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Research Article
Population Survey of Subterranean Termite *Coptotermes curvignathus* (Isoptera: Rhinotermitidae) on Infested Pine Boards

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Abstract

Background and Objective: So far, no scientific papers have reported on the termite population of subterranean termite *Coptotermes curvignathus* especially when they attack the wooden components in the building. This information is crucial for termite control such as system development, specifically capable of non-destructively detecting and predicting a termite population. A study was conducted to determine the termite population on the various volumes of pine boards. **Materials and Methods:** In this study, the exhaustive trapping technique was applied to the termite colonies. Thirty boards, infested with termites, were collected, after which the volumes were measured and dismantled carefully to determine termite population. A statistical analysis of linear regression is used to analyze the relationship between board volume (x) and termite population (y). **Results:** This survey showed that the board infested by *C. curvignathus* was dominated by termite workers (75.21±6.5101%) compared to termite soldiers (24.79±6.5101%). Based on the numerical analysis, the linear regression model (y = 40.09368+0.55031x) provides an overview of the number of termites present for a feeding test and provides an analysis of the extent to which the design of detection system will be able to predict a termite population. **Conclusion:** This research showed that the larger the board volume, the larger the termite population, since the larger board has an abundance of food sources containing large amounts of cellulose. This cellulose attracts termites to live inside it and also stops the process of further foraging.

Key words: *Coptotermes curvignathus*, caste composition, termite population

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Termites play an essential role in the tropical ecosystem[1]. In their natural habitat, termites are considered as beneficial insects because they can decompose the dead or dying plant materials and, thus are an important part of the nutrient cycle[2]. However, when termites eat wooden building structures and cellulose products, they are considered as pests[2-4]. Drywood termites and subterranean termites are two major termite groups that have the most significant damage impacts worldwide. In Asian regions, Kuswanto *et al.*[5] stated that 70% of damage to wooden buildings is caused by subterranean termites. The global damage caused by these termites was estimated at $32 billion in 2010[6]. Indonesia itself has the endemic species of subterranean termites, i.e., *Coptotermes curvignathus* which is the most aggressive one[7-12]. Rilatupa *et al.*[13] reported that this termite is capable of attacking a high-rise building's construction such as apartments and hotels in Jakarta-Indonesia up to the 33rd floor.

Termite species vary in their basic biology and ecology, including termite population, foraging territories, swarming, feeding, nesting and reproductive behavior. In terms of termite population, many researchers have investigated various natural habitats including forests[14-16], urban trees[17] and silvicultural plantations[18]. Until now, it is widely reported that the study of termite population in various regions has covered various families: Kalotermitidae (*Incitermes* nr. *bequaerti*, *Neotermesmona*, *Glyptotermes satsumensis*, *Glyptotermes fuscus*)[14,19], Rhinotermitidae (*Reticulitermes flaviceps*, *Reticulitermes flapives*, *Reticulitermes virginicus*)[15,19,20] and Termitidae (*Nasutitermes parvonasutus*, *Odontermes formosanus*, *Pericapriter mesnitobei*)[19]. However, to date, no scientific papers have reported on the termite population of subterranean termite *Coptotermes curvignathus*. Therefore, the results of this study will provide critical information regarding its population biology. In addition, according to the literature review, researchers only focus on surveying the termite population in particular areas of the tree such as the branch or trunk[14,16,18]. Keep in mind that besides termites attacking the tree, they also attack the wooden component on various volumes in the building. In this study, the pine boards in various volumes were used as a representation of the wooden component in the building.

This study is part of a substantial series of research, which is the system development specifically capable of non-destructively detecting and predicting the termite population. As it relates to both the scientific reports[21-23] and the tools available in the market[24,25], so far those are only capable of detecting the presence or absence of termites and have not been able to predict a population size. Basically, the proposed termite detection system is designed based on the board volume to be able to sense the signals generated by termites but each board volume has the different carrying capacity correspond to termite population size. Therefore, the knowledge of termite population biology in various board volumes is the key information that must be disclosed. This what extent the design of the detection system will be able to predict a termite population. Additionally, information can be used to estimate the wood damage rate and the termite control techniques.

MATERIALS AND METHODS

Study location: This survey was completed at the Termite Laboratory, Faculty of Forestry, Bogor Agricultural University, which has a facility for subterranean termite rearing. To keep the laboratory condition as a natural termite habitat, the temperature and humidity of this laboratory were arranged, i.e., 28°C and 89%, respectively. Historically, since 2012, the laboratory has successfully cultivated the subterranean termite *Coptotermes curvignathus* obtained from Yanlappa Experimental Forest, Bogor, Indonesia. In this laboratory, there are six concrete boxes that consist of an actively reared colony of *C. curvignathus* (used as a survey location). The visualization of the concrete box is given in Fig. 1. A brief description is as follows: (a) In composition, each box from bottom to top consists of the brick, tree trunk, soil, sawdust and pine boards, (b) Each box has a dimensional size of 180 (l) × 120 (w) × 130 (h) cm with the edge surrounded by stagnant water to avoid termites moving to another area, (c) To maintain the termite survival, every month the air-drying pine boards were served to the each box. Regarding the population size of the termite colony in each concrete box, so far, it has not been reported yet. However, this colony is always seen attacking the served pine boards aggressively. One way it that can be applied to know its population size is through mark-release-recapture technique[26]. However, this issue is not a concern in this study and that technique is only able to provide predictive value that may exceed the exact of the colony population size. In the end, the primary concern of this study was to survey the termite population size on various volumes of the pine boards, i.e. as many as five pine boards with signs of termite activity in each concrete box were selected as a sample (Fig. 1).

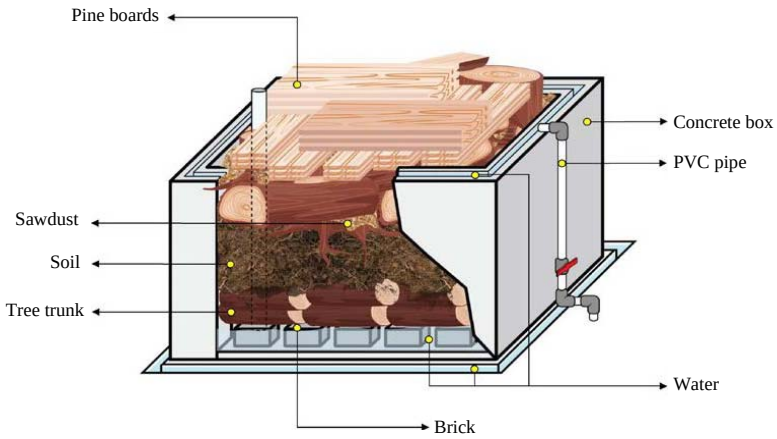

Fig. 1: Visualization of the concrete box for termite cultivation

Assessment of infested boards, population size and caste composition: To estimate the population size, the exhaustive trapping technique given by Thorne *et al.*[27] was applied to this study. This method is appropriate to apply to this investigation as the location of the study is not carried out in the natural habitat of the termite but rather in the laboratory-reared colonies. The advantage of this technique is that the number of termites that are isolated will not overestimate an actual population. Thus, it is conservative and beneficial in providing highly credible minimum estimates of termite population (an assumption only is made that termites are collected from a single food source or from food source(s) in close proximity).

To obtain credible information regarding the population size and caste composition, the termite gallery structure inside the board is dismantled carefully. Furthermore, all termites were sorted by member categories[28]: (1) Soldiers, (2) Worker, (3) Nymph and (4) Alate. The exact counts for each category were made. Equation 1 is used to calculate the caste composition (C_{com}), where, T is member categories and P_{size} is a termite population in each board. In addition, the board volume (V) is defined in Eq. 2:

$$C_{com} = \frac{T}{P_{size}} \times 100\ (\%) \quad (1)$$

$$V = l.w.h. \quad (2)$$

where, l, w and h represent the length, width and height of the board:

Statistical analysis: The core of this research is to analyze the relationship between the board volume and the termite population. To explore this, a linear regression method was performed on XLSTAT ©Addinsoft 1995-2014 (version 2014.5.03). This purpose of this method is to discuss the relationship between independent variable (x, board volume) and dependent variable (y, termite population). This method produces the linear regression model in the form Montgomery *et al.*[29] as shown in Eq. 3:

$$y = \beta_0 + \beta_1 x \quad (3)$$

where, β_0 is the y intercept, β_1 is the slope of the linear regression line. For assessing the overall accuracy of the model, we compute the root mean squared error (RMSE), which is the standard deviation of residuals (error prediction). The coefficient of determination (R^2) is also given in this analysis, if the value of R^2 is close to 1, then both variables (x and y) have very close correlation and the resulting model is more accurate. In addition, the quantile approach is used to identify deeply about the distribution of termite population on each quantile[30]. This approach graphed the termite population relation to the cumulative relative frequency (C_{rf}). Based on the C_{rf} value with the range of 0 to 1, the termite population on each quantile (Q) can be generated, i.e., the minimum (0 C_{rf}), Q_1 (0.25 C_{rf}), Q_2 (0.5 C_{rf}), Q_3(0.75 C_{rf}) and maximum (1 C_{rf}).

RESULTS

A study was conducted to survey the termite population within the 30 pine boards in various volumes. Based on the following parameter (i.e., board volume and termite population), the mathematics model was successfully developed by a linear regression approach to analyze the relationship of both parameters. As can be seen in Fig. 2, linear regression indicates a positive relationship between board volume and termite population in Eq. 4 as follows:

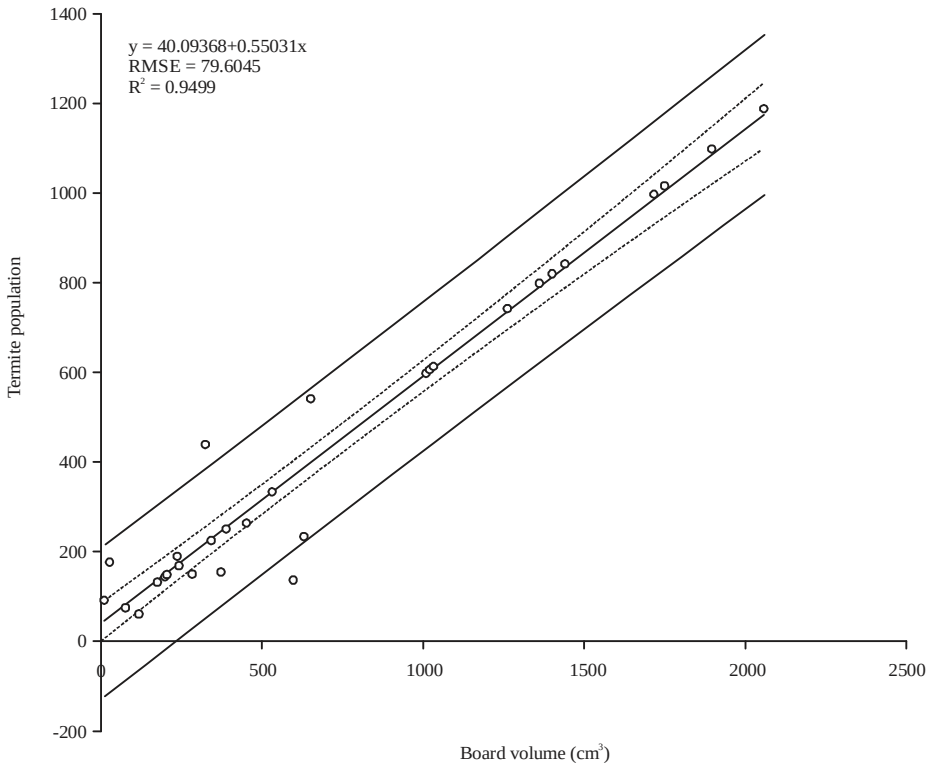

Fig. 2: Fitted relationship between board volume and termite population

$$y = 40.09368+0.55031\ x \quad (4)$$

With a RMSE of 79.6045, explains the error predictions generated from the model. In addition, based on numerical analysis, the board volume and the termite population have a very close correlation, which is indicated by the R^2 value of 0.9499.

In the practical framework, the population size of *C. curvignathus*, which attacks the wooden components in the building can be estimated with the input parameter x (board volume).

For example, if the board volume is 1000 cm^3, then the population size is about 590 individuals (round to nearest decimal, the exact calculation is 590.40). After their population is known, the next step is the termite control technique, especially the spraying method[31], with chemicals such as termiticide. However, the effectiveness of the termiticide dose to the termite population requires further identification. Of course, if this is practiced, it will greatly save the use of termiticide.

Figure 3 showed an overview of the distribution of termite population on each quantile according to cumulative relative frequency. It can be explained that the minimum, Q_1, Q_2, Q_3 and maximum of the termite population are 61, 148, 250, 676 and 1187 individuals, respectively. This survey found only the termite worker and soldier, the other members such as nymph and alate are not found. Therefore, based on the calculation of caste composition in Eq. 1, the subterranean termite *C. curvignathus* has the caste composition of

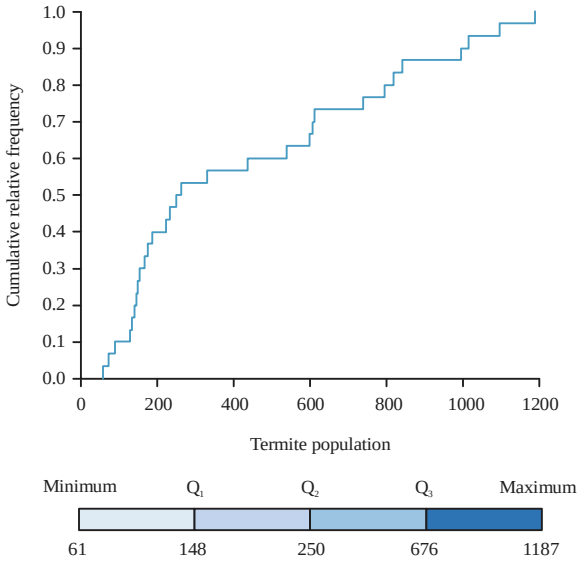

Fig. 3: Distribution of termite population on each quantile

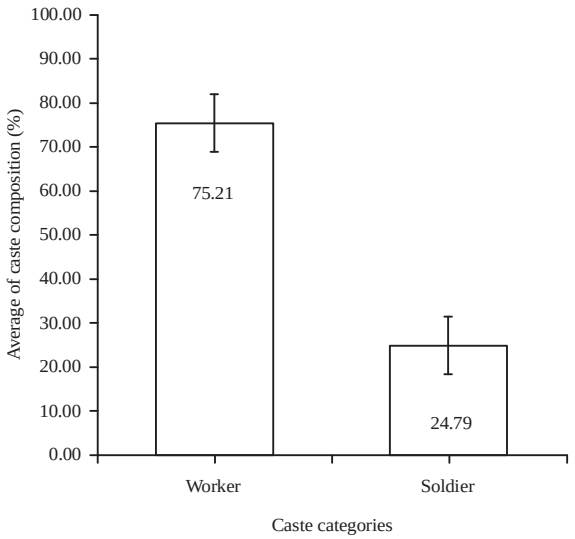

Fig. 4: Caste composition of *C. curvignathus*

75.21±6.5101% for termite worker and 24.79±6.5101% for termite soldier (Fig. 4). The caste proportions clearly show that a colony was dominated by termite workers. This, is in accordance with the statement of Kuswanto *et al*.[5] stated that the workers constituted the largest proportion in the colony. The excessive number of soldiers will burden the colony, because they have to be fed by workers from mouth-to-mouth or anus-to-mouth, this is known as trophallaxis[32]. If the number of soldiers is excessive, then this might break down the social structure of a colony and could be used to control termite population.

Once the termite population has been identified through the board volume, then the range of termite caste composition can also be estimated. For example, if the termite population attacking board is 590 individuals, refer to the caste composition results in Fig. 4, then there are at least 444±38 termite workers and 146±38 termite soldiers. The predicted results of that caste composition both termite workers and soldiers are round to nearest decimal. Information on the composition of this caste is very useful for standardizing wood and wood products' resistance test against wood destroying pest, *C. curvignathus*.

DISCUSSION

One of the main goals of this experiment was to survey the termite population on various volumes of the pine boards. The results showed that the larger the board volume, the larger the termite population. The selection of larger board by subterranean termites was also observed by Wang and Powell in a forest in Mississippi[33], Nobre *et al*.[18] in a managed silvicultural plantation and Manzoor *et al*.[16] in a forest in Pakistan. Their findings supported the results of this survey that the larger board tends to be more attractive for termites to feed on. Lenz *et al*.[34] and Togola *et al*.[35] explained that where there is a larger board, then it has an abundance of food sources containing large amounts of cellulose. This cellulose attracts termites to live inside it and also stop the process of further foraging. In addition, according to Kamaluddin *et al*.[36], their classic theory of the termite ecology, explains that the subterranean termite tends to prefer moist board and is mainly associated with board partially decomposed by fungi. The moisture availability is crucial to subterranean termites as they are thin-skinned insects that quickly dry up when exposed to the wind and strong sunshine, consequently, they require a constant supply of moisture[18]. Also, generally, the termites will follow the direction of board fibers (longitudinal) in foraging and excavating to build their gallery system[37].

This study confirmed that the termite caste attacking the board consists of termite workers and soldiers only. The other members such as nymph and alate were not found. This study contradicts with previous research conducted by Manzoor *et al*.[16] and Jones *et al*.[14], where they have surveyed the termite populations in their natural habitat and found the members such as nymph and alate. The difference in the survey location is considered as a reason why in this study did not see those members. In addition, regarding termite ecology, both termite workers and soldiers are foraging population that have a role in finding food sources. Keep in mind that a termite colony has three castes system based on their specific roles[5,38,39]. The castes include: (1) The reproductive termite or sexual adults, consists of king and queen that are tasked to inseminate and to spawn respectively, (2) The termite worker, being a member of the colony that has the primary task of finding food sources, (3) The termite soldier, whose role is to protect the colony, both workers and reproductive counterparts, from their natural enemy or other predators. This provides a clear reason why when searching for food sources, the colony represents only the workers and soldiers because it appropriates their role. In addition, common subterranean termite attacks the board to forage food sources only, they do not make the board a nest location. These food is brought to their nest in the soil, where the termite workers keep a certain liquid food and serve it to the other colony members such as reproductive caste, soldier, nymph and alate. Compared with the drywood termite, the subterranean termite such as *C. curvignathus* has a larger population when they explore for food. Therefore, overall the drywood termite is less economically important and has a

lower attack than a subterranean termite. In various regions of the world such as north America, Malaysia, China and Singapore, the same impact is seen where the subterranean termite in the genera of *Coptotermes* is the most economically important species[5,40].

As explained in introduction section, the results of this survey are basic information to supplement following research, i.e., the development of termite detection system, which is able to detect and predict precisely a termite population. In the previous study reported by Nanda *et al.*[21], they have successfully developed a termite detection system but it was only able to detect the presence or absence of termites. The main finding of this study is the linear regression model in Eq. 4, this is a crucial property which provides an overview of the number of termites for feeding test and determine the extent of the design of detection system to predict a termite population. For example, in practical application, the termite detection system is designed for sensing a termite signal on 10×10 cm board surface area and a depth of 4 cm, so its volume is 400 cm^3. Based on Eq. 4, this board is capable of being inhabited by at least 260 individuals (round to nearest decimal, the exact calculation is 260.22). This value estimate is significant as a reference to the minimum or maximum boundary of the termite population to be detected. If the maximum boundary is set to 260 individuals, then the feeding test will be performed on various populations such as 20, 40, 60, ..., 260 individuals and acquire the termite signals such as acoustic emission, temperature, moisture content and so on. Through a combination of distinctive termite signal and machine learning algorithms such as discriminant analysis, support vector machine, artificial neural network and deep learning[41-44], the system will able to predict precisely the termite population. Also, hopefully, the results of this investigation will attract future studies that involve subterranean termite in foraging and excavating behaviors as well as novel methods and techniques that will lead to more effective and efficient integrated pest management.

CONCLUSION

This research revealed the critical information regarding the termite population of *C. curvignathus* on various volumes of the pine boards. The results showed that the larger the board volume, the larger the termite population, since the larger board has an abundance of food sources containing large amounts of cellulose. This cellulose attracts termites to live inside it and also stops the process of further foraging. Also, this survey showed that the board infested by *C. curvignathus* was dominated by termite workers (75.21±6.5101%) compared to termite soldiers (24.79±6.5101%). The linear regression model (y = 40.09368+0.55031x) is an important property for developing the termite detection system, this models an overview of the number of termites for a feeding test and a perspective of what extent the design of detection system will be able to predict a termite population.

SIGNIFICANCE STATEMENT

The larger the board volume, the larger the termite population of *C. curvignathus*, since the larger board has an abundance of food sources containing large amounts of cellulose. The main finding of this study, i.e., the linear regression model (y =40.09368+0.55031x), will help the researchers for developing the termite detection population within board.

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REFERENCES

1. Osipitan, A.A. and A.E. Oseyemi, 2012. Evaluation of the bio-insecticidal potential of some tropical plant extracts against termite (Termitidae:Isoptera) in Ogun State, Nigeria. J. Entomol., 9: 257-265.
2. Bong, C.F.J., P.J.H. King, K.H. Ong and N.M. Mahadi, 2012. Termites assemblages in oil palm plantation in Sarawak, Malaysia. J. Entomol., 9: 68-78.
3. Peterson, C., T.L. Wagner, J.E. Mulrooney and T.G. Shelton, 2006. Subterranean Termites: Their Prevention and Control in Buildings. USDA Forest Service, Wood Products Insect Research Unit, USA., Pages: 32.
4. Bourmita, Y., A. Cheriti, M.D.O. El Hadj, K. Mahmoudi and N. Belboukhari, 2013. Anti-termitic activity of aqueous extracts from saharan toxic plants against *Anacanthotermes ochraceus*. J. Entomol., 10: 207-213.
5. Kuswanto, E., I. Ahmad and R. Dungani, 2015. Threat of subterranean termites attack on the wooden buildings in Asian countries and their control: A review. Indian J. Entomol., 77: 356-362.

6. Rust, M.K. and N.Y. Su, 2012. Managing social insects of urban importance. Annu. Rev. Entomol., 57: 355-375.
7. Nandika, D., Y. Rismayadi and F. Diba, 2015. [Termite: Biology and its Control]. 2nd Edn., Universitas Muhammadiyah Surakarta, Surakarta, Pages: 125-139.
8. Arinana, I. Philippines, Y. Koesmaryono, D. Nandika and A. Rauf *et al*., 2016. *Coptotermes curvignathus* holmgren (Isoptera: Rhinotermitidae) capability to maintain the temperature inside its nests. J. Entomol., 13: 199-202.
9. Arinana, A., R. Aldina, D. Nandika, A. Rauf, I.S. Harahap, I.M. Sumertajaya, E.T. Bahtiar, 2016. Termite diversity in urban landscape, South Jakarta, Indonesia. Insects, 7: 20-20.
10. Haneda, N.F., I.Y. Retmadhona, D. Nandika and Arinana, 2017. Biodiversity of subterranean termites on the *Acacia crassicarpa* plantation. Biodiversitas, 18: 1657-1662.
11. Nanda, M.A., K.B. Seminar and D. Nandika, 2017. Characteristics of acoustic emission for subterranean termite detection in wood. J. Tek. Pert., 5: 227-234.
12. Almeida, M.L.D.S., A.S. Oliveira, G.D.S. Carvalho, L.S. da Silva, L.B. Silva, E.C.B. dos Santos and F.E. Casarin, 2016. Toxicity of croton urucurana against the subterranean termite *Heterotermes sulcatus* (Isoptera: Rhinotermitidae). J. Entomol., 13: 48-54.
13. Rilatupa, J., S. Surjokusumo, Y. Sudohadi and N. Nugroho, 2007. [Characterizations of termite's attack and their assessing in the condition index of high-rise building's construction]. Forum Pasca, 30: 333-345.
14. Jones, S.C., C.A. Nalepa, E.A. McMahan and J.A. Torres, 1995. Survey and ecological studies of the termites (Isoptera: Kalotermitidae) of Mona Island. Florida Entomol., 78: 305-313.
15. Howard, R.W., S.C. Jones, J.K. Mauldin and R.H. Beal, 1982. Abundance, distribution and colony size estimates for *Reticulitermes* spp. (Isoptera: Rhinotermitidae) in Southern Mississippi. Environ. Entomol., 11: 1290-1293.
16. Manzoor, F., S.M.A. Rahim, B.A. Shiday, S. Malik, B. Habibpour, J.R.J. French and F. Jabeen, 2010. Survey of termites in forests of Punjab: Pakistan. Afr. J. Environ. Sci. Technol., 4: 790-796.
17. Azam, I., M.K. Sarwar, I. Waheed, I. Nadia and A. Fareeha, 2015. Studies on population density and diversity of termites of district Gujranwala, Pakistan. J. Entomol. Zool. Stud., 3: 160-163.
18. Nobre, T., L. Nunes and D.E. Bignell, 2009. Survey of subterranean termites (Isoptera: Rhinotermitidae) in a managed silvicultural plantation in Portugal, using a line-intersection method (LIS). Bull. Entomol. Res., 99: 11-21.
19. Li, H.F., J.S. Lin, Y.C. Lan, K.J.C. Pei and N.Y. Su, 2011. Survey of the termites (Isoptera: Kalotermitidae, Rhinotermitidae, Termitidae) in a Formosan pangolin habitat. Florida Entomol., 94: 534-538.
20. Long, C.E., B.L. Thorne and N.L. Breisch, 2003. Termite colony ontogeny: A long-term assessment of reproductive lifespan, caste ratios and colony size in *Reticulitermes flavipes* (Isoptera: Rhinotermitidae). Bull. Entomol. Res., 93: 439-445.
21. Nanda, M.A., K.B. Seminar, D. Nandika and A. Maddu, 2018. A comparison study of kernel functions in the support vector machine and its application for termite detection. Information, Vol. 9. 10.3390/info9010005.
22. Sutherland, A.M., R.L. Tabuchi, S. Moore and V.R. Lewis, 2014. Borescope-aided inspection may be useful in some drywood termite detection situations. Forest Prod. J., 64: 304-309.
23. Lewis, V.R., A.B. Power and M.I. Haverty, 2004. Surface and subsurface sensor performance in acoustically detecting the western drywood termite in naturally infested boards. For. Prod. J., 54: 57-62.
24. Lewis, V.R., 1997. Alternative control strategies for termites. J. Agric. Entomol., 14: 291-307.
25. Mankin, R.W., D.W. Hagstrum, M.T. Smith, A.L. Roda and M.T.K. Kairo, 2011. Perspective and promise: A century of insect acoustic detection and monitoring. Am. Entomol., 57: 30-44.
26. Habibpour, B., M. Ekhtelat, F. Khocheili and M.S. Mossadegh, 2010. Foraging population and territory estimates for *Microcerotermes diversus* (Isoptera: Termitidae) through mark-release-recapture in Ahwaz (Khouzestan, Iran). J. Econ. Entomol., 103: 2112-2117.
27. Thorne, B.L., E. Russek-Cohen, B.T. Forschler, N.L. Breisch and J.F. Traniello, 1996. Evaluation of mark-release-recapture methods for estimating forager population size of subterranean termite (Isoptera: Rhinotermitidae) colonies. Environ. Entomol., 25: 938-951.
28. Kuswanto, E., I. Ahmad, R.E. Putra and I.S. Harahap, 2015. Two novel volatile compounds as the key for intraspecific colony recognition in *Macrotermes gilvus* (Isoptera: Termitidae). J. Entomol., 12: 87-94.
29. Montgomery, D.C., E.A. Peck and G.G. Vining, 2012. Introduction to Linear Regression Analysis. John Wiley and Sons, New York, Pages: 12-13.
30. Hao, L. and D.Q. Naiman, 2007. Quantile Regression. SAGE, USA., ISBN: 9781412926287, Pages: 7-11.
31. Yii, J.E., C.F.J. Bong, J.H.P. King and K. Jugah, 2016. Feeding preferences of oil palm pest subterranean termite *Coptotermes curvignathus* (Isoptera: Rhinotermitidae). J. Entomol., 13: 1-10.
32. Scheffrahn, R.H., T. Bourguignon, C. Bordereau, R.A. Hernandez-Aguilar and V.M. Oelze *et al*., 2017. White-gutted soldiers: Simplification of the digestive tube for a non-particulate diet in higher old world termites (Isoptera: Termitidae). Insectes Sociaux, 64: 525-533.
33. Wang, C. and J. Powell, 2001. Survey of termites in the delta experimental forest of Mississippi. Florida Entomol., 84: 222-226.
34. Lenz, M., B. Kard, J.K. Mauldin, T.A. Evans, J.L. Etheridge and H. Abbey, 2001. Size of food resource determines brood placement in *Reticulitermes flavipes* (Isoptera: Rhinotermitidae). Sociobiology, 37: 361-362.

35. Togola, A., E.A. Kotoklo, F.E. Nwilene, K. Amevoin, I.A. Glitho, O.E. Oyetunji and P. Kiepe, 2012. Specific diversity and damage of termites on upland rice in Benin. J. Entomol., 9: 352-360.
36. Kamaluddin, N.N., A. Nakagawa-Izumi, S. Nishizawa, A. Fukunaga, S. Doi, T. Yoshimura and S. Horisawa, 2016. Evidence of subterranean termite feeding deterrent produced by brown rot fungus *Fibroporia radiculosa* (Peck) Parmasto 1968 (Polyporales, Fomitopsidaceae). Insects, Vol. 7. 10.3390/insects7030041.
37. Choi, B., S.K. Himmi and T. Yoshimura, 2017. Quantitative observation of the foraging tunnels in Sitka spruce and Japanese cypress caused by the drywood termite *Incisitermes minor* (Hagen) by 2D and 3D X-ray computer tomography (CT). Holzforschung, 71: 535-542.
38. Verma, M., S. Sharma and R. Prasad, 2009. Biological alternatives for termite control: A review. Int. Biodeterior. Biodegrad., 63: 959-972.
39. Femi-Ola, T.O. and E.Y. Aderibigbe, 2009. Effects of seasonal changes on the microflora in the hindgut of wood-eating termites. J. Entomol., 6: 67-71.
40. Wang, C., X. Zhou, S. Li, M. Schwinghammer, E.M. Scharf, G. Buczkowski and G.W. Bennett, 2009. Survey and identification of termites (Isoptera: Rhinotermitidae) in Indiana. Entomol. Soc. Am., 102: 1029-1036.
41. Nanda, M.A., K.B. Seminar, D. Nandika and A. Maddu, 2018. Discriminant analysis as a tool for detecting the acoustic signals of termites *Coptotermes curvignathus* (Isoptera: Rhinotermitidae). Int. J. Technol., 9: 840-851.
42. Nanda, M.A., K.B. Seminar, D. Nandika and A. Maddu, 2018. Time domain features in combination with a support vector machine classifier for constructing the termite detection system. IOP Conf. Ser.: Earth Environ. Sci., Vol. 157. 10.1088/1755-1315/157/1/012037.
43. Faricha, A., M. Suwito, M. Rivai, M.A. Nanda and D. Purwanto, 2018. Design of electronic nose system using gas chromatography principle and surface acoustic wave sensor. Telkomnika, 16: 1458-1467.
44. Kuo, H.F. and A. Faricha, 2016. Artificial neural network for diffraction based overlay measurement. IEEE Access, 4: 7479-7486.