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Original Research Paper

Structural Variation in the Underground Nest Architecture of *Camponotus compressus*

Dr. Vivek Mohan Agarwal[1*], Sant Kumar Khandekar[2], Bhagwati Sahu[3], Manisha Dehari[4]

[1]Assistant Professor, Department of Zoology, Govt. College Barpali-Korba, Chhattisgarh, India.
Email: vivekmohanagarwal@gmail.com
ORCID: https://orcid.org/0009-0006-1987-6119

[2]Assistant Professor, Department of Zoology, Govt. Naveen College Pali-Korba (C.G.)
Email: skkhandekar1971@gmail.com,
ORCID: https://orcid.org/0009-0008-3341-0344

[3]Research Scholar, Department of Zoology, C.M. Dubey PG. College Bilaspur, India.
Email: bsbhagwatisahu777@gmail.com.
ORCID : https://orcid.org/0009-0004-9529-5151

[4]Research Scholar, Department of Zoology, Govt. Bilasa Girls PG. College Bilaspur, India.
Email: deharimanisha54@gmail.com
ORCID: https://orcid.org/0009-0007-0943-3944

Corresponding Author : Dr. Vivek Mohan Agarwal
Email id : vivekmohanagarwal@gmail.com

Abstract

Ant nests are dynamic structures that provide shelter and spatial organization for colony activities. In subterranean ants, tunnels and chambers are produced through collective excavation and may vary among colonies and environmental conditions. The present study examined structural variation in underground nests of *Camponotus compressus* using quantitative measurements of tunnels, chambers, nest depth, external circumference, and total tunnel length. Eight apparently abandoned underground nests were examined. The number of tunnels ranged from 7 to 14, while the number of chambers ranged from 5 to 11. Nest depth varied from 9.3 to 17.9 cm, external circumference from 10.5 to 22.7 cm, and total tunnel length from 78.9 to 125.6 cm. A total of 75 tunnels and 57 chambers were recorded. Tunnel width ranged from 0.91 to 5.1 cm, while chamber length and width ranged from 1.1 to 9.3 cm and 1.6 to 8.1 cm, respectively. A significant negative relationship was observed between nest circumference and chamber diameter ($r = -0.735$, $p = 0.038$; $R^2 = 0.540$). Regression analysis also showed a strong positive relationship between the number of tunnels and number of chambers ($r = 0.825$, $R^2 = 0.681$, $p = 0.012$), whereas the relationship between nest circumference and total tunnel length was positive but not statistically significant ($r = 0.655$, $R^2 = 0.430$, $p = 0.078$). The observed variation indicates that underground nest architecture is multidimensional and cannot be adequately represented by nest depth or tunnel number alone. Because only eight apparently abandoned nests were examined, the findings should be regarded as preliminary and should be validated using larger samples and direct measurements of colony and environmental variables.

Keywords: *Camponotus compressus*; nest architecture; tunnel; chamber; colony development; formicidae; underground nest

Introduction

Ant colonies are highly organized social systems in which the nest provides physical protection as well as a spatial framework for collective activities. In subterranean ants, excavation produces networks of tunnels and chambers that facilitate movement, brood care, protection and other colony functions. Consequently, nest architecture may be considered an important component of colony organization rather than simply an empty physical cavity (Yang et al., 2022; Wills & Landis, 2018).

Ant nest architecture varies considerably among species and habitats. Differences may occur in nest depth, tunnel dimensions, chamber number, chamber shape and connectivity. These characteristics can influence the internal environment of colonies and may contribute to ventilation, temperature regulation and movement within the nest (Tschinkel, 2004; Forti et al., 2007; Moreira et al., 2004a, 2004b). Quantitative studies of subterranean ant nests have demonstrated that nest structure can vary substantially even among colonies belonging to the same species. For example, *Camponotus socius* constructs nests consisting of

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descending shafts and horizontal chambers, with nest size and chamber area related to the number of workers in the colony (Tschinkel, 2005).

Nest construction is a collective activity. Individual workers excavate and transport soil, but the resulting architecture emerges from the combined actions of numerous workers. Consequently, variation in nest structure may arise from colony size, worker composition, developmental condition and environmental factors (Wilson et al., 2021; Jesovnik et al., 2013; Solomon et al., 2011). Recent research has increasingly shifted from merely describing nest morphology toward investigating the behavioural processes that generate architectural patterns.

Foraging behaviour may contribute to nest architectural variation. A cross-species study demonstrated an association between foraging behaviour and nest architecture, suggesting that the structure of a nest can be related to how colonies interact with resources and their external environment (O'Fallon et al., 2023). Ant nests can also influence surrounding soil properties and vegetation, highlighting their broader ecological effects (Cammeraat et al., 2002; De Almeida et al., 2020; Bieber et al., 2011).

Environmental conditions can also influence excavation. Temperature, moisture and substrate properties may constrain the location and dimensions of tunnels and chambers. Experimental evidence has shown that ant nest architecture can respond plastically to temperature and can also exhibit patterns consistent with local adaptation (Sankovitz & Purcell, 2021). Nest structure is also associated with thermoregulation and ventilation in social insects (Jones & Oldroyd, 2006; Korb, 2003).

Recent research has provided an important new perspective on the relationship between colony biology and nest architecture. Rajendran et al. (2026), working with *Camponotus fellah*, experimentally demonstrated that colony demographic composition and worker age influence excavation behaviour. These findings indicate that nest architecture may partly reflect the demographic organization of a colony.

The genus *Camponotus* is particularly appropriate for studying these relationships because its species construct diverse subterranean nests. Earlier quantitative research on *Camponotus socius* demonstrated considerable variation in nest depth, chamber number and nest volume and showed positive relationships between nest dimensions and worker number.

Quantitative information on the underground nest architecture of *C. compressus* in India remains relatively limited. Previous work has described the nest-building capabilities of C. compressus (Wilson et al., 2021), while quantitative studies of other ants have documented variation in tunnel, chamber and nest dimensions (Tschinkel, 2004; Forti et al., 2007; Moreira et al., 2004a, 2004b). The available study underlying the present work examined underground nests using cement casting and documented tunnel and chamber dimensions, nest depth and orientation.

The present study was therefore undertaken to characterize the major architectural components of underground *Camponotus compressus* nests, quantify variation in the number and dimensions of tunnels and chambers among individual nests, examine relationships between tunnel and chamber dimensions, document directional variation in tunnel development, and evaluate the observed architectural variation in the context of colony development and environmental influences.

Materials and Methods

Study organism and study area

The investigated ants were identified as *Camponotus compressus* (Hymenoptera: Formicidae). A total of eight apparently abandoned underground nests were examined in an agroecosystem associated with okra (*Abelmoschus esculentus*) cultivation. The study was conducted from November 2025 to April 2026 at Sendri, Bilaspur district, Chhattisgarh, India.

Nest casting and excavation

Abandoned nest cavities of *Camponotus compressus* were examined using a casting and excavation technique adapted from established methods for characterizing subterranean ant nest architecture (Tschinkel, 2005; Cerquera & Tschinkel, 2010). After confirming the absence of worker activity at the nest entrance, the entrance was carefully cleaned. Approximately 3 kg of white Portland cement mixed with 10 L of clean water was prepared and introduced gradually into each nest cavity through a funnel fitted at the nest entrance. The slurry was allowed to flow through the tunnel system under gravity, with care taken to minimize spillage. The casting material was allowed to harden for approximately 24 h. The surrounding soil was then carefully removed manually to expose the cast of tunnels, shafts, and chambers. Recovered casts were cleaned, numbered, measured, and documented to characterize the three-dimensional architecture of the abandoned nests. A flexible measuring tape and digital Vernier caliper were used for measurements. Species-level identification was made with the aid of a stereozoom trinocular microscope using the taxonomic literature cited in this study, including Hölldobler and Wilson (1990) and Bolton (1994).

Statistical analysis

Architectural characteristics were summarized using range, mean, and standard deviation (SD). Pearson's correlation coefficient (r) was used to examine the relationships between nest circumference and the measured architectural variables. Simple linear regression was used for selected relationships among nest architectural variables, and the coefficient of determination (R^2), p-value, and F-statistic were reported. Because only eight nests (n = 8) were examined, the analyses were considered exploratory, and correlation and regression coefficients were interpreted as measures of association rather than evidence of causation.

Results

Considerable variation was observed in the structural characteristics of the eight nests (Table 1). Nest depth ranged from 9.3 to 17.9 cm, with a mean of 13.9 ± 3.0 cm, while nest circumference ranged from 10.5 to 22.7 cm, with a mean of 14.9 ± 3.9 cm (Table 2). Nest IV was the deepest nest (17.9 cm), whereas Nest V was the shallowest (9.3 cm). Nest II had the greatest circumference (22.7 cm), despite having only eight tunnels and six chambers.

The number of tunnels varied from 7 to 14, with a mean of 9.4 ± 2.4, whereas the number of chambers ranged from 5 to 11, with a mean of 7.1 ± 2.0. Nest I contained the highest number of tunnels (14) and chambers (11). It also recorded the greatest total tunnel length (125.6 cm). In contrast, Nest VI had the fewest tunnels (7), but its total tunnel length was relatively high (109.7 cm), indicating that the number of tunnels did not necessarily correspond directly to total tunnel length.

Total tunnel length varied from 78.9 to 125.6 cm, with a mean of 96.9 ± 15.5 cm. The greatest total tunnel length was recorded in Nest I, followed by Nest II (111.7 cm) and Nest VI (109.7 cm). These observations indicate substantial differences in the internal tunnel arrangement among nests.

Table 1. Characteristics of the nests studied (n = 8)

Nest	No. of tunnels	No. of chambers	Depth of nest (cm)	Circumference of nests (cm)	Total tunnel length (cm)
I	14	11	13.4	16.4	125.6
II	8	6	10.9	22.7	111.7
III	11	7	13.7	12.3	78.9
IV	9	5	17.9	10.5	89.5
V	8	6	9.3	14.8	85.7
VI	7	6	16.9	16.8	109.7
VII	8	7	15.2	14.4	84.5
VIII	10	9	14.3	11.5	89.9

Further variation was observed in tunnel and chamber dimensions (Table 2). Tunnel width ranged from 0.91 to 5.10 cm (2.4 ± 1.6 cm), while chamber length and width ranged from 1.1–9.3 cm (5.2 ± 2.9 cm) and 1.6–8.1 cm (5.1 ± 2.3 cm), respectively. Total chamber area ranged from 3.52 to 58.59 cm², with a mean of 27.41 ± 18.64 cm². Chamber diameter ranged from 0.9 to 3.2 cm, with a mean of 2.1 ± 0.9 cm.

Correlation analysis showed that nest circumference had a moderate positive relationship with total tunnel length ($r = 0.655$, $p = 0.078$), although this relationship was not statistically significant. Nest circumference showed weak to moderate negative relationships with nest depth ($r = -0.479$, $p = 0.230$), tunnel number ($r = -0.199$, $p = 0.637$), tunnel width ($r = -0.455$, $p = 0.257$), number of chambers ($r = -0.031$, $p = 0.943$), and chamber width ($r = -0.612$, $p = 0.107$); none were statistically significant. Similarly, chamber length showed a very weak relationship with nest circumference ($r = 0.080$, $p = 0.850$), while total chamber area showed a weak positive relationship ($r = 0.270$, $p = 0.518$).

The strongest relationship observed was between nest circumference and chamber diameter, which was negative and statistically significant ($r = -0.735$, $p = 0.038$; $F = 7.069$; $R^2 = 0.540$). This indicates that nests with greater circumference tended to have smaller chamber diameters. Because the sample size was small, this association should be interpreted cautiously.

Table 2. Summary statistics and correlations of nest architectural variables with nest circumference (n = 8)

Variables	Range	Mean ± SD	Correlation (r)	P-value	F
Nest circumference (cm)	10.5 - 22.7	14.9 ± 3.9	—	—	—
Nest depth (cm)	9.3-17.9	13.9 ± 3.0	−0.479	0.230	1.787
No. of tunnels	7-14	9.4 ± 2.4	−0.199	0.637	0.247
Tunnel length (cm)	78.9 – 125.6	96.9 ± 15.5	0.655	0.078	4.519

Tunnel width (cm)	0.91 -5.1	2.4 ± 1.6	−0.455	0.25 7	1.5 69
No. of chambers	5.0- 11	7.1 ± 2.0	−0.031	0.94 3	0.0 06
Chamber length (cm)	1.1- 9.3	5.2 ± 2.9	0.080	0.10 7	0.0 39
Chamber width (cm)	3.52 –	5.1 ± 2.3	−0.612	0.1 07	3.5 90

	58.5 9				
Total chamber area (cm^2)	3.5 2– 58. 59	27. 41 ± 18. 64	−0.735	0.03 8	0.4 70
Chamber diameter (cm)	0.9- 3.2	2.1 ± 0.9	−0.735	0.03 8	7.0 69

Simple linear regression revealed a strong positive relationship between the number of tunnels and number of chambers ($r = 0.825$, $R^2 = 0.681$, $p = 0.012$; $F = 12.87$), indicating that nests with more tunnels generally contained more chambers (Fig. 1).

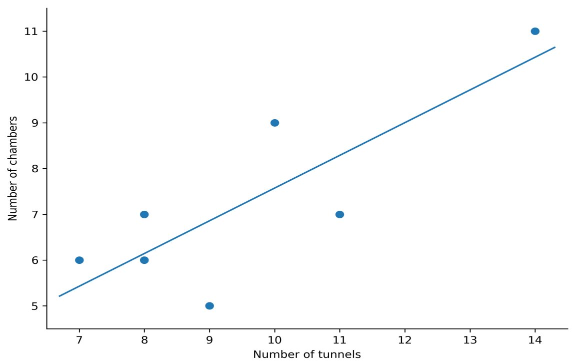

Figure 1. Simple linear regression showing the relationship between number of tunnels and number of chambers in nests of *Camponotus compressus* (n = 8).

Nest circumference showed a moderate positive relationship with total tunnel length ($r = 0.655$, $R^2 = 0.430$, $p = 0.078$; $F = 4.519$). Although the relationship was not statistically significant, the positive trend suggests that nests with greater circumference tended to possess longer tunnel systems (Fig. 2).

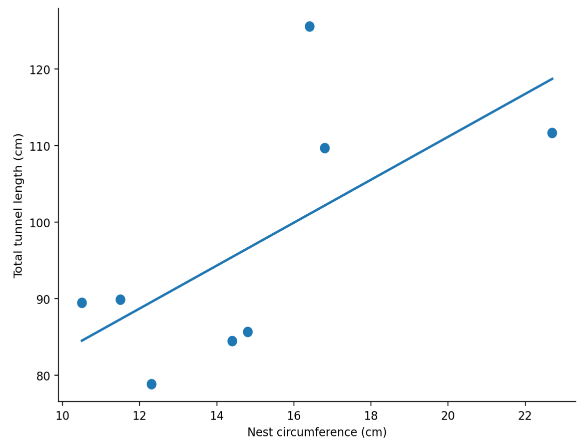

Figure 2. Simple linear regression showing the relationship between nest circumference and total tunnel length in *Camponotus compressus* nests (n = 8).

A significant negative relationship was observed between nest circumference and chamber diameter ($r = -0.735$, $R^2 = 0.540$, $p = 0.038$; $F = 7.069$), indicating that nests with greater circumference tended to have smaller chamber diameters (Fig. 3).

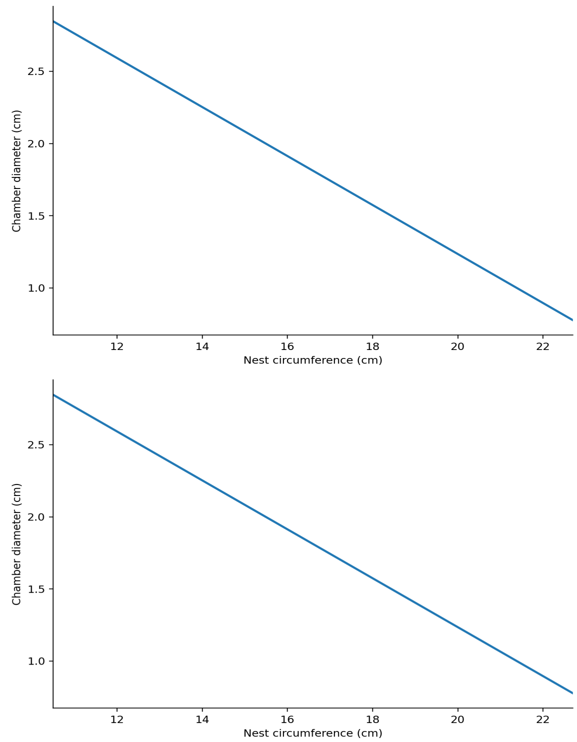

Figure 3. Simple linear regression showing the relationship between nest circumference and chamber diameter in *Camponotus compressus* nests (n = 8).

Discussion

The present study demonstrates considerable variation in the architecture of the studied nests. The differences observed in nest depth, circumference, tunnel number, tunnel length, chamber number, and chamber dimensions indicate that nest structure was not uniform among the eight nests. This variation may reflect differences in colony requirements and the utilization of available underground space; however, these factors were not directly measured in the present study.

Nest I had the highest number of tunnels (14), chambers (11), and total tunnel length (125.6 cm), indicating a relatively extensive internal tunnel network. However, the deepest nest was Nest IV (17.9 cm), while Nest V was the shallowest (9.3 cm). Importantly, Nest IV did not have the highest number of tunnels or chambers. This lack of correspondence between depth and internal complexity suggests that vertical extension of the nest was not necessarily accompanied by greater development of the tunnel–chamber network. Similarly, Nest VI had only seven tunnels but a relatively high total tunnel length of 109.7 cm. Thus, the number of tunnels alone may not adequately represent the extent of the underground tunnel system.

Nest II provides another important example of variation in nest architecture. It had the greatest circumference (22.7 cm), but only eight tunnels and six chambers. Its total tunnel length was nevertheless relatively high (111.7 cm). This suggests that greater external nest circumference does not necessarily result from an increase in the number of tunnels or chambers. Instead, nests may differ in the arrangement, length, and spatial distribution of their internal structures. This interpretation is consistent with studies showing that ant nest architecture can be associated with foraging behaviour and can respond to environmental conditions such as temperature (O’Fallon et al., 2023; Sankovitz & Purcell, 2021).

The correlation analysis further supports this interpretation. The relationship between nest circumference and total tunnel length was positive and relatively strong ($r = 0.655$), although it was not statistically significant ($p = 0.078$). This may indicate a tendency for nests with greater circumference to possess a more extensive tunnel system; however, the relationship should not be considered conclusive because of the small sample size (n = 8). Similarly, the relationships between circumference and tunnel number ($r = -0.199$), chamber number ($r = -0.031$), and tunnel width ($r = -0.455$) were not statistically significant. These findings indicate that external nest dimensions cannot reliably be used as indicators of internal nest complexity.

The most important statistical finding was the significant negative correlation between nest circumference and chamber diameter ($r = -0.735$, $p = 0.038$; $F = 7.069$). This indicates that nests with larger circumferences tended to have smaller chamber diameters. One possible explanation is that nest construction may involve different architectural strategies: some nests may occupy a relatively larger external area while maintaining smaller individual chambers, whereas other nests may have fewer but relatively larger chambers. However, this interpretation should be considered as a possible explanation rather than a demonstrated mechanism, since the present study did not directly examine the behavioural or environmental factors responsible for chamber construction.

The chamber measurements also showed substantial variation. Total chamber area ranged from 3.52 to 58.59 cm², indicating marked differences in chamber size among nests. Nevertheless, total chamber area was not significantly correlated with nest circumference ($r = 0.270$, $p = 0.518$). This further supports the observation that a larger nest perimeter does not necessarily indicate a greater chamber area. Similar variation in internal nest organization has been reported in other ant taxa (Forti et al., 2007; Moreira et al., 2004a, 2004b; Jesovnik et al., 2013; Solomon et al., 2011). Similarly, chamber length showed almost no relationship with circumference ($r = 0.080$, $p = 0.850$).

Overall, the findings suggest that nest architecture should be considered as a combination of several independent but potentially interacting structural components rather than as a single measure of nest size. Tunnel number and total tunnel length describe the extent of the tunnel network, whereas chamber number, chamber diameter, and chamber area describe the internal living or functional spaces. Nest depth and circumference represent different aspects of spatial expansion. The contrasting architecture of Nests I, II, IV, V, and VI demonstrates that these components can vary independently. Similar multidimensional architectural patterns have been documented across diverse ant taxa (Tschinkel, 2004; Forti et al., 2007; Moreira et al., 2004a, 2004b; Lapointe et al., 1998). Recent experimental work on *Camponotus fellah* further indicates that colony demographic composition and worker age can influence excavation behaviour (Rajendran et al., 2026).

Conclusion

The eight examined *Camponotus compressus* nests showed substantial variation in tunnel and chamber architecture. The number of tunnels was positively associated with the number of chambers, whereas nest circumference was significantly and negatively associated with chamber diameter. Other architectural relationships were weak or non-significant, indicating that nest size should not be represented by a single structural measure. Because the sample consisted of only eight apparently abandoned nests, larger studies incorporating colony size, soil properties, moisture, environmental conditions, and nest occupancy are needed to determine the drivers of this architectural variation.

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