

Termite Occurrence And Damage Assessment In Urban Trees From Different Parks Of Lahore, Punjab, Pakistan

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Abstract

Termite infestation is one of the fundamental problems associated with the loss of urban trees and ecological services. However, no such study has been performed in Pakistan to investigate the termite occurrence and assess such damages to urban trees caused by termites. For Lahore, research and comparable data on urban tree damages are rare or missing. This study surveyed six different microhabitats, including Bagh-e-Jinnah, Canal vegetation, Model Town Park, Jallo forestry, Race-course Park, and F.C. College vegetation employing three belt transects (100×5 m) method. We geo-referenced termite infested trees to investigate the termite occurrence on living and dead standing trees, termite diversity and assess the tree damage by termites' attack. We recorded four termite species (*Odontotermes obesus*, *Coptotermes heimi*, *Heterotermes indicola*, and *Microtermes obesi*) representing two families (Rhinotermitidae and Termitidae). However, the diversity indices result revealed that *O. obesus* (higher termite) and *C. heimi* (lower termite) were dominant and key species with 46.60 and 36% of occurrence among observed trees, respectively. Kernel density function indicated that the Lahore Canal and Bagh-e-Jinnah plantation shared all four termites' infestation evenly compared to other study sites. We observed the maximum number of damaged trees by termites in canal plantations with the most damaged exotic tree species *Populus euramericana* along the canal green belt.

Additionally, we observed significant ($P < 0.05$) termite-tree interactions with exotic, living, and dead standing tree species and found termite colony size positively ($R = 0.985$) correlated with the tree trunk diameter up to breast height DBH. The average population of termites per unit volume of deadwood log was ($0.39/\text{cm}^3$) within all plantations-sites. In conclusion, this study provides simple, reckless, and inexpensive knowledge about the assessment of termite damage of trees, which may give a better idea in making decisions on tree selection and management in urban ecosystems.

Introduction

In the urban environment, trees are usually considered a crucial and desirable part of landscape development. The exponential growth of the urban population has created an alarming situation for urban plantation to deliver ecological services critical to humans and biodiversity's wellbeing. Ecological services are much important in terms of environment and categorized as regulating (e.g., microclimate & nutrients, seizing carbon, eliminating airborne pollutants and green infrastructure), cultural (e.g., recreational, spiritual, historical, and tourism), provisioning (e.g., food, water, and fiber) and supporting (e.g., pollination & soil formation) (Endreny, 2018). Urban forestry is defined as "the inclusive trees canopy across the metropolitan areas comprised on individual trees, fauna and forest covers located in public or private properties including parks, open spaces, canal banks, streets residential areas and alongside the roads" (Wolf & Kruger, 2010; Zorzenon & Campos, 2015). Urban parks are generally open space areas reserved for public recreation in cities dominated by the tree canopy and water resources. The federal government has been planning and managing urban vegetation in Pakistan; however, cities still endure unwitting projects such as imprecise selection for plant species that results in several ecological problems. These concerns may range from simple pest infestation to whole tree falling on the roads, streets, and open spaces, causing accidents with a variable level of penalties (Zorzenon & De, 2014). Besides, such a problem can lead to loss of tree canopy and associated impacts on groundwater level, heating/cooling costs, and quality of human life (U.S. Forest Service <https://www.fs.fed.us/managing-land/invasive-species>). Since the symptoms and signs of tree defects, especially termite infestations, are not considered or identified correctly. It may be due to monitoring and assessing the risks associated with tree health and status that have not received feasible consideration in developing countries. Three major concerns related to tree damage assessment include fostering tree longevity by predicting and preventing structure failure and public and onsite workers' safety (Karlinasari et al., 2018). Visual Tree Assessment (VTA) has

been developed as a principal method by Mattheck and Breloer to assess the risks associated with tree status (Mattheck & Breloer, 1994). Subterranean termites' infestation in urban trees is common and causes some trees to fall (Zorzenon & Campos, 2015). Subterranean termites feed approximately all fibrous material types because of their wide range of feeding preferences (Rasib et al., 2014; Afzal et al., 2017). Termites' incidence of landscape trees is increasing year by year in the urban environment of Pakistan. Approximately 52 termites' species occur throughout the four provinces of Pakistan (Akhtar, 1974). In the largest province, Punjab, various kinds of severe termite attacks on urban trees have been observed in the last few decades of climate change events. Lahore is the capital city of the province of Punjab and was known as the garden city but, now going through a severe environmental crisis due to overpopulation, unsustainable development projects and climate change issues (W.W.F., Pakistan). In this situation, termite incidence and damage assessment on trees of green belts and parks of Lahore is too critical in order to save the horticulture as well as nature biodiversity management. Only one study was reported the survey of termite infested houses, indigenous building materials and construction techniques in Pakistan by Manzoor and Mir (2010). However, this survey was just including 185 houses from different regions of Punjab and did not include urban and landscape forestry for termite infestation. To understand the infestation by subterranean termites in urban trees of Lahore, Pakistan, this study was aimed four major objectives to obtain basic information to support upright urban trees management in six major microhabitats *i.e.*, Bagh-e-Jinnah (Lawrence Garden), Canal vegetation, Race-course Park, Model Town Park, Jallo forestry and F.C. College botanical garden, i) to register the termite species occurrence and frequency of termite damage to living and dead tree species in studied area, ii) to assess the urban tree damage by termites and termite feeding preferences, iii) to infer correlation between termite richness (n) and diameter of infested tree upto breast height (DBH), iv) to determine the effect of tree species type (native and exotic), tree status (living and dead), and DBH on the termites infestation.

Materials And Methods

Study Sites and Termite Sampling

We selected the study area based on the dense tree canopy and history of tree damage by the Parks and Horticulture Authority, Lahore, Pakistan. Study-sites were included parks and vegetation named F.C. College botanical garden (0.75 km²), Canal vegetation (60 km²), Jallo Park (1.75 km²), Bagh-e-Jinnah (0.57 km²), Model Town Park (0.51 km²), and Race-course vegetation (0.36 km²) are located in the metropolitan areas of Lahore, Punjab Pakistan (31.520418° N, 74.35871° E) as shown in Fig. 1. These study-sites parks/vegetations are considered the primary biodiversity hotspots in the thickly populated city comprising various evergreen and seasonal wood tree species. Surveys were carried out for each month of 2019-2020 (from one rainy season to the next rainy season) for subterranean termite collection, diversity, and tree damage assessment attacked by termites.

In each of the six study sites, three consistent transects of tree belts (100 × 5 m) were conducted and used the distance of 100 m between each transect (Dahlsjö et al., 2020). The collection of termites' specimens was made in each transect from the base of infested living trees, mud tubes, termite mounds, and dead logs by breaching and handpicking using soft forceps. We preserved the collected termite samples in 70% ethanol for morphological identification using a taxonomic key for termite soldiers by Akhtar (1983). We used a mobile app (Soviet Military Maps) to classify the study area's geographic locations, elevations, and termite-infested tree locations. Plants species from each survey area were registered, identified, and clustered into two major groups as "native" and "exotic" tree species with the guidance by respective park gardener & botanist. The relationship between termite colony size and diameter of a tree trunk up to breast height (DBH) was assessed by Spearman rank correlation at a significance level of $p < 0.05$ (McDonald, 2014).

Termite Damage Assessment

This study determined the tree damage in living and dead standing trees from each sampling sites by Visual Tree Assessment (VTA) using American Wood Protection Authority (AWPA E21-17) visual rating scale and photography in all trees with ten or >10 cm at breast height (B.H. = 1.2 m). Visual rating scale was categorized as; no attack = 0%, low damage = 1-25%, moderate damage = 26-50 %, high damage = 51-75% and very high damage = 76-100%. We assessed Internal termite damage (any more superficial damage under the tree bark) according to the methodology proposed by Gould et al. (1993) and Mandal et al. (2010). We also inspected the infested parts of standing living and dead tree trunks for any termites' commotion, e.g. tunneling mud tubes, fecal pellets, and any other symbol of termites' infestation. For each tree, the range of termite damage, volume of the tree's infested part, and tree height were determined to assess the trees' damaged proportion. The volume of an infested part of the tree was determined by quantifying the diameter and length of the tree log by applying the formula.

$$V = \pi r^2 L.$$

Where V = volume of infested part; L = length of tree log; r = radius or diameter of the wood. The size and composition of termite colonies from infested tree log were brought to the entomology laboratory. Each cast, i.e., alates, nymphs, workers, and soldiers, was examined and counted under the trinocular stereomicroscope Optika® 500 series. The Pearson correlation coefficient was determined to analyze the relationship between the termite richness (n) and the infested tree diameter up to breast height, using S.A.S. software (S.A.S. Institute, 2017). The frequency of damage associated with tree species in each sampling site was deterring by using the following formula.

$$\text{Frequency of Damage} = \frac{\text{No. of termite infested trees}}{\text{Total no. of all inspected tree species}} \times 100$$

Termite richness and climatic factors

Climatic factors, including atmospheric temperature, rainfall, and relative humidity, have been observed significantly to termite foraging behaviour (Haverty et al., 2010; Moura et al., 2006; Sattar et al., 2013). Atmospheric temperature, rainfall, and relative humidity average data of 2019-20 daily were collected from the Meteorological Department of Lahore (<http://rmcpunjab.pmd.gov.pk/molahore/MO-Lahore-intro.php>). The climatic factors' impact was determined using temperature, rainfall, and relative humidity for each termite species' richness (n).

Data analysis

The location of termite-infested trees in surveyed sites was geo-referenced using ArcGIS 10.2V. The descriptive statistic was used to determine each termite species' abundance concerning the survey site/habitat. Diversity indices Taxa (S), Dominance (D), Simpson ($1-D$), Shannon (H'), Evenness (e^H/S), Brillouin, Equitability (J), Fisher alpha (α), and Berger-Parker (B.P.) were determined for each termite species, and t-statistics applied to investigate the significant difference. We performed the Kernel Density Function using 12 bins to check the normal distribution of termite species across the surveyed sites by PAST 4.03 Version. Furthermore, data were analyzed using the GENMOD procedure by S.A.S. software 9.04 to model the probability of termite presence in urban trees using tree clusters (exotic and indigenous), DBH, tree status, and their interaction as independent variables (Calderón-Cortés et al., 2018).

Results

Termite occurrence

Overall, termite species belonging to four genera (*Odontotermes*, *Coptotermes*, *Microtermes*, and *Heterotermes*) representing two families (Rhinotermitidae and Termitidae) were recorded on trees in Bagh-e-Jinnah, Canal vegetation, Race-course Park, Model Town Park, Jallo forestry, and FC College botanical garden. Based on morphological features, this study recognized the higher termites *Odontotermes obesus* Rambur and *Microtermes obesi* Holmgren. They have frequently collected from mud plaster and galleries the bark of tree trunk. In contrast, the lower termites *Coptotermes heimi* and *Heterotermes indicola* Wasmann were collected from internal tree nest galleries and mud tube trials in both living and dead standing trees (Fig 2). A total of >7451 termite individuals were logged from all six habitats of district Lahore metropolitan area from 2019-20, with the relative abundance of *O. obesus*, *C. heimi*, *H. indicola*, and *M. obesi* was 47, 36, 16, and 1% in overall study areas respectively (Fig. 2). Canal and Bagh-e-Jinnah had significantly ($P < 0.05$; $df = 6$; F -value = 68.84) higher species abundance of both lower and higher termites as compared to Race-course Park, Model Town Park, Jallo forestry, and FCCU botanical garden (Supplementary Table 1). In collected termite species from all sampling sites, *O. obesus* were high in number all vegetation sites; however, the frequency of tree damage was caused by *C. heimi* followed by *H. indicola*.

The results of some general diversity indices including Dominance (D), Simpson (1-D), Shannon (H'), Evenness (e^H/S), Brillouin, Equitability (J), Fisher alpha (α), and Berger-Parker (B.P.) for each termite species were determined as shown in Table 1. Termite species *C. heimi* and *H. indicola* had moderately high dominance (D) that was 0.614 and 0.552, respectively, than *O. obesus* and *M. obesi* (0.343 and 0.209) in all surveyed parks. Likewise, *C. heimi* and *H. indicola* had significantly lowest (0.385 and 0.448) Simpson index (1-D), representing high diversity. In contrast, high values (0.790 and 0.675) of the Simpson index for *M. obesi* and *O. obesus* were observed, respectively, indicating the low diversity in the respected study area. Shannon index (entropy) was recorded 1.584, 1.366, 0.857, and 0.828 for *M. obesi*, *O. obesus*, *H. indicola* and *C. heimi*, respectively. Same patterns ($M. obesi > O. obesus > H. indicola > C. heimi$) were observed in the Evenness, Brillouin, and Equitability indices. Berger-Parker (B.P.) index was 774 and 718 for *C. heimi* and *H. indicola*, respectively, which is higher than the B.P. index (0.527 and 0.261) of *O. besus* and *M. obesi* as shown in Table 1.

Table 1. Diversity indices Dominance (D), Simpson (1-D), Shannon (H'), Evenness (e^H/S), Brillouin, Equitability (J), Fisher alpha (α), and Berger-Parker (B.P.) for each termite species in sampling sites.

Diversity indices	Termite species				t-statistics	p-Value
	<i>O. obesus</i>	<i>H. indicola</i>	<i>C. heimi</i>	<i>M. obesi</i>		
Taxa_(S)	6	4	5	5	0.52156	p > 0.01
Individuals	3780	718	2524	429	0.361066	p > 0.01
Dominance_(D)	0.343	0.552	0.6148	0.2098	0.447725	p > 0.05
Simpson_(1-D)	0.657	0.448	0.3852	0.7902	0.447725	p > 0.05
Shannon_(H)	1.366	0.8573	0.8285	1.584	0.428518	p > 0.05
Evenness_(e^H/S)	0.6532	0.5892	0.458	0.9749	0.387678	p > 0.05
Brillouin	1.361	0.8452	0.8233	1.557	0.432901	p > 0.05
Equitability (J)	0.7623	0.6184	0.5148	0.9842	0.422245	p > 0.05
Fisher_alpha (α)	0.6979	0.5587	0.5991	0.7945	0.315449	p > 0.05
Berger-Parker (BP)	0.5278	0.7187	0.7746	0.2611	0.377423	p > 0.05

The kernel density function for the distribution of termite in surveyed areas indicated that canal vegetation, Bagh-e-Jinnah and Racecourse park had higher and normal distribution than F.C. College, Model town park, and Jallo park, respectively, as shown in Figure 3.

Damage Assessment

The percentage and number of trees attacked by termites in district Lahore study sites varied by tree cluster (exotic or native) and region (Fig. 4). In the current survey, overall, 1290 trees to species level in six different vegetations were examined, out of which 290(22%) specimens were severely damaged by termite attack. The canal plantation, which was mostly comprised of exotic tree species, out of a total of 425 inspected tree species, 114(39.31%) exotic and 8(2.75%) native tree species were highly infested by termites. Whereas, in Bagh-e-Jinnah, out of a total of 294 inspected trees, 47(16%) native and only 5(1.7%) exotic tree species were damaged by termite attack (Fig. 4). Similarly, in Jallo forestry and Race-course park, 180 and 160 trees were inspected, 21(7.24%) native & 5(1.72%) exotic and 18(6.25%) native & 7(2.41%) exotic trees species were damaged by termites, respectively. The minimum termite infestation was observed in Model town park and F.C. College vegetations, where a total of 130 and 101 trees inspected, only 17(5.83%) native & 6(2.07%) exotic in Model town park and 20(6.89%) native & 3(1.03%) exotic tree species were attacked by termites (Fig. 4).

Exotic and native tree clusters characterize all surveyed parks. In exotic species, *Populus euramericana*, *Hibiscus rosa*, *Alstonia scholaris*, *Albizia porecera*, *Grevillea robusta*, *Jacaranda mimosifolia*, and *Delonix regia* were included. Whereas, *Acacia nilotica*, *Aegle marmelos*, *Albizia lebbeck*, *Azadirachta indica*, *Bambusa vulgaris*, *Bauhinia variegata*, *Butea frondosa*, *Cassia fistula*, *Dalbergia sissoo*, *Erythrina subrosa*, *Ficus religiosa*, *Heterophragma adenophyllum*, *Melia azedarach*, *Morus alba*, *Pinus roxburghii*, and *Thuja accidentals* were indigenous tree species (Table 2).

Termite abundance and palatability of different tree species were varied among termite species. *Populus euramericana* and *Morus alba* were most susceptible against all termite species. Whereas, *Cassia fistula*, *Grevillia robusta*, *Eagle marmelos*, *Ficus religiosa*, *Acacia nilotica*, *Artocarpus integrifolia*, *Bombax malabaricum*, *Callistemon citrinus*, *Chukrasia tabularis*, *Citharexylum sipnosum*, *Erthrina suberosa*, *Eucalyptus citriodora*, *Gleditsia triacathos*, *Phyllanthus emblica*, *Platanus orientalis*, and *Polyathia longifolia* were the least preferable against all termites species (Supplementary Table. 2).

Significant variations in infested trees were calculated within surveyed localities, evident that termites' attacks on trees vary as well as localities (Supplementary Fig 1). The results of the visual tree assessment indicated that an exotic tree species, *P. euramericana* had severe damage with the absolute frequency of 145 and 50% relative frequency by all termite species.

Table 2. Visual tree damage assessment with an absolute and relative frequency of the indigenous and native trees in the six different Lahore city parks of Punjab, Pakistan.

Tree clusters	Tree names	No attack	Low damage	Moderate Damage	High damage	Very High damage	Absolute frequency (n)	Relative frequency (%)
Indigenous	<i>Eagle marmelos</i>	9	1	0	0	0	01	0.34
	<i>Albizzia lebbeck</i>	27	4	0	0	0	04	1.37
	<i>Azadirachta indica</i>	30	3	0	0	0	03	1.03
	<i>Bambus sp.</i>	25	4	0	0	0	04	1.37
	<i>Bauhinia variegata</i>	30	0	9	0	0	09	3.10
	<i>Acacia nilotica</i>	42	3	5	0	0	08	2.70
	<i>Butea frondosa</i>	45	1	3	8	5	17	5.86
	<i>Cassia fistula</i>	43	1	0	0	0	01	0.34
	<i>Dalbergia sissoo</i>	65	5	9	3	0	17	5.87
	<i>Erythrina suberosa</i>	72	7	5	10	0	22	7.58
	<i>Ficus religiosa</i>	15	1	0	0	0	01	0.34
	<i>Heterophragma adenophyllum</i>	39	0	7	2	0	09	3.10
	<i>Melia azedarach</i>	45	2	2	0	0	04	1.37
	<i>Morus alba</i>	62	0	7	10	8	25	8.62
	<i>Pinus roxburghii</i>	20	4	0	0	0	4	1.37
<i>Thuja occidentalis</i>	21	2	0	0	0	2	0.68	
Exotic	<i>Populus euramericana</i>	255	4	30	85	26	145	50.00
	<i>Hibiscus rosa</i>	10	0	0	1	0	1	0.34
	<i>Alstonia scholaris</i>	42	3	2	0	0	5	1.72
	<i>Albizzia procera</i>	22	2	0	0	0	2	0.68
	<i>Grevillea robusta</i>	24	0	1	0	0	1	0.34
	<i>Jacaranda ovalifolia</i>	36	3	0	0	0	3	1.03
	<i>Delonix regia</i>	21	2	0	0	0	2	0.68

Total	1000	52	80	119	39	290	100
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However, the damage frequency of all other tree species by termite infestation was significantly less than, except *M. alba* a native tree species, was highly damage by termites' attack with 8.62% relative frequency and 25 absolute frequency (n). Minimum visual tree damage among exotic species was observed in *Grevillea robusta*, *Hibiscus rosa*, *Albizzia. procera*, and *Delonix regia*, while *Eagle marmelos*, *Cassia fistula*, *Ficus religiosa* and *Thuja accidentalis* had minimum termite damage frequency among native tree species.

Table 3. Multivariate analysis for the main effects and interactions of regressors including tree diameter breast height, tree clusters (exotic/native), and tree status (dead/living) concerning termite infestation

Parameter	Variable's categories		D.F.	Estimate	Standard Error	95% Confidence Limits	Wald Chi-Square	Pr > Chi Sq
Intercept1			1	1.0668	0.1358	0.8007-1.3329	61.75	0.000
DBH			1	-0.1242	0.0177	-0.1590-0.0895	49.09	0.000
Tree cluster	Exotic		1	0.8145	0.1967	0.4291-1.2000	17.15	0.000
Tree cluster	Native		0	0.0000	0.0000	0.0000-0.0000	.	.
Tree status		Dead	1	-1.5315	0.3626	-2.2422-0.8208	17.84	0.000
Tree status		Live	0	0.0000	0.0000	0.0000-0.0000	.	.
DBH*Tree cluster*Tree status	Exotic	Live	1	-0.0037	0.0295	-0.0617-0.0542	0.02	0.899
DBH*Tree cluster*Tree status	Exotic	Dead	1	-0.0434	0.0155	-0.0737-0.0131	7.88	0.005
DBH*Tree cluster*Tree status	Native	Dead	1	-0.0643	0.0439	-0.1503-0.0217	2.14	0.143
DBH*Tree cluster*Tree status	Native	Live	0	0.0000	0.0000	0.0000-0.0000	.	.
DBH*Tree cluster	Exotic		0	0.0000	0.0000	0.0000-0.0000	.	.
DBH*Tree cluster	Native		0	0.0000	0.0000	0.0000-0.0000	.	.
DBH*Tree status		Dead	0	0.0000	0.0000	0.0000-0.0000	.	.
DBH*Tree status		Live	0	0.0000	0.0000	0.0000-0.0000	.	.
Tree cluster*Tree status	Exotic	Dead	1	-0.2256	0.5458	-1.2954-0.8442	0.17	0.679
Tree cluster*Tree status	Exotic	Live	0	0.0000	0.0000	0.0000-0.0000	.	.
Tree cluster*Tree status	Native	Dead	0	0.0000	0.0000	0.0000-0.0000	.	.
Tree cluster*Tree status	Native	Live	0	0.0000	0.0000	0.0000-0.0000	.	.
DBH*DBH			1	0.0022	0.0004	0.0015-0.0029	35.45	0.000
Scale			0	1.0000	0.0000	1.0000-1.0000		

Termite-Tree Interactions

Interaction between tree features (tree diameter up to breast height, tree clusters (exotic/native), and tree status (dead/living)) and termite infestation has been observed, as shown in table 3. There were significant main effects of DBH ($\chi^2 = 49.09$, $P = 0.000$), tree status, if the tree is dead ($\chi^2 = 17.15$, $P = 0.000$) and tree cluster if tree is exotic ($\chi^2 = 17.84$, $P = 0.000$) on termite infestation. Whereas no significant interaction was observed among DBH, tree cluster, and

tree status regarding the termite infestation, except the interaction between DBH, exotic tree cluster type, and living tree status showed a significant effect ($\chi^2 = 7.88, P = 0.005$) on termite infestation (Table 3).

Foraging Ecology of Termites

High termite occurrence was affected by different factors such as tree diameter, termite species and climatic factors. Termite abundance was positively and significantly correlated ($r = 0.994; P < 0.05$) with the diameter of standing trees up to breast height (Fig 5). The correlation analysis of termite abundance with climatic factors indicated that foraging subterranean termites *O. obesus*, *C. heimi*, *H. indicola* and *M. obesi* observed to be more reliant on temperature and rainfall than relative humidity, as shown in Table 4.

No significant infestation by any termite species was observed in the winter season months when the temperature was minimum (January, February, March, and December). In contrast, the relative humidity was noted high (Fig. 6). However, when the temperature upsurged in the summer season (June, July, August, and September), termite infestation was recorded high (Table 4).

The correlation of each subterranean was not strong and significant with humidity. However, the temperature and rainfall showed a significant and positive correlation (Table 4). Higher termite *O. obesus* and lower termite *C. heimi* were most abundant in September when post-monsoon occurs in Lahore.

Table 4. The correlation between climatic factors (temperature, relative humidity, and rainfall) and abundance of each termite species (*O. obesus*, *M. obesi*, *C. heimi* and *H. indicola*).

Climatic Factors	<i>O. obesus</i>	<i>H. indicola</i>	<i>C. heimi</i>	<i>M. obesi</i>
Temperature (°C)	$r = 0.7002; P = 0.014$	$r = 0.5834; P = 0.053$	$r = 0.6934; P = 0.015$	$r = 0.5739; P = 0.021$
Rainfall (mm)	$r = 0.5491; P = 0.051$	$r = 0.4998; P = 0.068$	$r = 0.6670; P = 0.026$	$r = 0.5209; P = 0.050$
Humidity (%)	$r = 0.3371; P = 0.262$	$r = 0.3969; P = 0.183$	$r = 0.4169; P = 0.151$	$r = 0.3256; P = 0.331$

Discussion

Termites are the serious economic pests of woodwork, as they damage the urban trees and wooden products in building in tropical and subtropical regions of the world. The prime size of biomass and abundance among invertebrates in tropical areas is carried out by termites (Bignell & Eggleton, 2000). Termites also occupy the decomposing wood, leaf litter, arboreal/soil mounds, tree bark covering, inside the living trees/deadwood logs under the forest canopy due to the prodigious diversity of microhabitats, which have tree species and micro-climatic factors. Therefore, it is difficult to estimate the insects' density in microhabitats (Eggleton et al., 1995). In Pakistan, only a few studies have been conducted against termite infestation on urban trees in city parks and green belt of roads and canal (Akhtar, 1974; Akhtar, 1987; Salihah et al., 1988; Akhtar & Shahid, 1989; Akhtar & Sarwar, 1993, 1997, 2003; Manzoor et al., 2011; Manzoor & Mir, 2010). In the current study, we assessed the termite occurrence on living and dead standing tree species (native/exotic) in six microhabitats, including parks and canal green belts, based on the proportion of damaged trees with termites.

Termite Diversity and Richness

The parks of district Lahore, Punjab Pakistan region provide the optimal habitat for insects like termites as it is widely vegetative and pass through all seasonal variations. The study sites Canal vegetation, and Bagh-e-Jinnah shared all

four species (*O. obesus*, *C. heimi*, *H. indicola*, and *M. obesi*). In comparison, other sites shared only two higher termite species *O. obesus* and *M. obesi*. Termite assemblage structures did not exhibit any consistency over the distance; however, all sites are located not more than 50 km. It indicates that microhabitats' distance does not significantly affect the termite colony structure rather than climatic and tree species differences. All study-sites showed access to different termite species pools that may have contributed to the high divergence levels (Dahlsjö et al., 2020). Both lower and higher termites comprising of two genera and four termite species, *i.e.* *O. obesus*, *C. heimi*, *H. indicola*, and *M. obesi* were focused on being the most destructive ones recorded in the study area. Diversity indices revealed that the higher termite species *O. obesus* and lower *C. heimi* were identified as dominant key pest species. Higher termite *O. obesus* was not only foraging openly, making mud tubes on the outer surface of the tree trunk, it also made internal galleries and replaced whole cellulose with mud in the present visualization. In comparison, *C. heimi* damaged the live and dead trees internally (inside the nest galleries) by constructing the moistened wood galleries in the tree trunk.

The kernel density function curves suggest that study sites canal vegetation and Bagh-e-Jinnah trees had high termite richness and even distribution than other study sites including Jallo forestry, Model Town Park, Race-Course Park, and F.C. college vegetation. High termite species richness in Bagh-e-Jinnah and Canal vegetation would be due to the presence of old trees and most palatable an exotic tree species *Populus euramericana* (Rasib et al., 2014). Moreover, thick vegetation and canal bank produce high moisture content in the soil, which result in high termites' attack on standing trees. Shady trees in urban recreational parks and have been reported with the highest termite infestation by *Coptotermes sp.* in Florida, U.S.A. (Hochmair & Scheffrahn, 2010). It indicates that temperature and humidity factors increase the infestation of wood-feeding termite species collaboratively.

Generally, five feeding-groups of termites have been categorized universally with some minor feeding groups of termites (Dahlsjö et al., 2020; Inward et al., 2007). All major termite feeding groups inhabit District Lahore, Pakistan (Manzoor et al., 2011) *i.e.* the wood-feeding termites (non-Termitidae species) placed in feeding-group I (FGI), feeding-group II (FGII) that infests on wood & leaf litter comprising on Termitidae family, FGIII termite group that feeds on hummus with visible plant composites (Termitidae), and only soil feeders without visible plant material placed in FGIV that also comprises on Termitidae family (Dahlsjö et al., 2020). In the current study, *C. heimi* and *H. indicola* fall in feeding-group I (FG1), whereas, soil and litter feeders *O. obesus* and *M. obesi* belong to feeding groups II & III based on their foraging activities. It was predicted that differences in species-density of different feeding-groups between study-sites would primarily be observed in wood-feeder *C. heimi* and *H. indicola* (FGI) due to their absence in microhabitats comprising a young and abridged variety of tree population. Whereas, the species density of soil dwellers and litter feeders *O. obesus* and *M. obesi* were not significantly different between study sites. The effect size for wood forgers (*C. heimi* and *H. indicola*) and soil-dwellers (*O. obesus* and *M. obesi*) between study-sites was larger and minimum, respectively. It may be results of metabolic activity fluctuations in termites gut due to tree species variations, nutritional changes in low energy substrates (humus and soil) because of climatic factors such as temperature and humidity (Dahlsjö et al., 2015; Eggleton et al., 1998; Newbery et al., 2000). In a study, Korboulewsky et al., (2016) revealed that diversity in tree species in a forest, predominantly the presence of broad-leaved tree species enhance the diversity of soil fauna due to their microhabitats full of nutrient resources. Consequently, the disparities in termite feeding-groups relative frequency of termite attack/abundance between different study sites may have been linked with high number and type of tree species (Lozano et al., 2010) that is why termite abundance was highly positively correlated with breast height diameter of tree trunk in the current study.

Termite-Tree interaction and damage assessment

In the current study, termite-tree interaction is based on different trees' parameters, including the tree type (exotic/native), tree status (living/dead), and the tree trunk's breast height diameter. The interactions indicate that the

availability of living and dead standing exotic tree species is associated with trees' density under termite attack. Specifically, the proportion of exotic and native tree species with living and dead standing tree status was different among microhabitats such as canal vegetation had higher exotic tree species (*P. euramericana*) than other study-sites indicating that microhabitat characteristics might affect the termite presence on trees. A study conducted in Mississippi by Wang and Powell (2001) revealed that the foraging behavior of subterranean termites is in direct proportion to wood size. Therefore, we observed higher tree frequency with termite activity in canal vegetation for both living and dead standing trees than other study-sites. This termite attack pattern difference can be explained by the availability of the resources (i.e. necromass) for the termites (Calderón-Cortés et al., 2018). While, Lenz et al., (2000) and Eggleton et al. (2002) reported that termites also prefer deadwood logs over live trees. Interestingly, our results indicate that the highest absolute and relative frequency (45-50%) of exotic live and dead standing tree species were associated with termite attacks in canal vegetation. Furthermore, the density of termite-infested living and dead standing trees was higher in trees of larger sizes (> 20 cm DBH) for which we observed a higher number of dead trees. In contrast, Calderón-Cortés et al., (2018) revealed a high density of dead standing trees with termite infestation of < 15 cm DBH. Overall, these results suggest that exotic tree species, standing dead tree availability and larger breast height diameter might be the prime factor for high termite occurrence in study-sites.

Visual assessment of tree damage was varied in study-sites by tree and termite species. The highest urban tree damage was assessed in canal vegetation, where *C. heimi* were also dominant destructive wood feeders, approximately all *P. euramericana* trees were damaged moderately to severe (51-100%) followed by *M. alba* (< 50%). In a study, Cheng et al., (2008) also reported that *Coptotermessp.* as best wood feeder lower termites, damaging to palm trees even capable to kill the trees due to having cellulose-degrading microbiota in their gut. However, the *H. indicola* attacked the root system of *P. euramericana* and kill the plant their cryptic nature. Likewise, in Bagh-e-Jinnah *M. alba* and *B. frondosa* were moderately damaged (< 50) by *C. heimi* and *H. indicola*. While *O. obesus* and *M. obesi* covered the wood with mud plaster and low damaged (10%) by infesting the bark of trees. During the evaluation of feeding preference, *P. euramericana* and *M. alba* were the most preferable food source for each termite species. Whereas, *S. cumini*, *Cassia fistula*, *G. robusta*, *T. grandis*, *E. suberosa*, *P. orientalis*, *P. longifolia*, *P. emblica*, *A. catechu*, *A. modesta*, *A. integrifolia*, *B. malabaricum*, *G. triacathos*, *C. citrinus*, *E. citriodora*, *C. tabularis* and *C. sipnosum* were highly resistance trees depending upon their chemical composition (Afzal et al., 2017; Rasib & Ashraf, 2014; Rasib et al., 2014; Rasib et al., 2017).

Climatic factors and termite foraging ecology

In the present study, we recorded three climatic factors including temperature (°C), rainfall (mm), and humidity (%) around the year due to their known correlation with termite foraging activities and termite richness (Jones & Eggleton, 2000; Sattar et al., 2013). On average, greater tree damage frequency by termites was observed in the summer rainy season than winter, which indicates that all subterranean termite colonies appeared to be dependent on temperature. The studies by Cao & Su, (2016) and Smith & Rust, (1994) revealed that subterranean will not silage in areas where the soil surface temperature is too hot or too cold. The results of correlation analysis revealed that the richness of all termite species was positively and significantly associated with temperature and rainfall data, while the humidity was not significantly associated with termite richness. These results suggest that the foraging activities particularly by *C. heimi* and *O. obesus* were significantly influenced the temperature, total rainfall, and maximum relative humidity (Evans & Gleeson, 2001; Rust et al., 1996). It may be due to an increase in the palatability of wood by optimal temperature and moistened contents that make the wood softened and edible for termites.

Conclusion

In this study, we geo-referenced the damaged trees by termites in six different parks (microhabitats) from Lahore Punjab, Pakistan, and present the four termite genera that had never been scientifically recorded with more species expected to be encountered. Two species (*O. obesus* and *C. heimi*) were nominated as key pests, capable of damaging trees within all microhabitats. Exertions to confirm that such data are comparable among study-sites to enable inclusive practices are stimulated. Moreover, termite attacking frequency, data on wood preference among different feeding-groups, and termite-tree interaction in a range of microhabitats will better understand the urban ecosystem's functioning (Bignell & Eggleton, 2000). The maximum damage by termites was assessed in canal plantations than other surveyed vegetations. The exotic tree species *P. euramericana* along the canal green belt was found highly damaged and dead by termites' attack. This study also recommends that initially attacked trees by termites must be treated using slow-acting chemicals or advanced baiting techniques. Still, trees with a high damage rate (70% or above) must be cut off, as they have a high risk of falling. The damage assessment and feeding preference results in this study may help select termite resistance tree species for long-life wood products and recommend a safe plantation in the urban ecosystem.

Declarations

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Authors' Contribution

Khalid Zamir Rasib led the study design and approved the study. Muhammad Afzal conceived the study, carried out surveys, experiments, analyzed the data, and constructed the whole manuscript.

Ethical approval & consent to participate

This study does not need ethical approval since no human data or participation involved in the study.

Consent to publish

Not applicable.

Competing interest

Authors declare that they don't have any competing financial and technical, or personal conflicts of interest regarding the article's work and data.

Availability of data & materials

Additional evidence of termite occurrence and tree damage is available in the supplementary material in the form of tables and figures. However, the raw data will be available by the corresponding author on a reasonable request.

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Figures

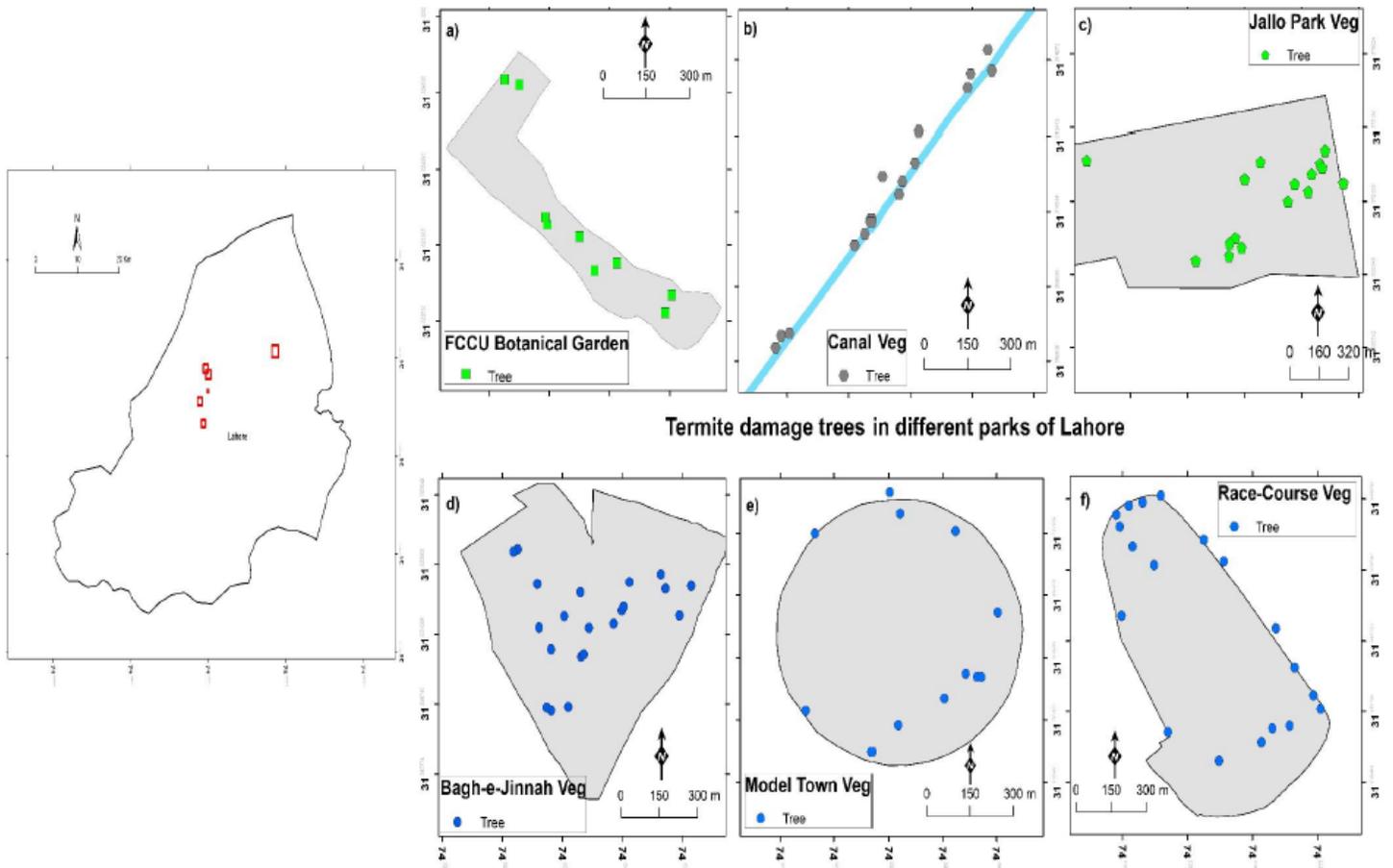


Figure 1

Study-sites comprising of six different parks and vegetations in district Lahore, Punjab Pakistan, represented by the geo-referencing of termite infested trees.

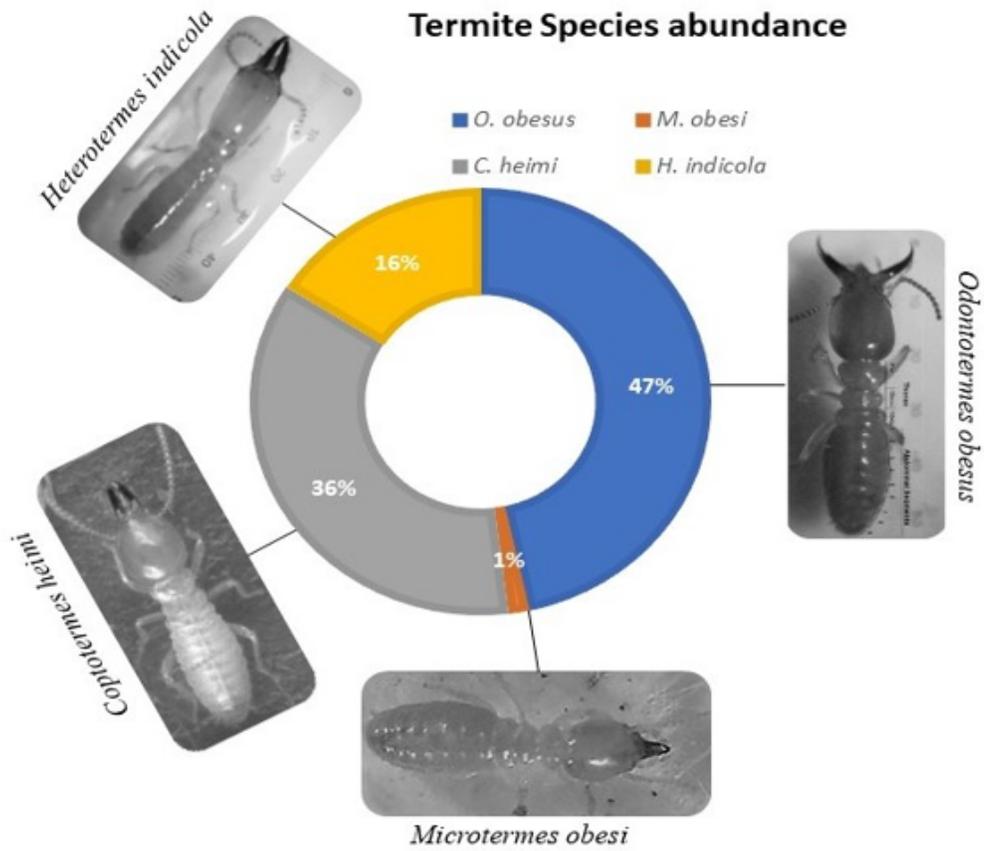


Figure 2

Termite species abundance collected from infested trees in Bagh-e-Jinnah, Canal vegetation, Race-course Park, Model Town Park, Jallo forestry, and FCCU botanical garden.

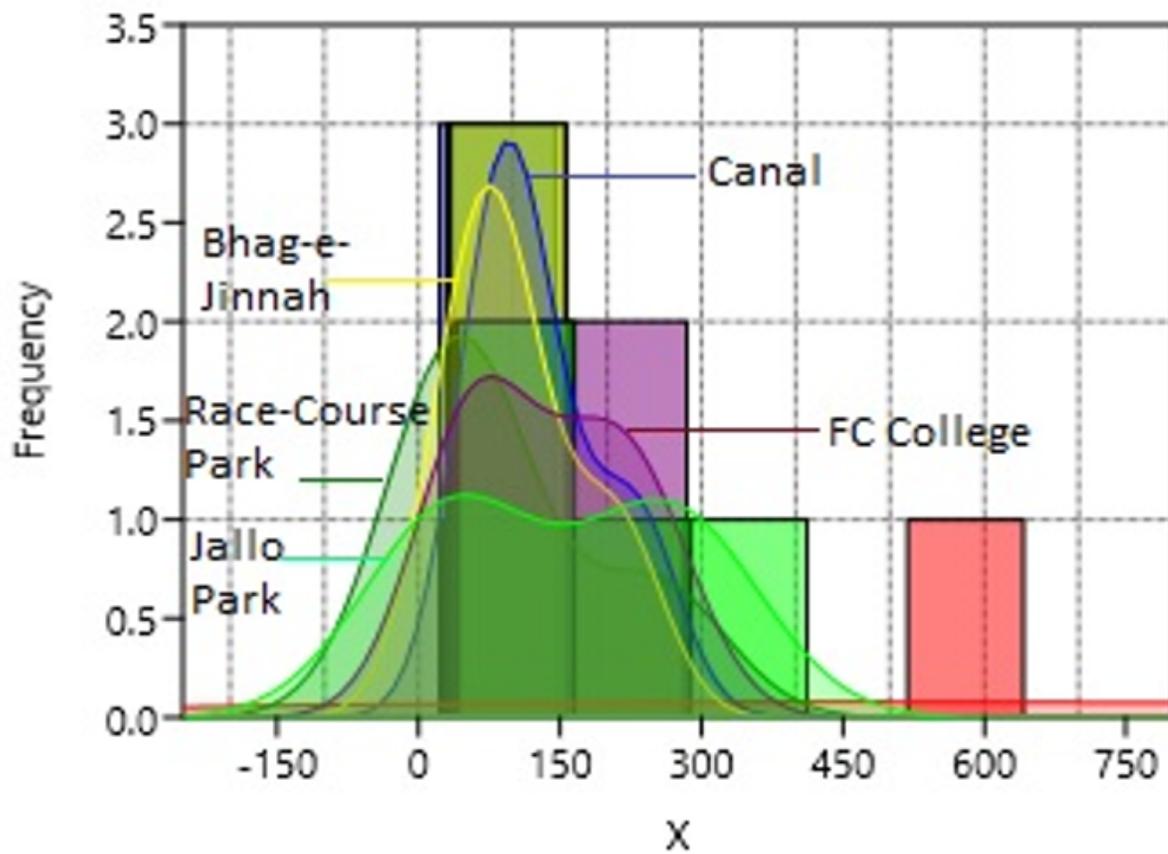


Figure 3

Kernel density function indicating normal curve distribution in different six parks.

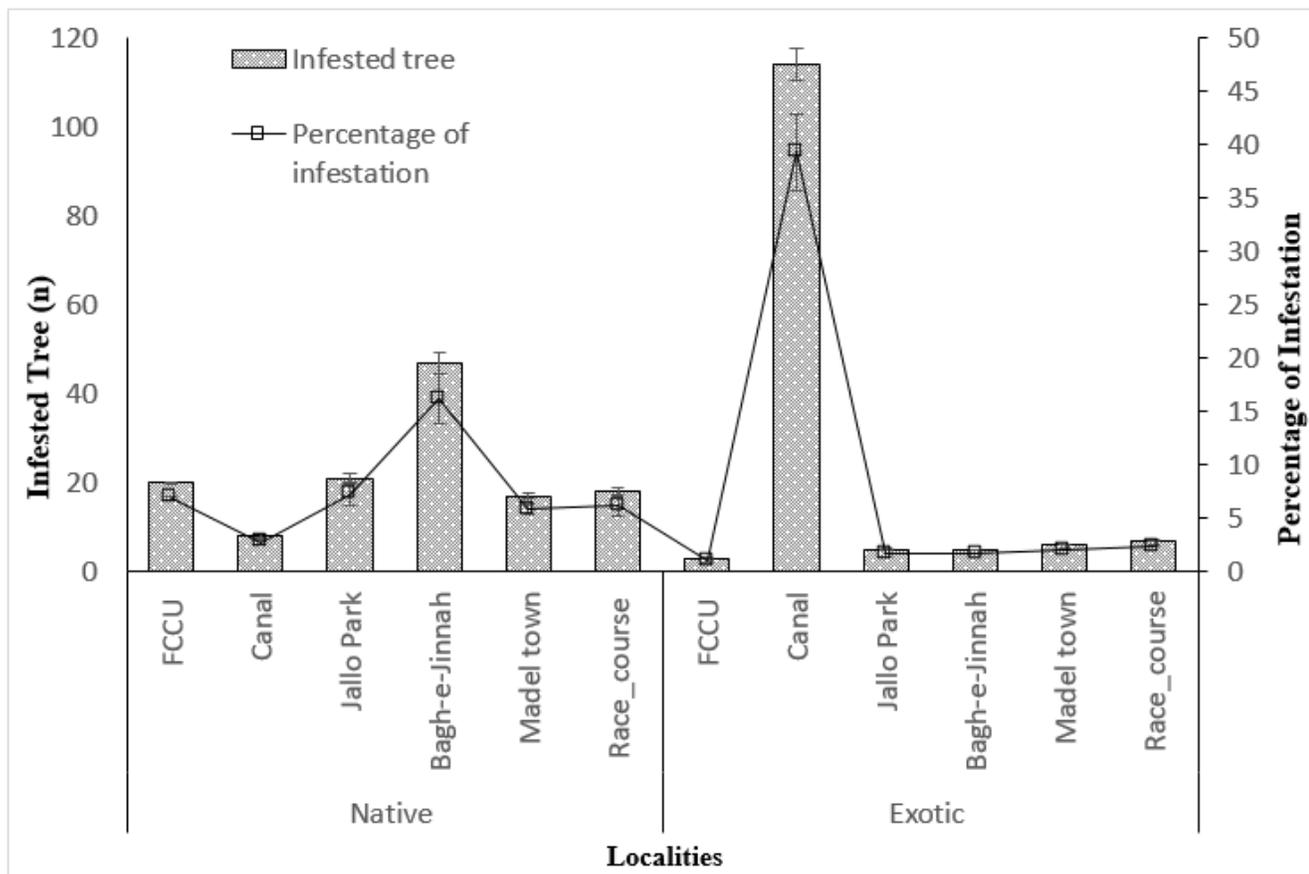


Figure 4

The number of infested trees and percentage of infestation in native and exotic tree clusters from surveyed localities.

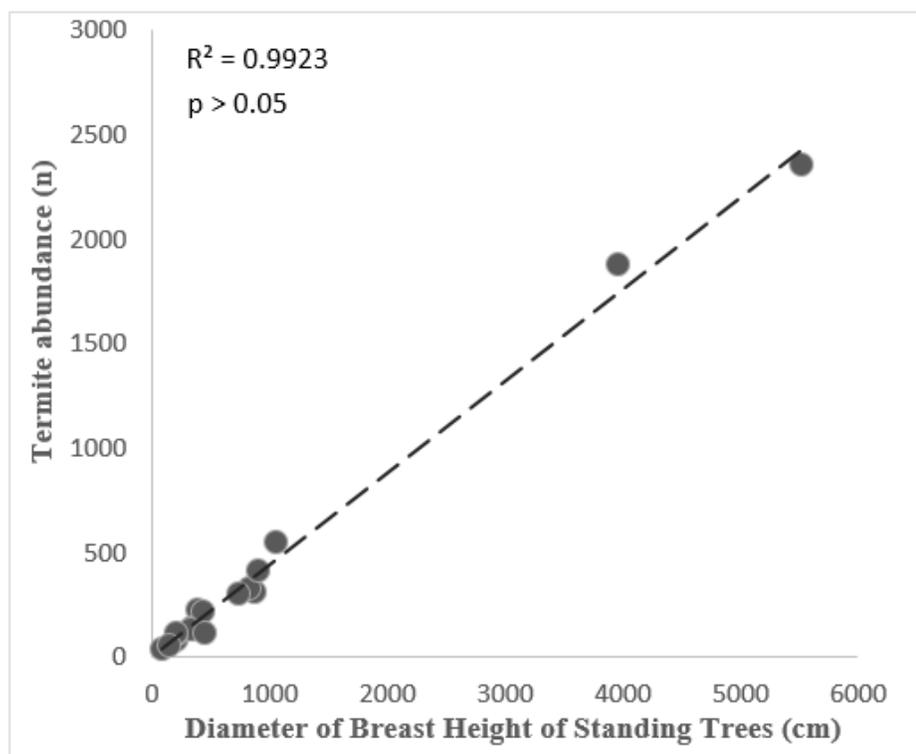


Figure 5

Relationship between the termite abundance with a diameter of breast height of standing trees (cm) in all surveyed parks. The estimated linear regression is $y = 0.4447x - 14.179$.

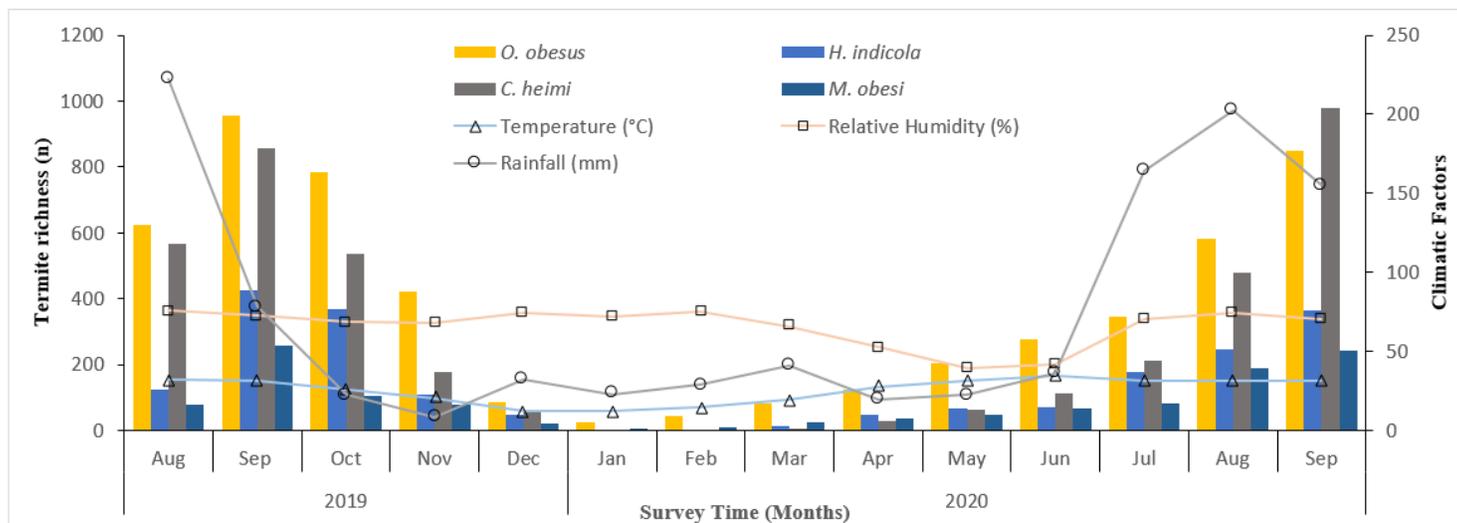


Figure 6

Monthly average temperature (°C), rainfall (mm), and relative humidity (%) with respect to the richness of termite species *O. obesus*, *M. obesi*, *C. heimi* and *H. indicola* during the sampling months of 2019-20 from surveyed vegetation of Lahore.

Supplementary Files

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