVIRONMENTAL BIOLOGY, FACULTY OF LIFE SCIENCES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE UNIVERSITY OF BENIN, BENIN CITY, AWARD OF BACHELOR OF SCIENCE (B.Sc HONS) DEGREE

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CERTIFICATION

This is to certify that this project work was carried out by Ephraim Oghenerabome SECONDI of the Department of Animal and Environmental Biology, Faculty of Life Sciences, University of Benin, Benin City.

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DEDICATION

This work is dedicated to God Almighty and all lovers of sciences that seek to entangle the mysteries in our beloved universal.

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I appreciate God Almighty for the gift of life, strength and courage all through this study.

I am more grateful to my supervisor Dr. I. N. Egbon for his sacrifice of love and efforts to make this project a success. Thanks for pushing me to the walls in other to learn and get things done. I cannot be grateful enough sir, God bless you.

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ABSTRACT

Termite mounds are good examples of a well regulated ecosystem structure. These social insects are ecosystem engineers that are capable of building mounds of various sizes. *Macrotermes* mounds are equipped with several openings at various positions to mitigate thermoregulation and ventilation. One possible means of understanding the thermoregulatory pattern and ventilation strategies within a *Macrotermes* mound is to assess the relationships between its respiratory structures and geometry. Here, correlation test were done to test the level of significant relationships between the mound geometry and ventilatory structures. Results showed that the ventilatory structures above the base of *Macrotermes* mound is significantly (p<0.05) related to its overall size (height, column, width) with correlation coefficient of 0.7323142, 0.668158 and 0.6531674 but had no relationship with the depth and perimeter of a *Macrotermes* mound. However, the ventilatory structure at the basal portion was significantly related to the depth with correlation coefficient of 0.7428268 and not necessarily the size of a mound. The temperature of a mound surrounding is also related to the internal temperature (R=0.7074602, p=0.0004, R^2=0.5005), and also deterministic factor in assessing the temperature flow within a *Macrotermes* mound. This ventilatory structures coupled with temperature are typical strategies used by termites to create a well thermoregulated and ventilated structures. The implications of these findings are that *Macrotermes bellicossus* mounds can be employed by humans in the construction of buildings, such that a time we come where there will be little or no need for artificial ventilators like Air conditioners.

CHAPTER ONE INTRODUCTION

1.1 Background to the study

Termite mound are the nest of Termite where colonies reside (Fleming *et al*., 2003). The structure of the mound allows the interior portion to remain dark though ventilated with many orifices. The most common genus termitaria found in the tropics are *Macrotermes* (traore *et al*., 2008) and their mounds vary in shape, size and location (Dangerfield *et al*., 1998). The mound can be arboreal situated in trees, subterranean on dead log of wood. The mounds are equipped with ventilatory structures for thermoregulation (Johanna, 1985).

Termitaria are key structures in tropical ecosystem. Termite act as ecosystem system engineers and can build enormous mound that reaches a height of several metres from the ground (Justice *et al.,* 2020). The overall size of a mound depends on the level of invasion by other animals and plants that seek refuge. The intruding animals and plants exhibit mutualistic relationship with this termite mound either deliberately or by chance (Cristaldo *et al.,* 2012).

Termite mound soil has been proven to positively affect soil properties, biogeochemical cycling and overall rate of degradation. This soil is used for planting alongside other planting materials because of its richness in several minor and major nutrients that enhances plant growth and development (Myer *et al*., 2019). Similarly, it has been observed that several edible fungus species are usually found growing in the mound of termite and as such, they are included in the food web of their ecosystem; since it serves as location of food to organisms that feed on these fungi (Subi *et al*., 2019). The mound and soil of termite are also used for cementing, pottering works and shelter for animals (Arnold 2017). The mound structure enhances renewal of oxygen supply and convectional flow of heat. Termitarium is built with their chambers aligning towards the North pole (Korb *et al*., 2000).

Due to termites' sensitive to dessication, their mounds play a significant thermoregulatory role (Remi *et al*., 2017). Hence, the mound protects them from harsh weather conditions. Termite also performs behavioural thermoregulation by either fanning their wings or building their mound in places where there is high level of humidity (Hunter *et al.,* 2015). Though the mound was design to resist external temperature, but studies has it that the environmental temperature has a way of influencing the mound internal temperature in both short term and long term (Remi *et al*., 2017). It was also affirmed that the environmental conditions of a termite mound jointly determine its component structure and internal conditions (Tadeu *et al*., 2020).

1.2 Aim

The aim of this study is to understand the thermodynamics of termite mounds and how the mound sizes correlate with their ventilator structures.

1.2.1 Specific objectives

To achieve the above aim, the study specifically evaluated the following objectives:

(i) The inner and surface temperature of termitaria built by M.bellicosus.

(ii) The relationship between mound size and vents structure.

CHAPTER TWO LITERATURE REVIEW

In 1998, korb *et al*, determined the structure of *Macrotermes bellicosus* mound relative to gaseous flow and temperature regulation. When the CO_2 levels were measure and monitored, it was observed that mounds in the gallery forest were more complex in structure than those of the savannah. However, the CO_2 level of the forest in daylight was higher than those of the savannah but with lesser temperature. They indicated that the efficiency of ventilation mechanism are reduced at night but high production of CO_2 are a trade cost for this low temperature condition. This was confirmed by a previous work done by Darlington *et al*., (1997) that estimated the CO_2 level of *Macrotermes michaelseni*; a similar species to *M. bellicosus* to be about 500l in a single day.

Hunter *et al*., (2015) discussed the use of diurnal temperature for ventilation in termite mound. Upon observation, they compared the temperature which drives the regular flow of oxygen and removal of CO_2 in a termitarium and stated that a combination of geometry, porosity and heterogeneous thermal flow allows termite mound to use temperature for ventilation. His report had it that mound chambers heat up first before it base and the structure of a mound surface were design to ease the problem of gaseous diffusion. When the prevailing structural and thermodynamic measurement was collected, they also reported that the materials use in mound architecture are of high porosity with healthy mounds having no visible holes in its surface and if there is, immediate repairs response were initiated. He further reported that during the day, when gaseous flows were small, CO_2 tend to build up within the mound and at night when convective flow are large, it becomes less accumulated. He concluded that at various heights, the termite nest is the coolest part with metabolic heat also controlling thermoregulation. The diurnal heat gradient facilitates gaseous exchange and transport in a mound, making it an homeostatic microhabitat.

In 2016, Joseph et al., discussed how microclimate resist hot temperature using a termite mound as a case study in dry environment. He stated that mound of termite was observed to withstand drought by providing refuge for plant revegetation. The temperature manipulation effects by *Macrotermes* termite mound allows agricultural and conservative decision making. As temperature changes begins to impact the integrity of ecological processes, they suggested that self-organized spatial vegetation pattern associated with termite mound can buffer against extreme temperature in dry land ecosystem, fire, and drought. The temperature manipulation effects of termite was reported to be greater than those of his environment making it a microclimate. Hence, he concluded that the mound of termite provide a cooling effect within its architecture and a good microclimate for temperature modulation.

Remi *et al*., 2017 evaluated the heat loss and gain in three termitaria of *Procornitermes araujol* using a heat model. To resolve this challenge, the mound internal dynamics was tested against its environment factors within a period of 14 days with proper monitoring of temperature fluctuation within its structure at regular time interval. The internal temperatures at various point in the three mound was substituted into the model to yield a mean temperature. The temperature at the top of the mound was higher compared to the centre and mound temperature was higher than soil and air temperatures at a distance of 5cm and 20cm. Nonetheless, the centre temperature was fairly stable.

In assessing the relevance of radiant energy from the sun as a drive for ventilation in the mound of *Macrotermes michaelseni* Samuel et al., (2017) tested the internal dynamics that drives gaseous exchange and airflow within the mound against the external dynamics of the mound environment. All models adopted were monitored at all hours of the day to understand daily fluctuation patterns. When all the results were collated from thirty (30) mounds, they reported that airflow was greater down the mound at night and upward during the day. Similarly, they observed that the eastern part of the mound was heated first, next the north, west and the south was the coolest part. This trend follows the sun nature to rise from the east and set in the west. He concluded that the thermodynamics and ventilation of termite mound of *Macrotermes michaelseni* follows the sun radiation pattern.

The temperature changes in *Macrotermes natalensi* mound are associated with their sizes and neighbouring plant shade (Ndiovu *et al.*, 2018). Mound sizes, temperature and vegetation shade were tested and compared and reports had it that the temperature deviation was minimal, and both active and passive mounds are affected by temperature. However, it was recognized that active mounds has the tendency to regulate and maintain temperature more than passive mounds and also, large mounds maintained temperature deviation more than small mounds. He further reported that the mound size is a stronger deterministic factor than the vegetation shade in determining the internal mound temperature and its stability.

A study conducted to determine the regulation of temperature by termite mounds and the diversity of fungus species they harbor, Risto *et al.*, (2019) sampled over a 100 mound and stated that termitarium with open ventilatory structures harbours a different fungi species from those with closed ventilator system. When the temperatures of all mounds harbouring different fungi species were observed, they noticed that the temperatures were different from mound to mound; suggesting that the different fungus has different temperature requirements and tolerance. When the yearly temperatures of location were observed, they noticed that the differences between them were minimal. This was also the case for soil temperature and air temperature (similar). They finally asserted that mound with closed system had higher temperature than open mound and the mound size is directly proportional to its ventilatory structure.

In evaluating the response of termite mound orientation to the sun, local wind and heat transfer, Tadeu *et al.,* (2020) reported that the external structural curvature of termite mound aligns with the poles of the earth magnetic field with a slight deviation. They also reported that the heat requirement of termite shapes this orientation pattern of termite mound and when the prevailing environmental conditions were tested, the structural characteristics of the mound were a response to the combine effects of solar radiation and wind conditions thus, resulting in a thermally regulated internal medium with uniform temperature in termite mounds.

The high strength and ventilation of *Odontotermes obesus* mounds are facilitated by its architecture (Nikita *et al*., 2020). They stated that a mound structure was design to resist harsh environmental conditions due to its strong core and porous wall that allows for thermoregulation. These termites mound utilize daytime temperature for ventilation with convectional current flowing across day and night. They reported that the mound chambers are involved in gaseous exchange with the surrounding and its tensile strength increase from the chambers down to the base. When the soil strength, porosity and air permeability was measured and compared to the mound geometry in terms of slope stability and safety factors, they further reported that termite mound tend to maintain tensile strength which are greater at the supporting chamber. The thickness of *Odontotermes* mound increases towards the center with the permeability of air at the core less than those at the base, indicating that ventilatory structure at the base are larger in size than those found at the core.

To demonstrate the relationship between the environmental factors and its corresponding effects in shaping the mound of termite, Tadeu et al., (2020) reported that the mound superstructure and internal conditions strongly depend on the combine effects of environmental forces. They noticed that the higher the exposure of a mound to the sun, the greater the angle of inclination of its column. This angle of inclination is dependent on mound geographical location. They stated that the wind had less significant effects in determining mound structure but a relevant factor that controls the internal dynamics of the mound. When prevailing forces due to interaction of the mound superstructure and atmospheric turbulent wind flow was taken into account, they further reported that the mound of *pseudocanthotermes* in very hot environment can be almost twice as high compared those in cool areas. However, mound of *M. michaelseni* in shaded areas were noticed to be more upright compared to those in open sunlight. They also observed that mound without internal channels shows characteristic difference compared to those with open channels. Though mound without internal channels was found to show negligible response to environmental conditions, but they all respond in a way that the northern base heats up while distancing the whole nest from excess external heat transfer.

CHAPTER THREE MATERIAL AND METHODOLOGY

3.0 STUDY AREA

This survey was conducted at the Nigerian Institute for Oil and Palm research (NIFOR) located at Edo State, Nigeria. Samples were collected from the savannah region as well as palm plantation region respectively.

3.1 MATERIALS

In executing this survey, the underlisted materials were used.

(i) 100ft/30m tape

(ii) 16ft/3.5m tape

(iii) Hand held GPS device

(iv) Data sheet

(v) Digital Thermometer

3.2 DATA COLLECTION

Fifteen mound were assessed within a Grassland and five were assessed within the Oil Palm Farm. The Grassland had a slopy terrain (topography) unlike the Oil Palm farm which was flat. All Termitaria within the Grassland were randomly accessed unlike the Oil Palm where all the Termitaria in sight were evaluated. The parameters include the following:

(i) The height, width and perimeter of the termitarium

(ii) Numbers of basal vents (basal openings)

(iii) Depth of five (5) randomly picked basal vents

(iv) Width of five (5) randomly picked basal vents

(v) Numbers of chambers in the termitarium

(vi) Numbers of apical vents in the termitarium

(vii) Width of five (5) randomly picked apical vents.

(viii) Numbers of chambers in all coordinates

(ix) Temperature of three (3) randomly picked basal and apical vents

(x) Longitude and latitude of the termitarium.

3.2.1 DATA COLLECTION PROCEDURES

Visual count was used to determine the number of termitaria in the sampling area. The 30m/100ft tape was used to measure the perimeter of the termitaria. Thereafter, the 16ft tape as used to measure the width and height of the termitaria.. Visual count was done to determine the numbers of basal and apical vents in each termitarium studied. The depth and width of basal and apical vents were measured using the 16ft tape. Numbers of chambers was determined with visual count across the whole termitarium. The longitude and latitude was determined using the hand held GPS device. Temperatures of randomly picked basal and apical vents were collected. Finally, the 30m tape was used to measure the distance of the nearest neighbour. The last five sampling were done in the palm plantation and the same procedures were repeated. However, the palm plantation had fewer numbers of termitaria and 4/5 of them had no neighbor in sight and as such was not sampled.

3.2.2 DATA ANALYSIS

All data set were subjected to test for normality and homoscedasticity of variance using Shapiro-wilks and levene’s test in R and if the assumption of parametric test were met, the data would be subjected to pearson correlation test, otherwise, non parametric test will be used. In this study, all data set were the assumption of normality. Hence, the data were analyzed using a pearson correlation test and the significance level were analyse with the T-test.

CHAPTER FOUR RESULTS

4.0 Structural relationships and significance

In assessing the thermodynamics of *Macrotermes* mound, the location of ventilatory structures at the basal portion significantly correlated with the vents above its base (R=0.7197946, *p*=0.0003461). The ventilatory structures of a mound above its base account for 51.81% of vents at the basal portion (R^2=0.5181).The ventilatory structures above a termitarium base is significantly related with its height. These open structures contributes 53.63% to the size of a termitarium (R=0.7323142, *p*=0.0002413, R^2=0.5363). The respiratory structures at the bottom portion of a termite mound has no significant relationship with its height and only accounts for 7.99% of a mound size (R=0.28265, *p*=0.2273, R^2=0.0799). The vent count above the mound base is significantly related with the numbers of column within it. These vent numbers accounted for 44.64% of the column numbers in a termitarium (R=0.668158, *p*=0.001282, R^2=0.4464). The vents found at the bottom portion of a mound is not significantly related with its column numbers and only contributes 11.41% in determining the numbers of column within the termitarium (R=0.3377702, *p*=0.1453, R^2=0.1141). The vents at the basal portion of a termitarium is significantly related to its mean depth and accounts for 55.18% of a termite mound depth (R=0.7428268, *p*=0.0001756, R^2=0.5518).The ventilator structures found above a mound base is significantly related with its width. The width account for 42.66% of a vent numbers within a termitarium (R=0.6531674, *p*=0.001793, R^2=0.4266). The width of a termite mound is not strongly related with the vent mean diameter found at the basal portion, with a contribution of 26.02% of its width (R=0.5100562, *p*=0.02158, R^2=0.2602). The internal and external temperature was significantly correlated with the data accounting for 50.05% of the temperature flow within and around the mound (R=0.7074602, *p*=0.0004, R^2=0.5005).

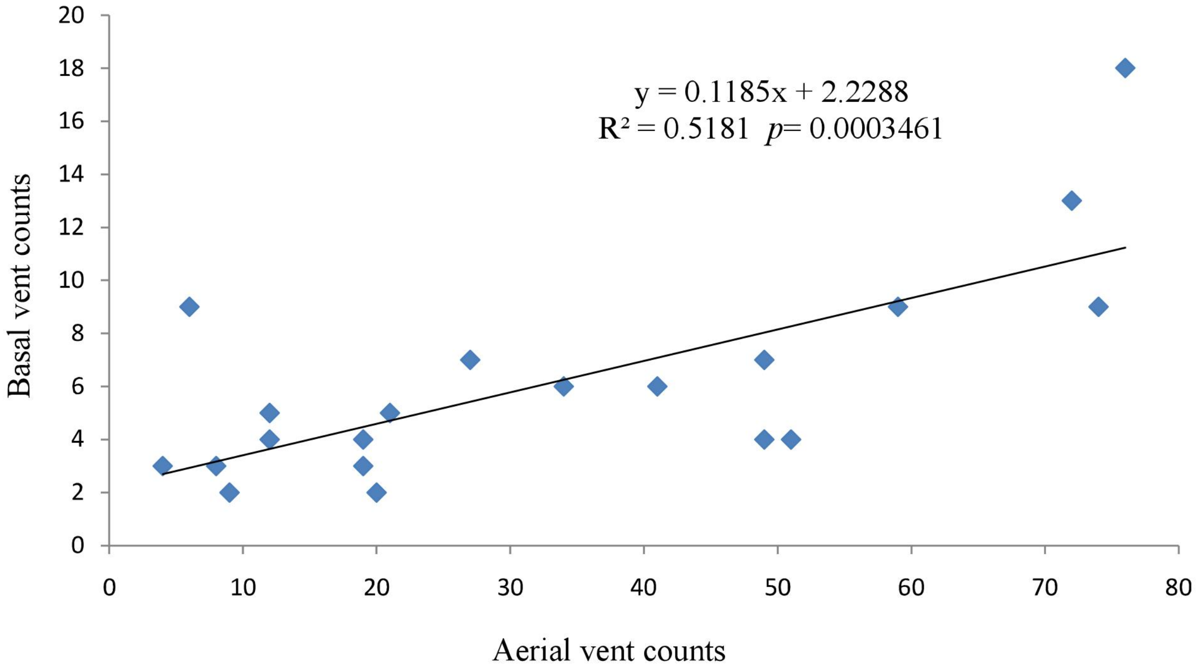

Figure 1: Basal vent counts correlated against Aerial vent counts.

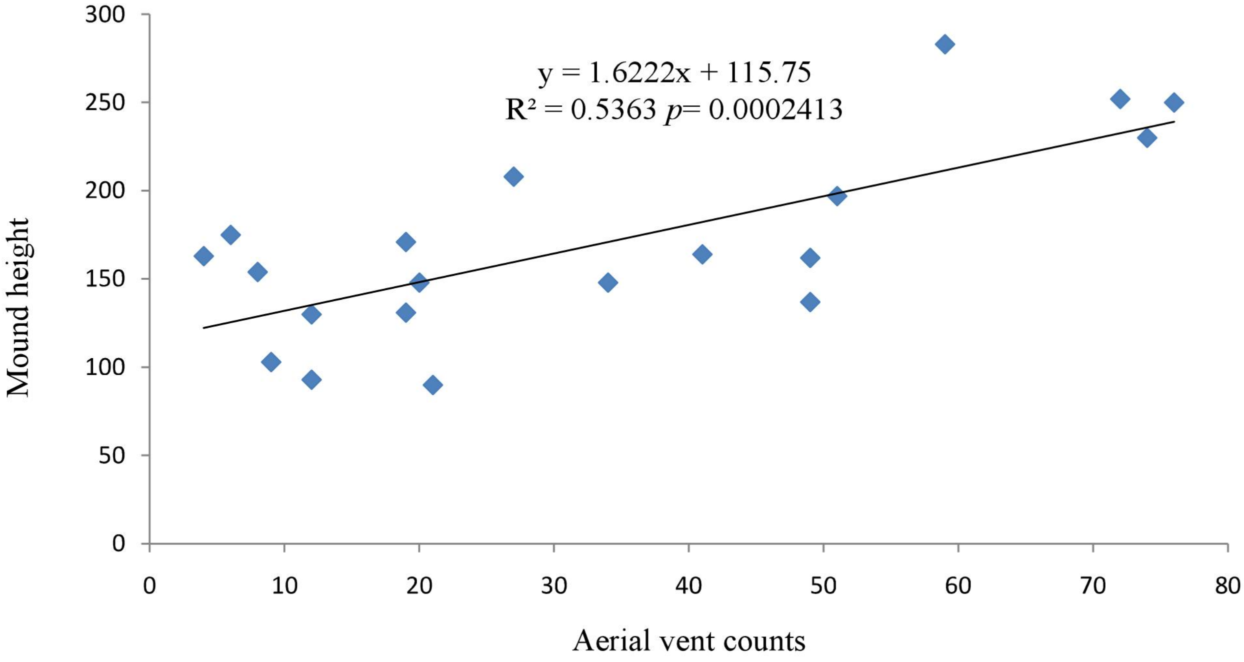

Figure 2: Mound height correlated against aerial vent counts

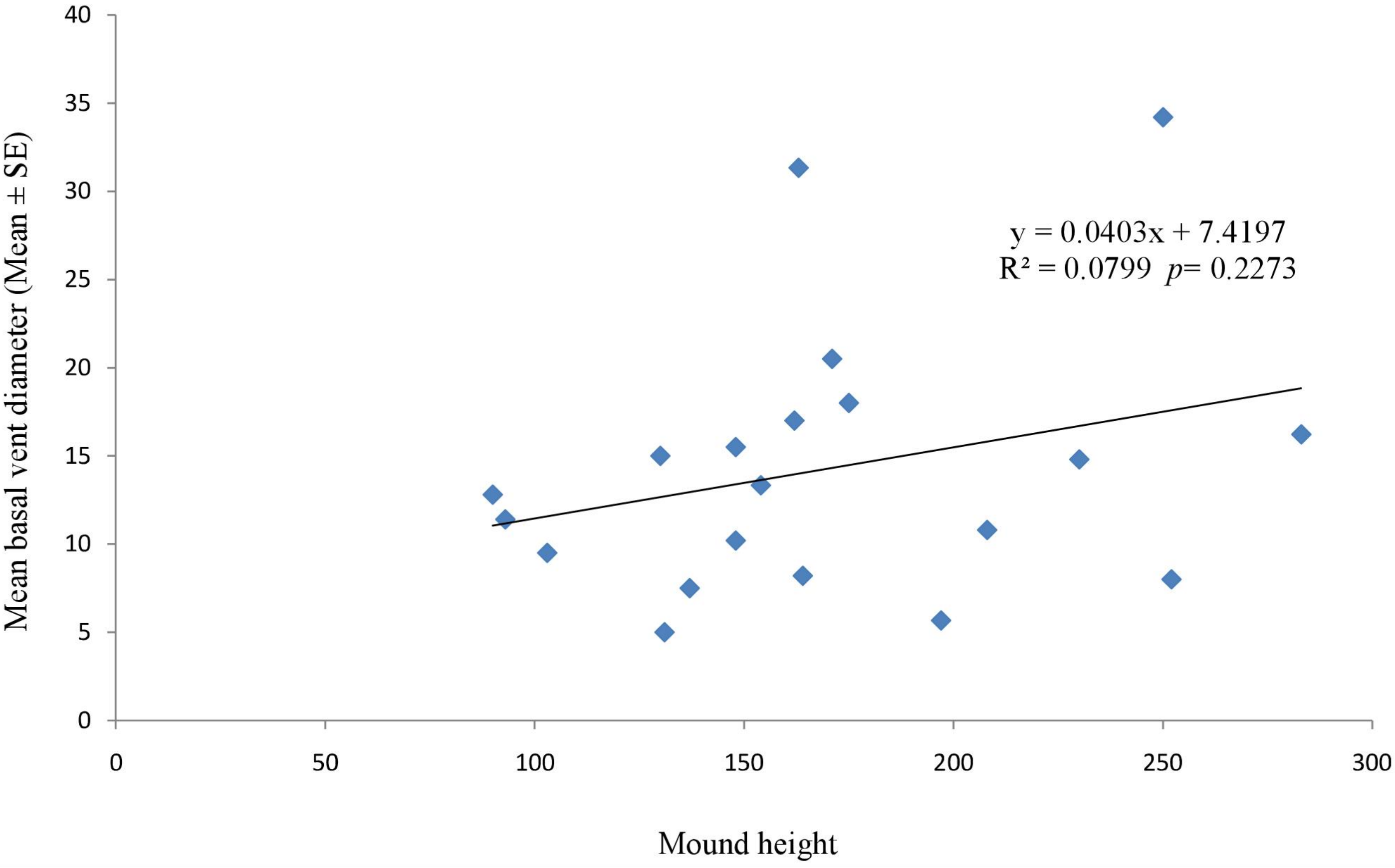

Figure 3: Average of basal vents correlated against Mound height

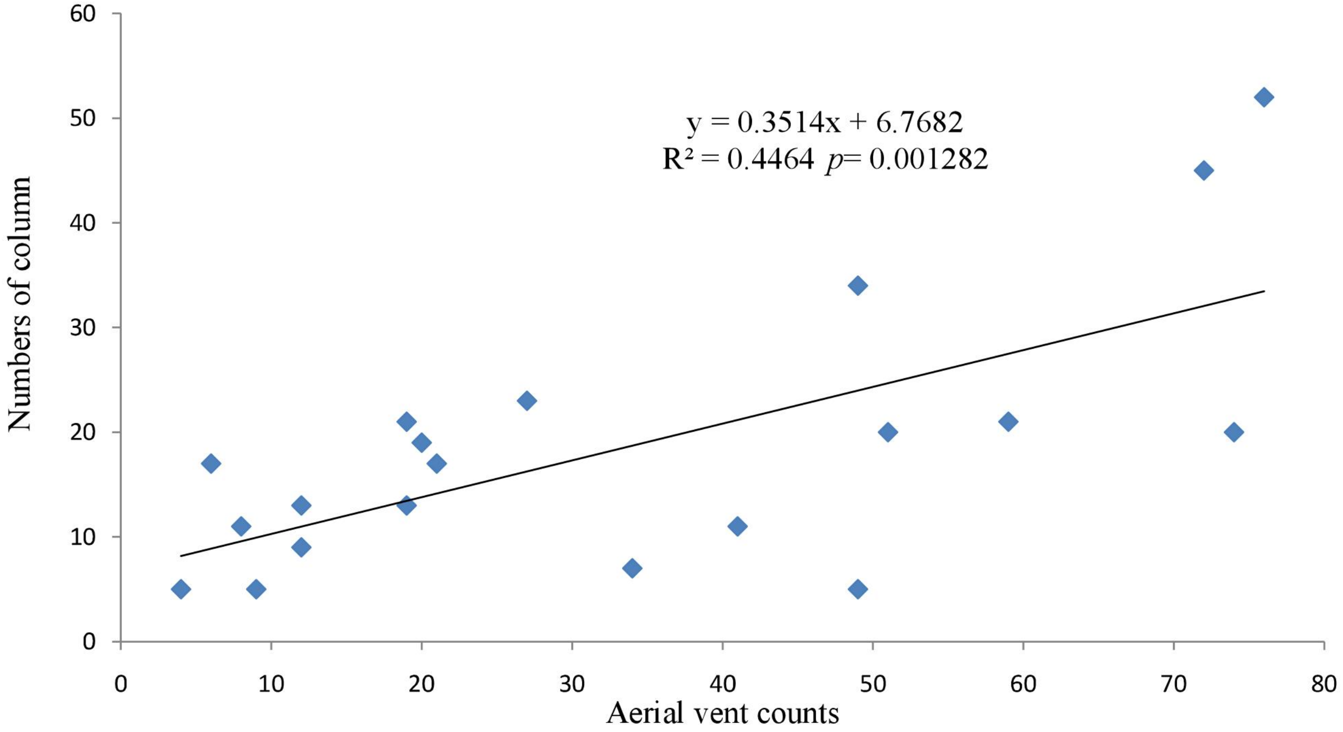

Figure 4: Numbers of column correlated against aerial vent counts

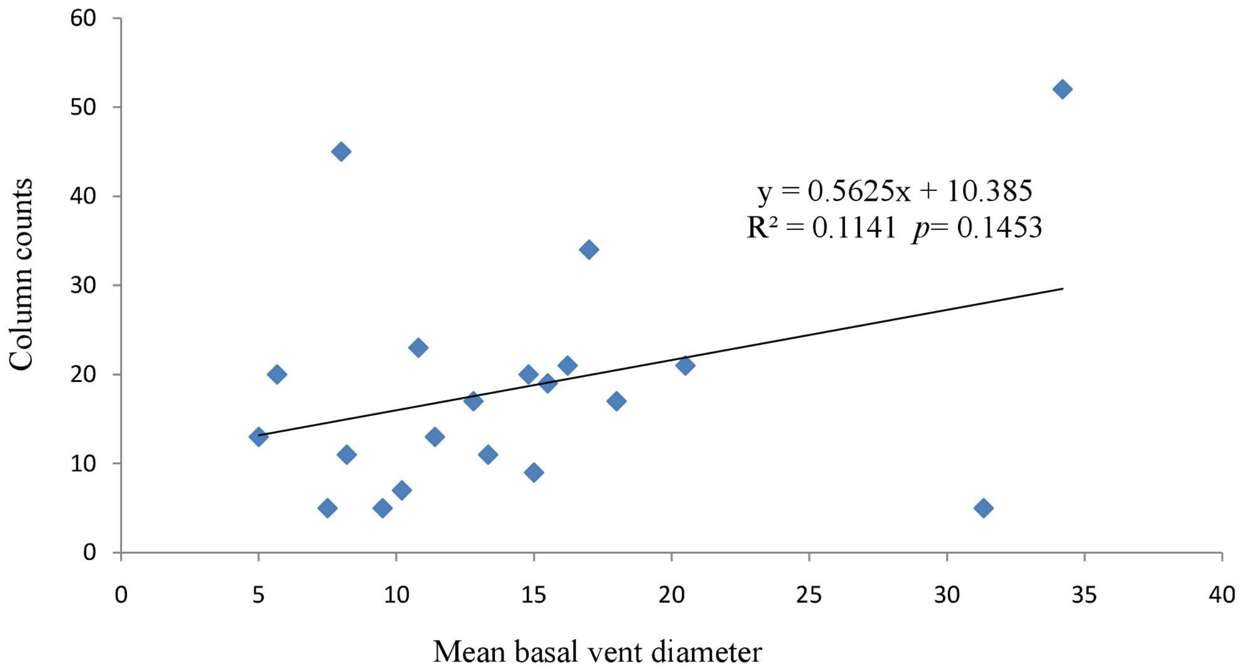

Figure 5: Column counts correlated against average basal vent diameter.

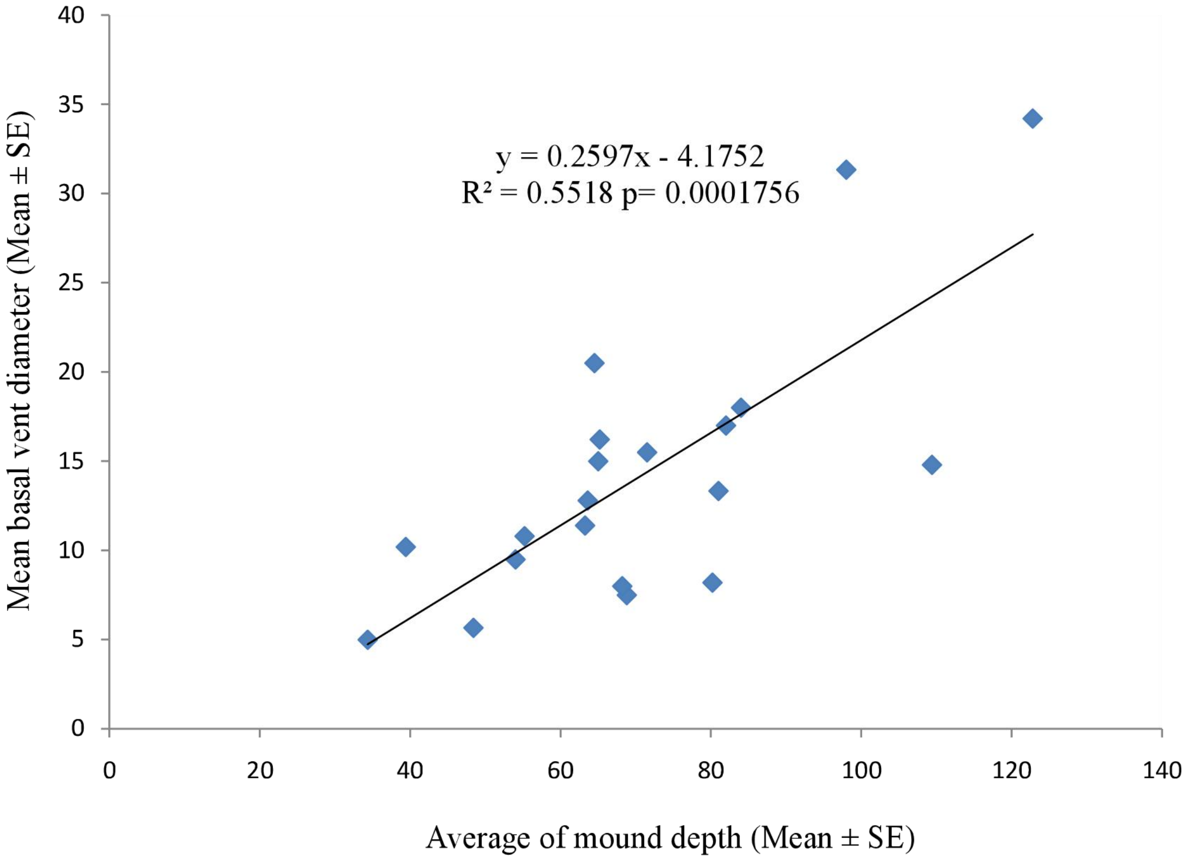

Figure 6: Average basal vent diameter correlated against mound mean depth.

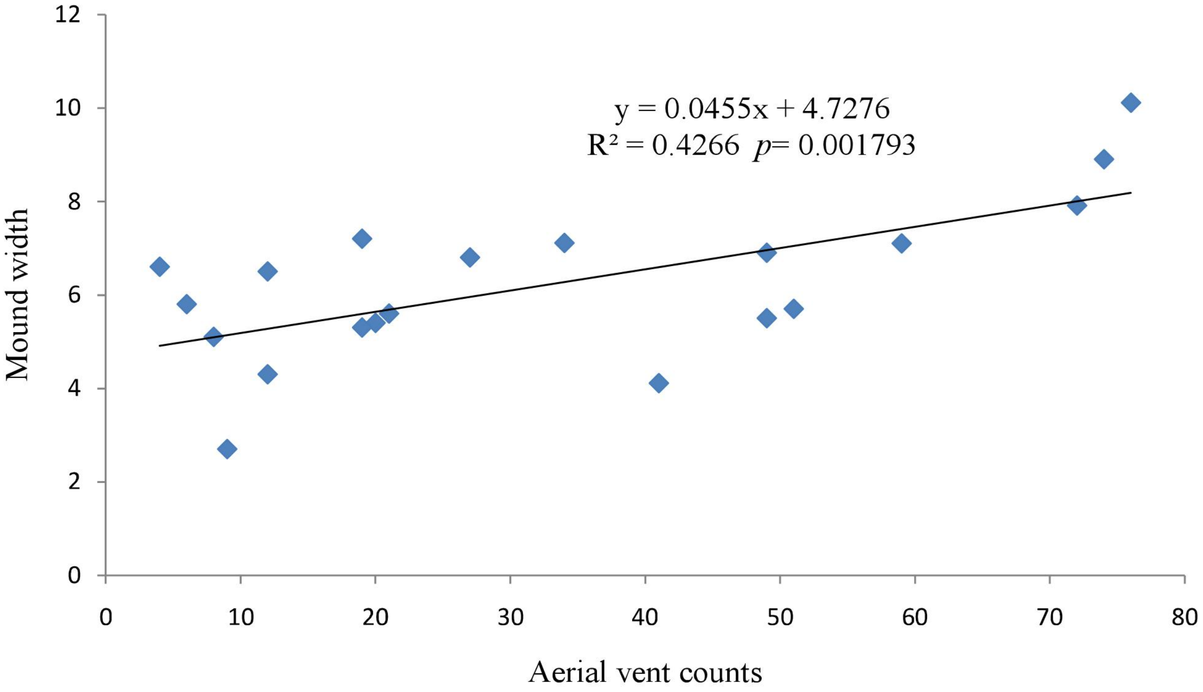

Figure 7: Mound width correlated against aerial vent counts.

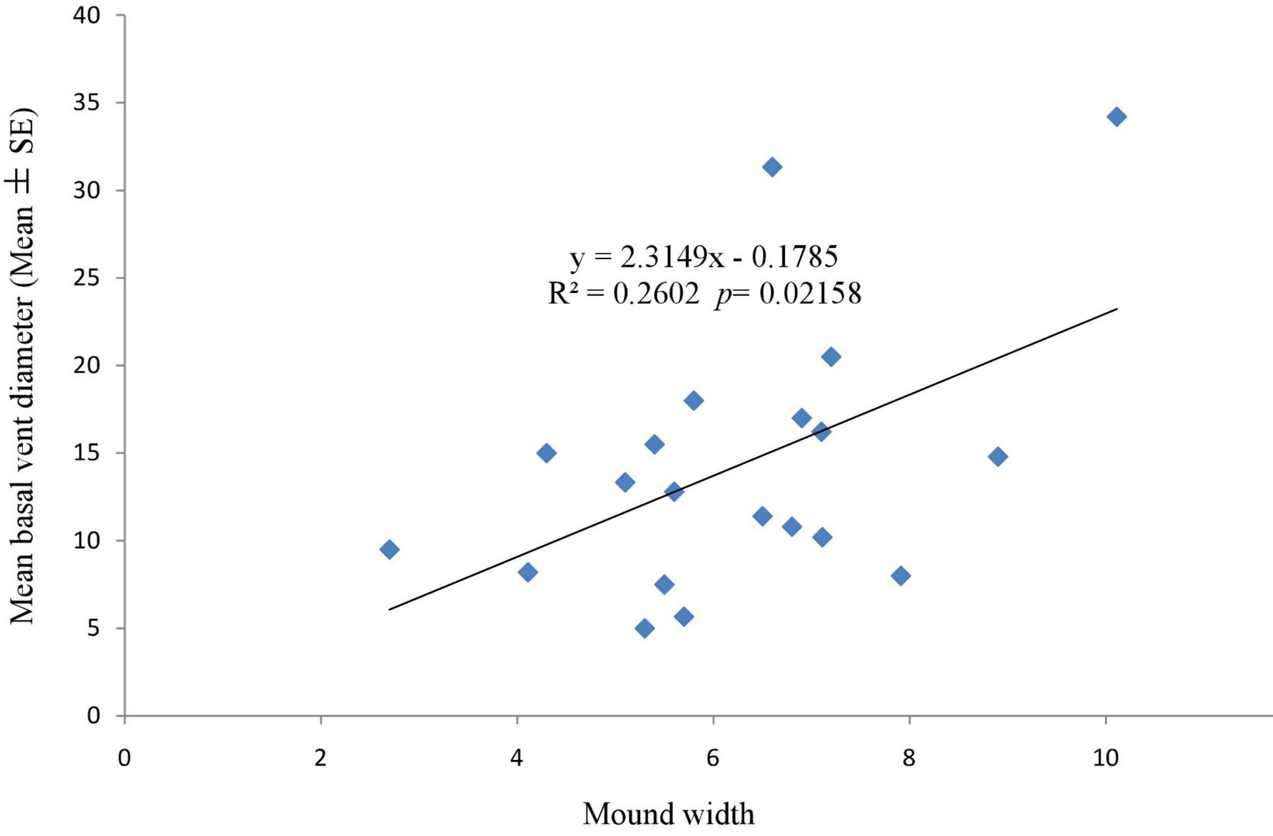

Figure 8: Average of basal vent diameter correlated against mound width

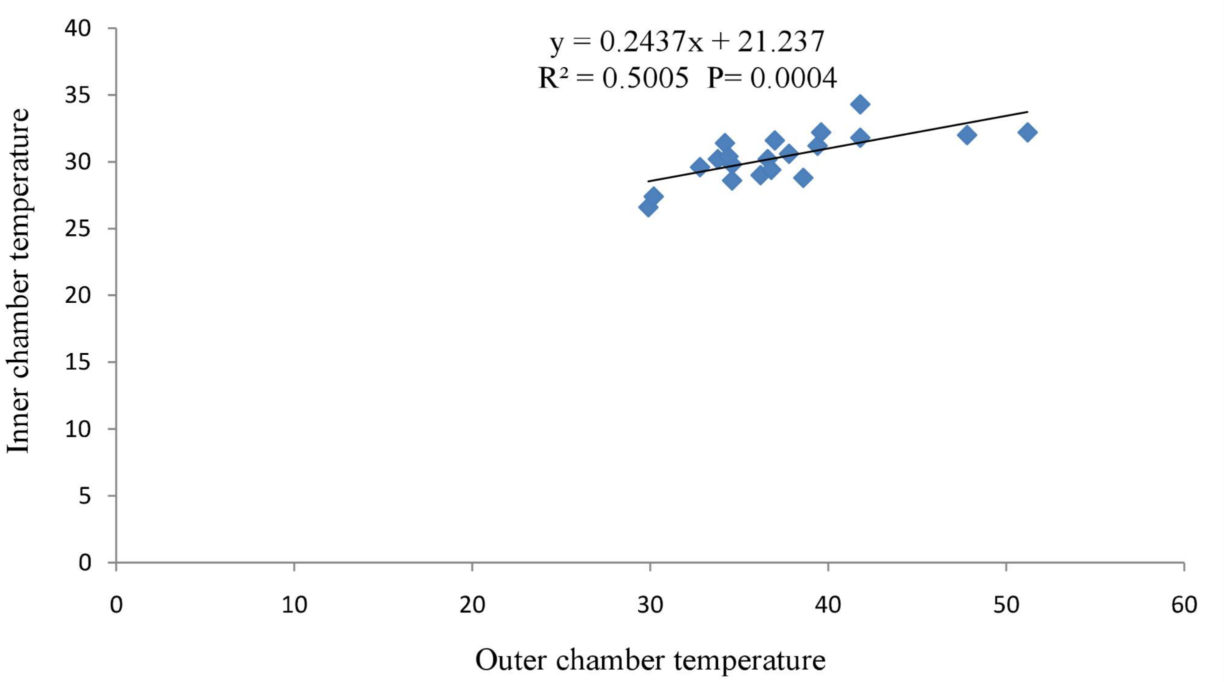

Figure 9: Inner chamber temperature correlated against outer chamber temperature.

CHAPTER FIVE DISCUSSION

Termite Mounds are a good example of thermoregulated structures. however studies has shown that there is no fixed thermoregulatory mechanism in this Mound (Luscher, 1961). Here, we made a count of the aerial vents and correlated them to the mound height, column count, basal vent count, width, perimeter and estimate height of neighbouring vegetation. This is aimed at accessing the relationships between this structures and their role in mound thermodynamics. The correlation coefficient showed that the aerial vent count has a strong significant relationship with the basal vent count which suggests that an increase in the numbers of basal vent also result in an increase in the aerial vent count. This prediction is in line with the research performed where large mound in the palm plantation has high numbers of basal vent and aerial vent. The relationship between the aerial vent count and mound height indicated that *M.bellicosus* creates more vents for airflow in relation to an increase in mound size. As the width of a termitarium increases, *M.bellicosus* tend to create more open chambers and column for ventilation which conforms to the reports of (Bignell *et al*., 2011 and Nikita *et al*., 2020). A previous result stated that enormous mound has more ventilatory structures that are large in size compared to small mound (Ristol *et al*., 2019). In this current observation, termite mounds combine geometry, columns, size and porosity as a strategy for harnessing temperature for ventilation within the mound (Hunter et al., 2015). This current study did not show any relationship between the aerial vent count and the mean depth of the mound. The size of the mound (perimeter) was associated with the aerial vent counts unlike the width of the mound.

The basal vent diameter was similarly correlated with depth of the mound suggesting that the wider the basal vent, the deeper the termitarium. The mound basal vent diameter also had a moderate relationship with the mound width indicating that the basal vent diameter account less to the mound width. This current observation also suggest that the mound width is more involved in mound stability and tensile strength than the basal vent diameter that act as a ventilator structure and a determinant for species invasion. This observation is true when compared to the findings of (Cristaldo *et al*., 2012) who stated that termite mound are a refugee camp for small animal seeking thermoregulation. The mean basal vent diameter and aerial vents count of a mound has no relationship with the vegetation cover around them. Termite mound superstructure is a stronger determinant of internal mound temperature and stability compared to the vegetation cover around them. The basal vent diameter of a termitarium does not increase in size with a corresponding increase in mound superstructure. The overall size of a mound (perimeter) is not a deterministic factor in assessing the size of basal vent within a termitarium. Also, this result suggests that the respiratory functions of a mound column are not affected by the size of the basal vent. This current observations conforms with a previous result which stated that; neither the perimeter nor the height can predict the ventilatory and thermodynamic strategy of a mound (Risto *et al*., 2019)

The results of temperature correlation within and outside the mound showed that there is a positive relationship between them. The external temperature determines about half the internal temperature regulation strategy within a mound. Hence, temperature of a mound environment plays a deterministic role in assessing the internal temperature of mounds. This mutual relationship between internal and external temperature drives conventional current and gaseous exchange between the mound and its environment. Hence, the structural characteristic of a mound is a combine effect of environmental conditions resulting in a thermally regulated medium for these termites (Tadeu *et al*., 2020).

The results from this study indicates that not all mound structural parameters (like perimeter) are related to its ventilatory structures. However, the temperature of a mound environment jointly works together with the internal mound temperature to create a microclimate for these social insect seeking thermoregulation. The temperatures within and outside the mound corresponds to this ventilatory structures which in turn are significantly related to some structural parameters like the height, mean depth, and width..

Conclusively, it will be adequate to say that the size of a mound which is determined by the height, width and mean depth are related to its ventilatory structures which in line with temperature are typical strategies for thermoregulation within a mound. Hence, enormous mounds are likely to be more efficient in thermoregulation than a small mound.

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