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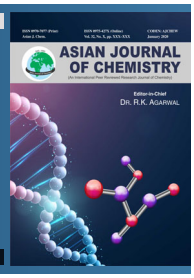

Chemical Ecology of Teak (*Tectona grandis* Linn.) Floral Volatiles

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In present work, the GC, GC-MS and GC-olfactory techniques were applied for the first time for the analysis of floral volatiles of teak. Chemical ecology of the teak flower is also studied by correlating each of the components in its volatile profile with the major classes of insect visitors and pollinators with the help of the internet databases. Sixty six components consisting of 84% of the oil were identified in the GC-MS analysis. Out of these 78% were oxygenated compounds while only 20% were various hydrocarbons, either sesquiterpenes or diterpenes. All the monoterpenes were in the oxidized form which reduces the therapeutic potentials of the oil while improving its perfumery value. The olfactory evaluation of the oil revealed the presence of a wide spectrum of impressions ranging from spicy-floral to mushroom-metallic and woody-earthy to honey-like. The main reason for the enormous number of insects visiting teak flower is the presence of large number of volatile compounds with diverge semiochemical behaviour. At the same time the presence of some specific allomones and alarm pheromones results in the repulsion of some effective pollinators. This leads to ineffective pollination and comparatively low fruit development in teak.

Keywords: *Tectona grandis* Linn., Teak, Floral, GC-olfactory.

INTRODUCTION

Teak (*Tectona grandis* Linn.) is one of the most valuable and widely planted tree species in south Asia and other tropical countries. Teak timber is valued for its durability as it is immune to insect and fungus attacks and resistant to wood rot. It is being grown in plantations in around 60 countries in Asia, Africa and Latin America although its natural occurrence is limited to India, Laos, Myanmar and Thailand [1]. It is widely used in making doors, furniture, wooden ceilings, beams and boat decks. The leaves were used in cooking some typical jack fruit items in India, central Java and Indonesia. In Kerala state of India, they were once used as packing materials in local shops. Teak is also considered as a major constituent in many folklore medicines [2,3].

A good phytochemical data is available on this large, deciduous tree every part of which was reported by traditional as well as modern studies to possess a wide range of medicinal indications [4]. A number of novel compounds with phytotoxic, allelopathic, antihyperglycemic, biopesticidal , antiulcer and antifungal activity were isolated from the bioactive extracts of leaves, bark and heartwood of the plant [5]. The preservative nature of teak wood oil was studied recently to identify the anti-rot compounds like tectol [6].

Teak belongs to the mint family lamiacea [7], which is better known for its aromatic members such as basil, rosemary and lavender all producing economically important essential oils. Teak is mainly an insect pollinated species like many other economically important crops [8]. A significant study by Mathew *et al.* [9] on the pollinators of teak in the southern state of Kerala identified 17 species of insect visitors on teak flowers. Among these 13 belonged to hymenopterans and two each to dipterans and lepidopterans. A later investigations by the research group at Kerala Forest Research Institute (KFRI) records altogether 60 species of insects visiting the teak flower [10]. Even though maximum in numbers lepidopterans were not revealed as true pollinators of teak as they were not found carrying pollen grains. Hymenopterans, which are considered as efficient pollinators are second in number. Of these groups, the bees were found to be very active but present only in small numbers [9,10].

Flowering season of teak is from February to August and there will be more than 300 inflorescences on a single teak

tree. About 10,000 flowers are produced per inflorescence [9]. Plenty of nectar is available for foraging insects and at this point, it is interesting to mention that the visiting frequency of the Indian honey bee, *Apis indica* which is considered as one of the most efficient pollinator was very low in teak flowers [10]. No increase was observed in this value while keeping colonies of Indian bees in the vicinity of trees under investigation. Many local bee-keepers have also reported that honey bees did not approach teak flowers in the corresponding seasons. This observations are to be cross-checked with the fact that low fruit production is one of the major problems in teak propagation [11] as only 0.6-1.0 % of the gigantic teak flowerings are being developed into fruits [9,10].

No work has so far been reported on the steam volatiles of teak, especially from the pleasant smelling flowers, herein, the analysis of floral volatiles of teak using GC, GC-MS and GC-olfactory (GC-O) techniques for the first time and also investigated the pollination syndromes in teak in connection with its floral volatile profile. This chemo-ecological work is the first of this kind carried out in this region especially in the case of an economically important hardwood timber.

EXPERIMENTAL

Plant collection: The teak flowers were collected from Malappuram district, Kerala state of India. It was identified by Dr. A.K. Pradeep, Department of Botany, University of Calicut and a specimen voucher is deposited in the specially maintained Herbarium of Chemistry Department of University of Calicut.

Extraction: Flowers (500 g) were separated and ground into a paste and subjected to steam distillation for 3 h. The oil was extracted by diethyl ether from the distillates. Then the ether extract was dried using anhydrous sodium sulphate and the pure oil was stored at 4 ºC until analyzed.

Gas chromatography/mass spectrometry/olfactometry: GC/GC-MS/GC-O was carried out using an Agilent 6890 gas chromatograph, fitted with a HP-5 (5 % diphenyl polysiloxane) capillary column (50 m × 0.32 mm × 0.52 µm), with He carrier gas, initial head pressure 15.0 psi (2.0 mL/min) constant flow mode. The column effluent was split between an Agilent 5975N inert MSD spectrometer and an in-house odour detection port *via* a capillary flow technology splitter plate with pressure set to 3.8 psi. The injector and odour port transfer line temperatures were held constant at 230 and 250 ºC, respectively. Injection of 1 µL at 500 ng/µL dilution in splitless mode with oven program: 35 ºC (3 min), 15 ºC/min ramp to 50 ºC then 5 ºC/min ramp to 280 ºC (held 10 min). Data was acquired and processed using MSD ChemStation (Rev. D.02.00.275). The odour assessments and description were carried out by experienced perfumers.

Gas chromatography/mass spectrometry: GC/MS was carried out using the same system but optimized for resolution with a linear temperature ramp of 2 ºC/min and calibrated for retention indices using C_7-C_{28} *n*-alkanes. The inert MSD was operated with source temperature of 230 ºC, quad temp.: 150 ºC and ionization voltage 70 eV. Target spectra were acquired and compared against in-house and commercial libraries from which identifications were assigned on the basis of both spectral match and retention data [12].

Gas chromatography/flame ionization detection: GC/FID analysis for quantization was carried out using an Agilent 6890 gas chromatograph, fitted with an Ultra 2 (5 % diphenyl-polysiloxane) capillary column (50 m × 0.2 mm × 0.33 µm), split injection (50:1) with He carrier gas (1.2 mL/min). The oven was programmed from 50-280 ºC (held for 6 min) at 2 ºC/min. The injector and detector temperatures were held constant at 230 and 300 ºC, respectively. Data was acquired and processed using HP ChemStation software (Rev. A.10.02 [1757]). Quantitative data was obtained from relative peak area (%RPA) without the use of response factors.

Study of pollination syndrome: Each components in the floral volatile profile were identified by GC and GC/MS are correlated with the major classes of insect visitors and pollinators of teak with the help of the internet database www.pherobase.com [13] and other various available literature. The semiochemical relationships (attractants, kairomones, pheromones and allomones) are tabulated and the findings are correlated with the earlier reports from the field.

RESULTS AND DISCUSSION

Hydrodistillation of fresh teak flower afforded an oil with pleasant floral aroma. The product was light yellow in colour and the yield was 0.027% of the fresh weight sample. This is the first authentic report of isolation of essential oil from any part of any of the species Tectona.

Chemical composition: Sixty six components consisting of 84.13% of the oil were identified in the GC-MS analysis. Out of these 52 compounds comprising of 78.8% were of oxygenated compounds while only 13 compounds comprising of 20% were various hydrocarbons. Nitrogen containing heterocyclic compound indole was also detected in the oil. Oxygenated compounds mainly consisted of 24 alcohols, 5 aldehydes, 5 ketones, 7 esters and 4 phenylpropanoids. Among the alcohols 17 of them were alcohols of mono-, di- or sesquiterpenes. The hydrocarbons comprised of 11 sesquiterpenes and 2 diterpenes (Table-1).

There were 13 aliphatic compounds among the identified components. The C-6 compounds dominated this group with two green leaf volatiles (GLV) *cis*-3-hexenol and *n*-hexanol and four hexenyl esters. Hexenyl ester of benzoic acid was also identified in the oil. Five C-8 aliphatics namely octan-1-ol, 3-octanol, oct-1-en-3-ol, 3-octanone and 1-octen-3-one were also identified.

All the hydrocarbons present in the oil were either sesquiterpenes or diterpenes. All the monoterpenes were present in the oxidized form; 8 of them were alcohols. It is evident that sesquiterpenes are not readily oxidised as monoterpene hydrocarbons due to their comparatively larger molecular size and lower volatility. Usually the absence of monoterpene hydrocarbons reduces the therapeutic potentials of the oil while the same improves its perfumery value [14].

Among the isolated compounds there were 9 diterpenoids, which are the largest and heaviest molecules found in essential oils produced by distillation [15]. These mainly consisted of

TABLE-1
TEAK FLOWER OIL-GC MS ANALYSIS WITH FID QUANTIFICATION

No	RI (lit)	RI	Name of compounds	%RPA (FID)	Identification
			Hydrocarbons-sesquiterpens		
1	1374	1383	α-Copaene	0.3	MS, RI (std)
2	1390	1394	7-*epi*-Sesquithujene	0.1	MS
3	1417	1429	Caryophyllene	1.9	MS, RI (std)
4	1432	1441	*trans*-α-Bergamotene	0.5	MS, RI (lit)
5	1440	1458	*cis*-β-Farnesene	0.1	MS, RI (std
6	1452	1463	α-Humulene	0.5	MS, RI (std)
7	1478	1484	γ-Muurolene	0.4	MS, RI (lit)
8	1479	1486	Curcumene	0.2	MS, RI (std)
9	1484	1490	Germacrene D	1.6	MS, RI (std)
10	1522	1530	δ-Cadinene	0.5	MS, RI (std)
11	-	1817	Sesquiterpene hydrocarbon	0.3	MS
			Hydrocarbons-diterpenes		
12	-	1920	Diterpene hydrocarbon	0.6	MS
13	-	1927	Diterpene hydrocarbon	0.7	MS
			Alcohols-aliphatic		
14	850	854	*cis*-3-Hexenol	0.5	MS, RI (std)
15	863	866	Hexanol	0.3	MS, RI (std)
16	974	978	Oct-1-en-3-ol	8.0	MS, RI (std)
17	988	995	3-Octanol	12.1	MS, RI (std)
18	1026	1033	Benzyl alcohol	0.4	MS, RI (std)
19	1063	1069	Octan-1-ol	0.4	MS, RI (std)
20	1106	1114	Phenylethyl alcohol	6.3	MS, RI (std)
			Alcohols-terpenoids		
21	1095	1100	Linalool	14.6	MS, RI (std)
22	1118	1123	*cis-para*-Menth-2-en-1-ol	0.2	MS, RI (std)
23	1136	1141	*trans-para*-Menth-2-en-1-ol	0.2	MS, RI (std)
24	1165	1169	Borneol	1.1	MS, RI (std)
25	1174	1180	Terpinen-4-ol	2.3	MS, RI (std)
26	1186	1193	α-Terpineol	3.5	MS, RI (std)
27	1227	1228	Nerol	0.4	MS, RI (std)
28	1249	1254	Geraniol	1.6	MS, RI (std)
29	1561	1566	*trans*-Nerolidol	0.5	MS, RI (std)
30	1674	1677	β-Bisabolol	0.7	MS, RI (std)
31	-	1960	Diterpene alcohol	1.2	MS
32	-	1960	Diterpene alcohol	2.0	MS
33	-	1990	Geranyl linalool isomer	0.5	MS, RI (std)
34	-	1991	Geranyl linalool isomer	1.1	MS, RI (std)
35	-	2003	Geranyl linalool isomer	0.5	MS
36	-	2006	Geranyl linalool isomer	0.4	MS
37	-	2173	Geranyl geraniol	0.9	MS, RI (std)
			Aldehydes		
38	952	958	Benzaldehyde	0.43	MS, RI (std)
39	1036	1042	Phenylacetaldehyde	0.3	MS, RI (std)
40	1100	1103	Nonanal	0.6	MS, RI (std)
41	1150	1152	2,6-Nonadienal	0.1	MS, RI (std)
42	1247	1254	Anisaldehyde	0.1	MS, RI (std)
			Ketones		
43	972	976	1-Octen-3-one	0.1	MS, RI (std)
44	979	985	3-Octanone	1.9	MS, RI (std)
45	1118	1121	Isophorone	0.2	MS, RI (std)
46	1453	1453	Geranyl acetone	0.1	MS, RI (std)
47	1806	1819	Nootkatone	0.3	MS, RI (std)
			Esters		
48	1184	1185	*cis*-Hex-3-enyl butyrate	0.2	MS, RI (std)
49	1190	1196	Methyl salicylate	0.2	MS, RI (std)
50	1229	1232	*cis*-3-Hexenyl 2-methylbutyrate	0.3	MS, RI (std)
51	1254	1256	Phenylethyl acetate	0.3	MS, RI (std)
52	1319	1324	*cis*-3-Hexenyl tiglate	0.1	MS, RI (std)
53	1378	1380	*cis*-3-Hexenyl hexanoate	0.3	MS, RI (std)
54	1565	1574	*cis*-Hex-3-enyl benzoate	0.2	MS, RI (std)

			Phenyl propanoids		
55	1309	1314	4-Vinyl guaiacol	0.1	MS, RI (std)
56	1356	1359	Eugenol	0.9	MS, RI (std)
57	1432	1440	Coumarin	0.6	MS, RI (std)
58	1555	1556	Elemicin	1.2	MS, RI (std)
			Other oxygenated compounds		
59	1067	1073	*cis*-Linalool oxide (furanoid)	0.4	MS, RI (std)
60	1084	1089	*trans*-Linalool oxide (furanoid)	0.3	MS, RI (std)
61	–	1269	Hydroquinone	1.0	MS, RI (std)
62	1542	1549	*cis*-Sesquisabinene hydrate	0.8	MS, RI (std)
63	1577	1585	*trans*-Sesquisabinene hydrate	0.2	MS, RI (std)
64	–	1595	β-Caryophyllene epoxide	3.9	MS, RI (std)
65	1608	1620	Humulene epoxide	1.1	MS, RI (std)
			Heterocyclic compound		
66	1290	1294	Indole	0.5	MS, RI (std)

RI (std) = by comparison of RI with in-house library of standards, RI (lit) = by comparison of RI with published data, MS = identification by MS match with in-house and commercial libraries (NIST, Adams, Mass finder)

geranyl geraniol and four isomers of geranyl linalool which can be correlated with the unidentified diterpene hydrocarbons through corresponding biosynthetic pathways [16]. Isomers of linalool oxides (furanoid) were also detected.

The most abundant component of the oil was the monoterpenoid linalool (14.6%) followed by 3-octanol (12.1%), oct-1-en-3-ol (8%) and 2-phenylethanol (6.3%). It is common to have linalool as the most abundant component in one of its enantiomeric forms in many flower essential oils [17]. The oil also consisted of nerol, geraniol and terpineol which have the same biosynthetic precursor as linalool. Other compounds of interest were indole (0.5%) and β-caryophyllene epoxide (3.9%). Indole can be expected as it is a common ingredient of fragrant white flowers such as jasmine and orange blossom [18] while the latter may be one of the resultants of the photo-oxidation of caryophyllene [19].

Olfactoric properties: The olfactory evaluation of the oil revealed the presence of a wide spectrum of impressions ranging from spicy-floral to mushroom-metallic and woody-earthy to honey-like. A total of 38 odour impressions were detected and correlated with the corresponding components (Table-2). Twenty five of these impressions corresponded to the compounds detected in GC-FID analysis. Five of the remaining impressions corresponded to compounds, which were similar in structure to those of the detected compounds while another five corresponded to undetected compounds. There were three impressions which could not be assigned chemically.

Sesquiterpene hydrocarbons in the oil mainly imparted herbal and woody odour as the base note. Three of the four phenylpropanoids stabilize this. Eugenol and an unidentified sesquiterpene hydrocarbon added spicy notes. β-Bisabolol, *cis*-sesquisabinene hydrate, β-caryophyllene epoxide, non-2-enal and octanoic acid were the other components enhancing the herbal woody note. The most abundant component linalool give the fresh floral impression which was enhanced by octan-1-ol, geraniol and phenylacetaldehyde. The other floral impressions were that of phenylethyl alcohol and sweet floral impression of vanillin and β-ionone (both undetected in GC-MS). β-Ionone, a rose ketone having comparatively high relative percentage of odour units is found to be very active even in very low quantities around 0.03 % [20]. The animallic-floral impression observed in the olfactogram corresponded to *p*-cresol while the similar note expected for indole was absent. All these synergize to give the pleasant floral impression.

Terpinen-4-ol and α-terpineol imparted a medicinal impression to the oil enhanced by methyl salicylate. Mushroom impressions were added by oct-1-en-3-ol and 3-octanol. A faint 'green-odour' due to hexane derivatives was also observed. The known grapefruit impression of nootkatone (0.35%) was not observed by the GC-olfactometry analysis. The honey-like sweet impression of phenylethyl acetate was detected more than once but they corresponded to the retention indices of phenylethyl alcohol and heliotropin. The impression directly from phenylethyl acetate may be masked by other floral notes. There were also unassigned peaks in the olfactogram for faint smokey, cresolic, phenolic and an earthy mossy geosmin like impressions. No peak on the MS trace could be observed in the region where the "strong earthy geosmin" impression was smelled, although the measured retention index of 1430 is close to the library value of 1420 for geosmin.

Thus, the olfactoric analysis allow the conclusion that the teak flower essential oil can be described as herbal-woody, spicy-floral, medicinal, mushroom-like and earthy geosmin-like. Even though of very low yield, the oil can be suggested for fine perfumery applications where these notes are essential.

Chemical ecology: It is established from the data analysis (Tables 3 and 4) that at least 45 out of 66 components in the teak flower oil hold strong semiochemical relationship with one or the other family of insect visitors identified. Of these 38 compounds are in relationship with more than one class. Four of them namely benzaldehyde, linalool, methyl salicylate and caryophyllene have interaction with all the six classes of insects analyzed. Thirteen compounds are affiliated with five families altogether in one or the other way.

Presence of large number of volatile compounds with diverge semiochemical behaviour may be main reason for the enormous number of insects visiting teak flower which is already rich in nectar. Of the insect families, Hymenopterans have maximum number (36) of affiliated molecules with 20 attractants,

TABLE-2
TEAK FLOWER OIL-GAS-CHROMATOGRAPHY-OLFACTOMETRY EVALUATION

No	Peak start	Peak end	Comment	RI	Identification
1	12.49	12.57	Faint green hexenol like	855	*cis*-3-Hexenol
2	16.39	16.52	Mushroom earthy strong	980	Oct-1-en-3-ol
4	17.01	17.17	Faint mushroom metallic	995	3-Octanol
5	18.41	18.48	Herbal eucalyptus like	1040	1,8-Cineole
6	18.66	18.79	Floral spicy slightly rosy	1048	Phenylacetaldehyde
7	19.34	19.44	Aldehydic slightly floral	1070	Octanol
8	19.58	19.65	Faint animalic jasmine	1075	*p*-Cresol
9	20.15	20.23	Faint smoky cresolic phenolic	1095	Not identified
10	20.36	20.49	Floral citrus linalool like	1102	Linalool
11	20.91	21.19	Floral spicy rosy PEA like	1121	Phenylethyl alcohol
12	21.82	21.92	Green hay faint	1150	*trans-p*-Menth-2-en-1-ol
13	22.02	22.16	Green dry hay like	1155	*cis*-3-Nonen-1-ol
14	22.27	22.41	Dry herbal/fougere like	1162	Non-2-enal
15	22.43	22.59	Herbal camphoraceous hay	1170	Octanoic acid
16	22.75	22.91	Dry hay herbal camphoraceaous	1179	Borneol
17	23.02	23.21	Herbal slightly medicinal terpineol like	1188	4-Terpineol
18	23.37	23.5	Medicinal terpineol like	1201	α-Terpineol
19	23.59	23.67	Medicinal salicylate like	1206	Methyl salicylate
20	24.64	24.76	Aniseed anisic strong	1246	Phenylacetic acid
21	24.98	25.11	Floral rosy citrus	1256	Geraniol
22	25.2	25.29	Anisic	1263	Anisaldehyde
23	25.44	25.64	Faint herbal sl. Floral powdery	1272	Hydroquinone
24	26.8	26.9	Dry herbal	1320	2,4-Decadienal/vinyl guaiacol
25	27.38	27.46	Honey like, sweet, Phenylacetaldehyde-like	1348	Heliotropin
26	27.97	28.08	Spicy clove eugenol	1366	Eugenol
27	28.51	28.56	Green aldehydic	1381	*cis*-3-Hexenyl hexanoate
28	29.35	29.44	Sweet floral sl. Vanillic	1410	Vanillin
29	29.69	29.84	Earthy geosmin strong	1430	No peak
30	30.01	30.1	Faint slightly woody	1445	Caryophyllene
31	30.39	30.58	Hay slightly herbal coumarin	1458	Coumarin
32	30.87	31.02	Faint slightly herbal woody	1479	Humulene
33	31.45	31.55	Sweet ionone like floral.	1499	β- Ionone
34	31.59	31.75	Green aldehydic estery	1508	Germacrene D + Alkyl thiopene
35	32.85	32.95	Faint herbal slightly woody	1559	Sesquisabinene hydrate/Elemicin
36	33.65	33.74	Woody sl. Spicy	1595	Unidentified sesquiterpene
37	34.19	34.33	Faint woody slightly earthy	1615	Caryophyllene epoxide
38	34.87	35.05	Earthy mossy geosmin like	1646	Not identified
39	35.88	36.01	Woody earthy damp	1688	β-Bisabolol

13 pheromones, 1 kairomones and 2 allomones. But the number of hymenopteran specie visiting the teak flower was less. This may be due to the presence of following compounds as allomones and alarm pheromones: benzaldehyde (a defence substance influencing hymenopteran species) [15], benzyl alcohol (a repellent of hymenopterans) [21] and *cis*-β-farnesene (a major alarm pheromone of aphids [22]).

Coleopterans with 20 attractants, 6 pheromones and 4 kairamone were also found fewer in number. This may be also attributed to the presence of 4 allomones especially benzaldehyde and hydroquinone [23]. Hemiptera with three allomones and thysanoptera with fewer semiochemicals (only a total of eight) was also fewer in number. There was a strong back up from six kairomones for thysanoptera but the presence of β-caryophyllene suspected to be a defense pheromone [24] may have blocked its way. Diptera with 16 attractants was also less in number clearly due to the presence of eugenol, which is a repellant for most of its species [25]. For lepidopterans, there was six kairamones at the same time not any allomone. Presence of phenylacetaldehyde having a low odour threshold of 4 units [26] and a high potency for attracting of lepidopterans [27] also favour this class. Thus, it became the prevalent group visiting teak flowers.

Role of linalool: Linalool was the most abundant component of the oil. It was also characterized by high volatility and low odour threshold value of six units [26]. In the present analysis, linalool held positive relationships with all the six insect families. Linalool was recognized as the universal fragrance constituents of white, night-blooming, insect-pollinated flowers worldwide [28]. Familiar examples of such plants are the evening primroses, nocturnal tobaccos, wild gingers, jasmines and long-spurred orchids. Linalool and its oxides along with the acyclic sesquiterpene nerolidol, heterocyclic compound indole and certain aromatic esters are detected as important components of the white floral olfactory [28]. All these compounds were identified in teak flower also. Linalool and other mentioned compounds also back up the presence of a large number of insect visitors.

TABLE-3
SEMIO-CHEMICAL RELATIONSHIP OF TEAK FLORAL VOLATILES AND INSECT VISITORS

No	Compound	Lepidoptera	Hymenoptera	Hemiptera	Coleoptera	Diptera	Thysano-ptra
1	*cis*-3-Hexenol	Kairamone	Attractant	Attractant	Attractant	Attractant	–
2	Hexanol	Kairamone	Pheromone	Allomone	Attractant	Kairamone	–
3	Benzaldehyde	Pheromone	Allomone	Pheromone	Allomone	Attractant	Kairamone
4	1-Octen-3-one	–	Kairamone	–	Kairamone	–	–
5	Oct-1-en-3-ol	–	–	Allomone	–	–	–
6	3-Octanone	–	Pheromone	–	Attractant	Attractant	–
7	3-Octanol	–	Pheromone	–	–	–	–
8	Benzyl alcohol	Attractant	Allomone	Pheromone	Attractant	Attractant	–
9	Phenylacetaldehyde	Attractant	Attractant	Attractant	Kairamone	Attractant	–
10	Octan-1-ol	Pheromone	Pheromone	Pheromone	Attractant	–	–
11	*cis*-Linalool oxide	Attractant	Attractant	–	Attractant	–	–
12	*t*-Linalool oxide	–	–	–	–	–	–
13	Linalool	Attractant	Attractant	Pheromone	Attractant	Attractant	Kairamone
14	Nonanal	Attractant	Pheromone	Kairamone	Attractant	Attractant	–
15	Phenylethyl alcohol	Pheromone	Pheromone	Pheromone	Pheromone	Attractant	–
16	Isophorone	Pheromone	–	–	–	–	–
17	2,6-Nonadienal	Pheromone	–	–	Allomone	–	–
18	Borneol	Attractant	Attractant	–	Pheromone	Attractant	–
19	Terpinen-4-ol	Kairamone	Attractant	Pheromone	Pheromone	Pheromone	–
20	Z-Hex-3-enyl butyrate	–	Attractant	–	–	Attractant	–
21	α-Terpineol	Attractant	Attractant	Pheromone	Attractant	Attractant	–
22	Methyl salicylate	Attractant	Attractant	Attractant	Attractant	Attractant	Attractant
23	Nerol	Pheromone	Pheromone	Pheromone	Pheromone	–	Kairamone
24	Geraniol	Pheromone	Pheromone	Pheromone	Attractant	–	Kairamone
25	Anisaldehyde	–	Attractant	–	Attractant	–	Kairamone
26	Phenylethyl acetate	Pheromone	Attractant	Pheromone	Kairamone	–	–
27	Hydroquinone	–	–	–	Allomone	–	–
28	Indole	Pheromone	Pheromone	Attractant	Attractant	Attractant	–
29	4-Vinyl guaiacol	–	–	–	Kairamone	–	–
30	Eugenol	Pheromone	Attractant	–	Attractant	Allomone	Kairamone
31	3-Hexenyl hexanoate	–	Attractant	–	–	–	–
32	α-Copaene	–	Attractant	–	Attractant	Attractant	–
33	7-Epi-Sesquithujene	–	–	–	Attractant	-	–
34	Caryophyllene	Pheromone	Attractant	Attractant	Attractant	Attractant	Pheromone
35	Coumarin	Attractant	–	–	Attractant	–	–
36	*trans*-α-Bergamotene	–	Pheromone	–	–	–	–
37	Geranyl acetone	Kairamone	Pheromone	Pheromone	Pheromone	Attractant	–
38	*cis*-β-Farnesene	–	Pheromone	–	–	–	–
39	α-Humulene	Kairamone	Attractant	Allomone	Attractant	Pheromone	–
40	γ-Muurolene	Attractant	Attractant	–	–	–	–
41	Curcumene	–	Attractant	Pheromone	–	–	–
42	Germacrene D	Attractant	–	–	–	–	–
43	δ-Cadinene	–	Pheromone	–	Allomone	–	–
44	*trans*-Nerolidol	Kairamone	Attractant	Attractant	Pheromone	–	–
45	β-Caryophyllene epoxide	Pheromone	Attractant	–	–	–	–
46	β-Bisabolol	–	–	–	Attractant	–	–

TABLE-4
SEMIO-CHEMICALS OF INSECT VISITORS OF TEAK FLOWER

Organism	Attractant	Kairamone	Pheromone	Allomone
Lepidoptera	11	6	12	0
Hymenoptera	20	1	13	2
Hemiptera	6	1	12	3
Coleoptera	20	4	6	4
Diptera	16	1	2	1
Thysanopetra	1	6	1	0

Honey bees and methyl salicylate: A number of compounds are present in teak flower oil as attractants for honeybees (order hymenoptera) among which phenylacetaldehyde [29] and linalool [30] are most significant. The phenolic ester methyl salicylate appeared as an attractant for all the six classes under investigation. But when approaching the case of honeybees it was often emerged as a potent repellent [30,31]. Methyl salicylate in combination with benzyl alcohol also showed repellency towards honeybees [31]. Also in some studies 3-octanone was also recognized as possessing some repellency against honey bees [30]. Thus the presence of methyl salicylate along with octanone and benzyl alcohol is the reason for the low visiting frequency of honey bees in teak flowers.

Conclusion

In this work, the floral volatiles of teak were analyzed by GC, GC-MS and GC-olfactory techniques, which revealed a large number of volatile organic compounds with diverging semiochemical behaviour. These compounds attract enormous number of insects belonging to different order. But the presence of some specific compounds *viz*. allomones and alarm pheromones results in the repulsion of some effective pollinators like Indian honey bee. The ultimate result is destruction of the floral organs, ineffective pollination and low fruit formation in teak. A biomolecular modification of the species aiming higher relative concentration of compounds like linalool and phenyl acetaldehyde and a lower relative concentration of both 3-octanone and methyl salicylate in the floral aroma can be recommended for a more effective pollination.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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