

Exploring the phytochemical composition and therapeutic potential of Pogostemon cablin Benth: A comparative study in sole cropping and intercropping under tappable rubber plantation

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Abstract

Patchouli (*Pogostemon cablin* Benth), is a herbaceous plant belongs to the Lamiaceae family characterized by its distinctive fragrance. The primary objective of its cultivation is the extraction of essential oil, which is widely utilized in various sectors, including cosmetics, perfumery, food and beverage production and pharmaceuticals. It is also a shade loving crop and suitable for intercropping in plantation crops especially coffee, tea, rubber and oil palm. The present study was conducted to screening out of the bioactive compounds and their pharmaceutical value in the essential oil of *P. cablin* grown under both rubber plantations and sole crop via gas chromatography and mass spectrometry. The results revealed that, steroids, terpenes, aromatic compounds and esters were found. In addition, several novel bioactive compounds with high pharmaceutical value are also found. These compounds which provides a way for the preparation of novel health care medicines to treat various health related problems. Hence, patchouli is recommended as the most suitable intercrop under rubber plantation.

1. Introduction

Patchouli (*Pogostemon cablin* Benth.) is a commercially significant aromatic plant that belongs to the Lamiaceae family which was predominantly cultivated in tropical regions, particularly in Southeast Asia being a primary area of production [1]. The plant synthesizes aromatic oil from its leaves, which is highly valued in both aromatherapy and perfumery due to its potent, spicy aroma. Patchoulol, the principal constituent of patchouli essential oil, plays a critical role in determining the fragrance's longevity and is commonly utilized as an indicator of the quality of essential oils [2].

The essential oil obtained from the twigs and leaves of patchouli is widely utilized in the commercial production of perfumes and cosmetics. Additionally, it possesses antifungal, diuretic, febrifuge, antibacterial, antioxidant activity, anti-inflammatory, sedative and anti-depressive [3, 4]. In the context of traditional Chinese medicine, a decoction of the leaves is employed in conjunction with other therapeutic agents to address conditions such as nausea, vomiting, diarrhoea, cold and headaches [5].

A significant function of patchouli oil is its role as a fixative agent, which reduces evaporation rates and enhances the stability of mixtures when combined with more volatile components [6]. This fixative property contributes to the strength and longevity of perfumes when blended with other essential oils [7]. Furthermore, the fixative characteristics of patchouli oil assist in minimizing evaporation and improving stability, rendering it valuable in the formulation of soaps, fragrances, body lotions, and detergents. In the realm of aromatherapy, patchouli oil is employed to calm nerves, suppress appetite, and alleviate symptoms of depression and stress. Additionally, it is included in the FDA's list of substances approved for human consumption as a flavoring agent in natural foods [8]. Within the food industry, patchouli oil is frequently used as a flavoring component in various products, including both alcoholic and non-alcoholic beverages [9], typically at low concentrations to flavor foods, beverages, confections and baked goods [10].

In India, the consumption of patchouli oil is significantly driven by innovations in multifunctional products and the development of novel fragrance combinations for both perfumery and aromatherapy applications. Moreover, patchouli serves as an essential ingredient in the fragrance industry, as no synthetic substitutes exist for perfumers. Patchouli essential oil is a high value commodity in both domestic and international markets. However, the existing supply is insufficient to meet the global demand [11].

P. cablin is recognized as a shade-tolerant crop that is particularly well-suited for intercropping within plantation systems particularly in coconut, tea, coffee and rubber plantations [11]. Rubber (*Hevea brasiliensis* Muell. Arg.) has emerged as a crucial strategic material and a significant economic crop across Southeast and South Asia [12]. However, economic viability of rubber plantations is often limited by the extensive spacing between rows, which leads to suboptimal land utilization. To enhance economic returns while efficiently utilizing limited land resources [13], intercropping presents a viable cultivation strategy that supports and enriches the plantation ecosystem [14]. This approach facilitates improved spatial organization and interspecific competition among crops, optimizes resource use [15], enhances the spatio-temporal utilization of farmland soil [16], promotes healthy crop development, and increases overall productivity[17]. Furthermore, intercropping systems have been shown to significantly influence the phytochemical and nutrient profiles of plants (Arenas-Salazar et al., 2024). However, the effects of intercropping *P. cablin* under tappable rubber plantations on phytochemicals found in the essential oil which are beneficial to human health have yet to be thoroughly investigated. This present study was conducted to evaluate the impact of intercropping patchouli under rubber ecosystem on the bioactive compounds in comparison to open cultivation conditions.

2. Materials and methods

2.1 Plant collection:

The planting material (*P. cablin* var. Shrestha) was collected from Central Institute of Medicinal and Aromatic Plants Regional Research Station, Bangalore, India. The plants were grown under rubber plantation with 60 x 45 cm spacing in Horticultural Research Station, Pechiparai, Kanyakumari district of Tamil Nadu, India during the year 2024 by following recommended package of practices. The leaves were collected at 120 days after planting in both open field and rubber plantation.

2.2 Extraction of essential oil

The freshly collected leaves were shade dried for 1 week, after which 100 g of the shade dried leaves were subjected to hydro distillation using a Clevenger apparatus. The distillation was performed using a heating mantle with an integrated thermostat, maintaining a temperature of 90°C until the mixture reached boiling, followed by a reduction to 70°C for a period of 3 hours. After allowing the distillate to cool to room temperature, the oil layer was permitted to settle and its volume was quantified using the formula provided below. The resulting essential oil was dried over anhydrous sodium sulphate, filtered and then stored in a sealed glass vial at 4°C prior to analysis.

$$\text{Essential oil (\% (v/w))} = \frac{\text{Volume of oil (ml)}}{\text{Weight of the sample (g)}} \times 100$$

2.3 Gas Chromatography Mass Spectrometry (GC-MS)

The essential oil was analyzed through gas chromatography-mass spectrometry (GC-MS) using a Thermo GC Ultra Clarus 500 system, which integrates a gas chromatograph with a mass spectrometer. This system incorporates an Elite-I fused RMS 5 silica capillary column composed of dimethyl polysiloxane, coupled with an electron ionization source operating at an ionization energy of 70 eV for detection. A sample volume of 1 µl was injected using a 10:1 split ratio, with helium (99.9%) employed as the carrier gas at a constant flow rate of 1 ml/min. The ion source and injector temperatures were set at 250°C and 260°C, respectively. The oven temperature commenced at 110°C, increasing by 5°C per minute until it reached 260°C, where it maintained an isothermal condition for three minutes. Mass spectra were obtained for fragment ranges of 50 to 650 Da with a scan interval of 0.5 seconds, and Turbo Mass software was utilized for the management of mass spectra and chromatograms. The percentage composition of each component was determined by comparing its average peak area to the total peak area.

2.4 Identification of phytochemicals

The interpretation of the mass spectrum obtained from the GC-MS analysis was conducted utilizing the National Institute of Standards and Technology (NIST) database, which contains over 90,000 compounds. Information was retrieved from the NIST Standard Reference Database 1A version 14 (<https://www.nist.gov/srd/nist-standard-reference-database1a-v14>). To facilitate the identification of unknown components, spectra from both the NIST and Wiley libraries were employed for comparative analysis. This approach enabled the determination of the identity, molecular formula, molecular weight and compositional profile of the identified bioactive compounds.

2.5 Identification of biological activity of phytochemicals:

Predictions regarding the biological activities of the phytochemicals were conducted using PASS (Prediction of Activity Spectra for Biologically Active Substances), which relies on the structural formulas of the compounds. As detailed in the PASS online database [18] various pharmacological effects, specific toxicities and potential modes of action were projected for these substances.

2.6 Statistical analysis

All data were analyzed utilizing standard statistical methodology *ie.*, analysis of variance (ANOVA). To assess the significance of differences between the means of sole crops and intercrops for essential oil yield and recovery (%) of *P. cablin*, a 't' test was conducted at a significance level of P = 0.05 using the software KAU grapes. The variances for both populations were estimated in accordance with the methodologies established by [19] and [20].

3. Results

3.1 Essential oil yield and recovery (%)

The essential oil yield and recovery per cent of patchouli under various growth conditions were represented in figure 1. Patchouli intercropped under tappable rubber plantations exhibited highest essential oil yield (1.27%) and recovery percent (1.05%) when compared to sole crop (1.25 and 0.92%)

3.2 Photochemical profiling of patchouli in various growth conditions

The list of identified bioactive compounds together with their molecular weight, molecular formula, peak area (%) and retention time (min) found in the essential oil of patchouli grown under rubber and open field conditions are illustrated Table 2 and 3. A chromatogram of diverse distinct bioactive chemicals found in patchouli grown under various conditions is shown in Fig. 2. The principle phytochemicals with significant pharmaceutical value identified in the essential oil of patchouli intercropped under rubber plantations include 2,6,10,14,18,22-tetracosahexaene, 2,6,10,15,19,23-hexamethyl-, (e)- (28.50%), phytol (12.65%), stigmasta-4,22-dien-3.β.-ol (8.42%), ethyl 4-ethoxybenzoate (7.13%), .γ.-sitosterol (6.85%), 1h-indole-2-ethanol, .β.-(3-ethylidene-1-methyl-4-piperidiny)-3- methyl (4.39%), dl-threitol (3.06%), dl.α.-tocopherol (2.70%), terephthalic acid, 4-octyl octyl ester (2.10%), campesterol (2.06%) and patchoulol (1.93%). The minor compounds are aromandendrane (0.94%), α gujanene (0.87%), benzene, 1-fluoro-4-(2-methoxyethenyl)-, (z)- (0.82%), 2,6-octadienal, 3,7-dimethyl- (0.81%), cyclohexane, 1-ethenyl-1-methyl-2,4-bis (1-methylethenyl)-, [1s-(1.α.pha.,2.β.,4.β.)]- (0.74%), 1,6-cyclodecadiene, 1-methyl-5-methylene-8-(1-methylethyl)-, [s-(E,E)]- (0.73%), 2,6-octadienal, 3,7-dimethyl-, (z) (0.69%) and 3(2H)-benzofuranone, 6,7-dimethyl- (0.67%).

The major phytochemicals found in patchouli grown under open field conditions are benzene, [1-(2,4-cyclopentadien-1-ylidene)ethyl]- (18.20%), phytol (9.29%), patchoulol (7.90%), 9,12,15-octadecatrien-1-ol, (Z,Z,Z)- (7.15%), β.-sitosterol (6.68%), n-hexadecanoic acid (6.27%), diglycerol (6.19%), 2,6,10,14,18,22-tetracosahexaene (4.67%), stigmasterol (4.39%), α guajene (3.35%), E,Z-1,3,12-nonadecatriene (3.08%), 1-isopropoxy-2-dimethyl-(allyl)-silyloxybenzene (2.49%), hexadecanoic acid, 2-hydroxy-1-(hydroxymethyl)ethyl ester (2.35%), ethyl 4-ethoxybenzoate (2.14%) and azulene, 1,2,3,4,5,6,7,8-octahydro - 1,4-dimethyl-7-(1-methylethenyl)-, [1s-(1.α.,4.α.,7.α.)]- (2.06%). The minor bioactive are bicyclo[3.1.1]heptane, 2,6,6-trimethyl(1.α.,2.β.,5.α.) (0.98%), octadecanoic acid, 2-hydroxy-1-(hydroxymethyl)ethyl ester (0.98%), caryophyllene (0.96%), seychellene (0.92%), 4-amino-furazan-3-carboxylic acid [2-(3,4-dimethoxy-phenyl)-ethyl]-amide (0.87%), 1-oxaspiro[2.5]octane, 5,5-dimethyl-4-(3-methyl-1,3-butadienyl)- (0.75%), 1- Naphthalene carbonitrile (0.64%), tetradecanoic acid (0.64%), 4h-pyran-4-one, 2,3-dihydro-3,5- di hydroxy-6-methyl (0.59%) and cedrene-v6 (0.55%) are detected in the essential oil of patchouli.

Figure 2. GC-MS chromatogram of identified bioactive compounds in *P. cablin* grown as intercrop and sole crop

Table 1
List of phytochemicals compounds identified in patchouli as intercrop rubber plantation

S.No	Compound	Retention time (min)	Peak area (%)	Molecular formula	Molecular weight
1.	2,6,10,14,18,22-Tetracosahexaene, 2,6,10,15,19,23-hexamethyl-, (allE)-	17.885	28.50	C ₃₀ H ₅₀	410.7
2.	Phytol	13.997	12.65	C ₂₀ H ₄₀ O	296.5
3.	Stigmasta-4,22-dien-3.β.-ol	21.718	8.42	C ₂₉ H ₄₆ O	410.7
4.	Ethyl 4-ethoxybenzoate	9.875	7.13	C ₁₁ H ₁₄ O ₃	194.23
5.	γ.-Sitosterol	22.473	6.85	C ₂₉ H ₅₀ O	414.7
6.	1H-Indole-2-ethanol, .β.-(3-ethylidene-1-methyl-4-piperidiny)-3-methyl	11.941	4.39	C ₂₀ H ₂₈ N ₂ O	312.4
7.	dl-Threitol	4.620	3.06	C ₄ H ₁₀ O ₄	122.12
8.	dl-α.-Tocopherol	20.263	2.70	C ₂₉ H ₅₀ O ₂	430.7
9.	Terephthalic acid, 4-octyl octyl ester	17.485	2.10	C ₂₃ H ₃₆ O ₄	376.5
10.	Campesterol	21.440	2.06	C ₂₈ H ₄₈ O	400.7
11.	Patchoulol	11.253	1.93	C ₁₅ H ₂₆ O	222.37
12.	Phthalic acid, benzyl 2-ethylhexyl ester	17.019	1.60	C ₂₃ H ₂₈ O ₄	368.5
13.	Decahydro-8a-ethyl-1,1,4a,6-tetramethylnaphthalene	12.197	1.55	C ₁₆ H ₃₀	222.41
14.	1,2,4-Trimethoxybenzene	11.430	1.48	C ₉ H ₁₂ O ₃	168.19
15.	Elemol	10.131	1.25	C ₁₅ H ₂₆ O	222.37
16.	4-Piperidinone, 1-methyl-	7.153	1.23	C ₆ H ₁₁ NO	113.16
17.	4H-Pyran-4-one, 2,3-dihydro-3,5-dihydroxy-6-methyl	6.398	1.22	C ₆ H ₈ O ₄	144.12
18.	2-Propanone, 1-(3,4,5-trimethoxyphenyl)-, oxime	16.308	1.21	C ₁₂ H ₁₇ NO ₄	239.27
19.	Caryophyllene	9.097	1.20	C ₁₅ H ₂₄	204.35
20.	Cyclohexanone	9.475	1.15	C ₆ H ₁₀ O	98.14

S.No	Compound	Retention time (min)	Peak area (%)	Molecular formula	Molecular weight
21.	Diethyl Phthalate	10.397	1.03	C ₁₂ H ₁₄ O ₄	222.24
22.	Caryophyllene oxide	10.486	1.02	C ₁₅ H ₂₄ O	220.35
23.	Aromandendrane	11.053	0.94	C ₁₅ H ₂₆	206.37
24.	Alpha Gujanene	9.764	0.87	C ₁₅ H ₂₄	204.35
25.	Benzene, 1-fluoro-4-(2-methoxyethenyl)-, (Z)-	12.075	0.82	C ₉ H ₉ FO	152.17
26.	2,6-Octadienal, 3,7-dimethyl-	7.586	0.81	C ₁₀ H ₁₆ O	152.23
27.	Cyclohexane,1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, [1S-(1.alpha.,2.beta.,4.beta.)]-	8.775	0.74	C ₁₅ H ₂₄	204.35
28.	1,6-Cyclodecadiene,1-methyl-5-methylene-8-(1-methylethyl)-, [s-(E,E)]-	9.620	0.73	C ₁₅ H ₂₄	204.35
29.	2,6-Octadienal, 3,7-dimethyl-, (Z)	7.309	0.69	C ₁₀ H ₁₆ O	152.23
30.	3(2H)-Benzofuranone, 6,7-dimethyl-	8.475	0.67	C ₁₀ H ₁₀ O ₂	162.18

Table 2
List of phytochemicals identified in patchouli grown under open field conditions

S. No	Compound	Retention time (min)	Peak area (%)	Molecular formula	Molecular weight
1.	Benzene, [1-(2,4-cyclopentadien-1-ylidene) ethyl]-	11.419	18.20	C ₁₄ H ₁₄ S	214.33
2.	Phytol	13.997	9.29	C ₂₀ H ₄₀ O	296.5
3.	Patchoulol	11.253	7.90	C ₁₅ H ₂₆ O	222.37
4.	9,12,15-Octadecatrien-1-ol, (Z,Z,Z)-	14.163	7.15	C ₁₈ H ₃₂ O	264.4
5.	β.-Sitosterol	22.473	6.68	C ₂₉ H ₅₀ O	414.7
6.	n-Hexadecanoic acid	13.019	6.27	C ₁₆ H ₃₂ O ₂	256.42
7.	Diglycerol	4.676	6.19	C ₆ H ₁₄ O ₅	166.17
8.	2,6,10,14,18,22-Tetracosahexaene	17.885	4.67	C ₂₄ H ₃₈	326.60
9.	Stigmasterol	21.718	4.39	C ₂₉ H ₄₈ O	412.7
10.	Alpha Guajene	9.764	3.35	C ₁₅ H ₂₄	204.35
11.	E,Z-1,3,12-Nonadecatriene	17.241	3.08	C ₁₉ H ₃₄ O ₂	294.5
12.	1-Isopropoxy-2-dimethyl-(allyl)-silyloxybenzene	18.174	2.49	C ₁₄ H ₂₂ O ₂ Si	250.41
13.	Hexadecanoic acid, 2-hydroxy-1-(hydroxymethyl)ethyl ester	16.308	2.35	C ₁₉ H ₃₈ O ₄	330.5
14.	Ethyl 4-ethoxybenzoate	9.875	2.14	C ₁₁ H ₁₄ O ₃	194.23
15.	Azulene, 1,2,3,4,5,6,7,8-octahydro - 1,4-dimethyl-7-(1-methylethenyl) -, [1S-(1.α.,4.α.,7.α.)]-	9.186	2.06	C ₁₅ H ₂₄	204.35
16.	Octadecanoic acid	14.297	1.43	C ₁₈ H ₃₆ O ₂	284.5
17.	5-Cholestene-3-ol, 24-methyl-	21.440	1.25	C ₂₈ H ₄₈ O	400.7
18.	Propanoic acid, 3-amino-3-(4-fluorophenyl)-, ethyl ester	11.930	1.18	C ₁₄ H ₁₉ FN ₂ O ₂	266.31
19.	A Patchoulene	9.508	1.03	C ₁₅ H ₂₄	204.35
20.	Patchoulene	11.042	1.01	C ₁₅ H ₂₄	204.35

S. No	Compound	Retention time (min)	Peak area (%)	Molecular formula	Molecular weight
21.	Bicyclo [3.1.1] heptane, 2,6,6-trimethyl(1.α.,2.β.,5.α.)	12.197	0.98	C ₁₀ H ₁₈	138.25
22.	Octadecanoic acid, 2-hydroxy-1-(hydroxymethyl)ethyl ester	17.374	0.98	C ₁₉ H ₃₈ O ₄	330.5
23.	Caryophyllene	9.097	0.96	C ₁₅ H ₂₄	204.35
24.	Seychellene	9.408	0.92	C ₁₅ H ₂₄	204.35
25.	4-Amino-furazan-3-carboxylic acid [2-(3,4-dimethoxy-phenyl)-ethyl]-amide	18.307	0.87	C ₉ H ₁₂ N ₄ O ₅	256.22
26.	1-Oxaspiro [2.5] octane, 5,5-dimethyl-4-(3-methyl-1,3-butadienyl)-	10.453	0.75	C ₁₄ H ₂₂ O	206.32
27.	1-Naphthalene carbonitrile	10.397	0.64	C ₁₁ H ₇ N	153.18
28.	Tetradecanoic acid	11.619	0.64	C ₁₄ H ₂₈ O ₂	228.37
29.	4H-Pyran-4-one, 2,3-dihydro-3,5-dihydroxy-6-methyl	6.387	0.59	C ₆ H ₈ O ₄	144.12
30.	Cedrene-V6	9.719	0.55	C ₁₅ H ₂₄	204.35

4. Discussion

The percentage of essential oil was significantly influenced by both intercropping and monocropping systems. Patchouli intercropped under rubber significantly recorded higher essential oil yield (%) and recovery percentage (%) in comparison with sole crop. This phenomenon can be attributed to the microenvironment, particularly the influences of leaf temperature, humidity and soil fertility. The positive effects of shade exert a considerable impact on the development and composition of quality indicators. In shaded conditions, secondary metabolites and alkaloids are produced through the degradation and resynthesis of primary metabolites, a process that is facilitated by the shaded environment. The biosynthesis of secondary metabolites in plants serves as an adaptive mechanism, enabling them to optimize their growth in shaded conditions and is intricately regulated by ambient environmental factors [21]. The enhanced oil yields observed in shade cultivation can be attributed to a greater cumulative dry herbage yield annually, a higher oil content in patchouli biomass, and reduced volatilization losses. Rao et al. [22] further concluded that, patchouli cultivated in a 50% shaded environment exhibited superior oil content compared to those grown in open conditions, which can be ascribed to the favorable climatic conditions and adequate moisture present in the red sandy loam soil of South India. It also confirm with the findings of Storck et al. [23].

Gas chromatography and mass spectrometry is an efficient and precise method for identifying a variety of metabolites, such as sugars, organic acids, polyols, and different phenolic and cyclic compounds. In our study, we found aromatic compounds, terpenes, flavonoids, esters, steroids, ketones, and alkaloids in the essential oil of *Pogostemon cablin* under both shaded and unshaded conditions.

Based on the findings via GC-MS analysis, a total of 30 compounds were identified in both the unshaded and shaded conditions. The pharmaceutical value of identified bioactive compounds of *P. cablin* in different ecosystem is represented in Table 3 and 4. Only few compounds are similar in both sole crop and intercropped condition which includes Phytol, Ethyl 4-ethoxybenzoate, Patchoulol, Caryophyllene yielded 12.65, 7.13, 1.93 and 1.20 per cent under rubber plantations and 9.29, 2.14, 7.90 and 0.96 respectively. Except patchoulol all the other phytochemicals was increased when grown under rubber plantation. This phenomenon may be due to the positive allelopathic effect between rubber and patchouli which triggers the production of phytochemicals as a various new phytochemicals as defensive mechanism. Similar findings was reported by Ntobela et al. [24].

Patchoulol is the major alkaloid found in *P. cablin*. Intercropping patchouli under rubber plantations reduced the patchoulol content than sole cropping system. This reduction was attributed due to low spectral quality of light which affects the production and chemical composition *P. cablin* [25].

Plant responses to light are species-specific, and the effects of light on the biosynthesis of secondary metabolites are distinct across different species. In natural environments, light intensity and photoperiod typically interact with various environmental factors, either synergistically or antagonistically, to regulate the biosynthesis of secondary metabolites in medicinal plants [26]. The production of secondary metabolites is depending upon environmental factors that influence their physiological characteristics by modifying metabolic pathways. Plants synthesize secondary metabolites as defensive compounds in response to stress induced by sunlight exposure [27]. The differences in the phytochemicals of *P. cablin* observed between monoculture and intercropping can be attributed to the effects of light on photosynthesis and respiration, which influence the movement of metabolites and diminish energy production through light reactions. This modification may subsequently affect the synthesis

Table 3

Pharmacological activity of identified bio active compounds in the essential of patchouli grown under rubber plantations

Name of the Compound	Nature of the compound	Pharmacological activity	References
2,6,10,14,18,22-Tetracosahexaene, 2,6,10,15,19,23-hexamethyl-, (allE)-	Polyene	Antiinflammatory	[28]
Phytol	Terpenoid	Antibacterial, antioxidant, antinociceptive, anti-inflammatory, and immune-modulating properties	[29, 30]
Stigmasta-4,22-dien-3.β.-ol	Steroid	Antimicrobial, antioxidant	[31, 32]
γ.-Sitosterol	Sterol	Antihyperlipidemic, Antidiabetic, Anticancer, Antiinflammatory	[33, 34]
1H-Indole-2-ethanol, .β.-(3-ethylidene-1-methyl-4-piperidiny)-3- methyl	Aromatic compound	Antidiabetic	[35]
dl-Threitol	Sugar alcohol	Antimicrobial and antioxidant	[36]
dl-α.-Tocopherol	Vitamin	Free radical scavenging, cytoprotective, and antioxidant properties	[37]
Terephthalic acid, 4-octyl octyl ester	Esters	Antimicrobial	[38]
Campesterol	Steroid	Reducing cholesterol, anticancer, anticarcinogenic	[39, 40]
Patchoulol	Sesquiterpenes	Antibacterial, antimicrobial, antidiabetic and antioxidant	[2, 41]
1,2,4-Trimethoxybenzene	Hydrocarbons	Inhibit NLRP3 inflammasome (Responsible for stroke, Parkinson's disease and multiple sclerosis)	[42]
Elemol	Sesquiterpenes	Anti-inflammatory, anti-microbial, antioxidant, hepatoprotective, and anti-tumor	[43]
4-Piperidinone, 1-methyl-	Nitrogen compounds	Antidiabetic, antipsychotic, antiallergic, anti-inflammatory, analgesic, antioxidant, anticancer, antibacterial, antimalarial and antifungal	[44]

Name of the Compound	Nature of the compound	Pharmacological activity	References
4H-Pyran-4-one, 2,3-dihydro-3,5-dihydroxy-6-methyl	Pyrans	Antioxidant, anti-inflammatory, antibacterial and antimutagenic	[45]
Caryophyllene	Sesqueterpene	anticarcinogenic, antibacterial, anti-inflammatory, and local anesthetic	[46]
Cyclohexanone	Cyclohexanones	Antiinflammatory and antiviral	[47, 48]
Diethyl Phthalate	Carboxylic acid	Antimicrobial	[49, 50]
Caryophyllene oxide	Terpenoid	Anti breast cancer, antiinflammatory and analgesic	[51, 52]
Aromandendrane	Terpenoid	Antifungal, antibacterial, and analgesic	[53]
2,6-Octadienal, 3,7-dimethyl-	Monoterpene	Fragrant agent, antifungal and antimicrobial agent	[54]

Table 4

Pharmacological activity of identified bio active compounds in the essential oil of patchouli grown under open field conditions

Compound	Nature of the compound	Pharmacological activity	References
Phytol	Terpenoid	Antibacterial, antioxidant, antinociceptive, anti-inflammatory and immune-modulating properties	[29, 30]
Patchoulol	Sesquiterpenes	antibacterial, antimicrobial, antidiabetic and antioxidant	[2, 41]
9,12,15-Octadecatrien-1-ol, (Z,Z,Z)-	Fatty alcohol	Antimicrobial	[55]
β -Sitosterol	Phytosterols	Anticancerous, antibacterial, immunomodulatory, anticancer, anti-diabetic, and antioxidant activities	[56, 57]
n-Hexadecanoic acid	Enzyme Inhibitors	anti-inflammatory, anti-cancer, antioxidant, antibacterial and hypocholesterolaemia	[58–60]
Diglycerol	alkylglycerol	Antiobesity, treated weight related problems, skin moisturizer	[61, 62]
2,6,10,14,18,22-Tetracosahexaene	Polyunsaturated hydrocarbons	Anticancerous, antibacterial and antioxidant	[63]
Stigmasterol	Phytosterols	Anti-cancer, reduced cholesterol, antidiabetic, antioxidant	[41, 64, 65]
E,Z-1,3,12-Nonadecatriene	Unsaturated fatty acid	Antimicrobial	[66]
Hexadecanoic acid, 2-hydroxy-1-(hydroxymethyl) ethyl ester	Esters	Hypocholesterolaemia, haemolytic, anti-androgenic and antioxidant	[67, 68]
Azulene, 1,2,3,4,5,6,7,8-octahydro - 1,4-dimethyl-7-(1-methylethenyl) -, [1S-(1.α.,4.α.,7.α.)]-	Alkene	Anti-inflammatory, antipyretic, antiseptic, antispasmodic, anti-ulcer, anti-allergic and anti-histaminic.	[69]
Octadecanoic acid	Fatty acid	Antioxidant, antitumor, antibacterial, inhibit covid 19 and cytotoxic activity	[70–74]
5-Cholestene-3-ol, 24-methyl-	Sterol	Skin conditioner, hormone replacement therapy, immunosuppressive and anti-inflammatory	[75]

Compound	Nature of the compound	Pharmacological activity	References
Octadecanoic acid, 2-hydroxy-1-(hydroxymethyl)ethyl ester	Stearic Acids	Antibacterial activity	[76]
Caryophyllene		Cytotoxic, antimicrobial, hypolipidemic, neuroprotective, cardioprotective, analgesic, anti-inflammatory, anticancer, and antioxidant	[46, 77]
Seychellene	Terpenes	Antioxidant	[78]
1-Naphthalene carbonitrile	Aromatic compound	Antimicrobial and anticonvulsant	[79, 80]
Tetradecanoic acid	Fatty acid	Antioxidant, haemolytic, antifibrinolytic, anti-inflammatory, antivirulence, anticancer, and 5-reductase inhibitory	[81, 82]
4H-Pyran-4-one, 2,3-dihydro-3,5-di hydroxy-6-methyl	Pyrans	antioxidant, antimutagenic, antibacterial, and anti-inflammatory	[45]

and accumulation of essential constituents in medicinal and aromatic plants. The bioproduction of phytochemicals is significantly influenced by light intensity and spectral quality [83]. To mitigate the detrimental effects of high

irradiance and UV radiation, plants accumulate phenolic compounds and various antioxidants, including carotenoids, flavonoids, and anthocyanins. Thus, manipulating spectral quality and light intensity can induce morphological and physiological changes that ultimately impact the biosynthesis, accumulation, and retention of phytochemicals.

While intercropping under rubber which induces the various novel compounds in *P. cablin* with high pharmaceutical value especially 2,6,10,14,18,22-Tetracosahexaene, 2,6,10,15,19,23-hexamethyl-, (allE)- which has anti inflammatory properties, Stigmasta-4,22-dien-3.β.-ol as antimicrobial and antioxidant, γ.- Sitosterol as Antihyperlipidemic, Antidiabetic, Anticancer and anti inflammatory, 1H-Indole-2-ethanol, .β.- (3-ethylidene-1-methyl-4-piperidiny)-3- methyl as antidiabetic, dl-Threitolas antimicrobial and antioxidant, 1,2,4-Trimethoxybenzene which inhibit NLRP3 inflammasome which was responsible for stroke, Parkinson's disease and multiple sclerosis.

5. Conclusion

Based on our finds, intercropping *P. cablin* under rubber plantation which significantly improve the essential oil yield (%), essential oil recovery (%) and produces novel bioactive compounds. The concentration of bioactives compounds found in the essential oil of *P. cablin* known for its significant

pharmacological and biological properties, was analyzed. These novel phytochemicals which was significantly utilized for the production of novel health care medicine. Hence, patchouli is the suitable intercrop under tappable rubber plantation under pechiparai conditions and it is recommended for the rubber planters.

Declarations

Acknowledgement: Not applicable

Authors contribution

Jaya Jasmine A, Rajakumar D and Sivakumar K designed the present study. Material preparation, data collection and analysis were performed by Sabarivasan M, Rubika R, Vasantharaj P and Deepikakrishnaveni T. The first draft of the manuscript was written by Sabarivasan M and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Plant guidelines: The authors confirm that the use of plant (Patchouli) in the present study complies with international, national and/or institutional guidelines.

Data availability: The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request

Code availability: Not applicable

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Figures

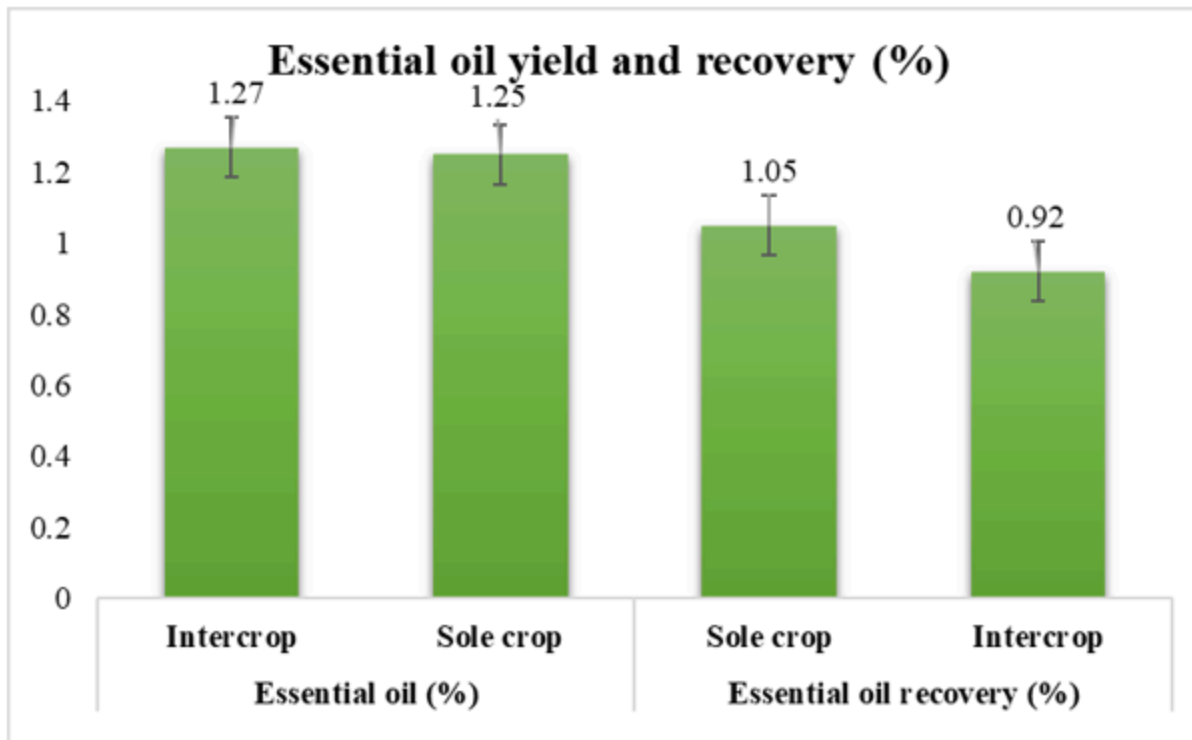


Figure 1

Essential oil yield and recovery (%) of *P. cablin* grown under different ecosystem

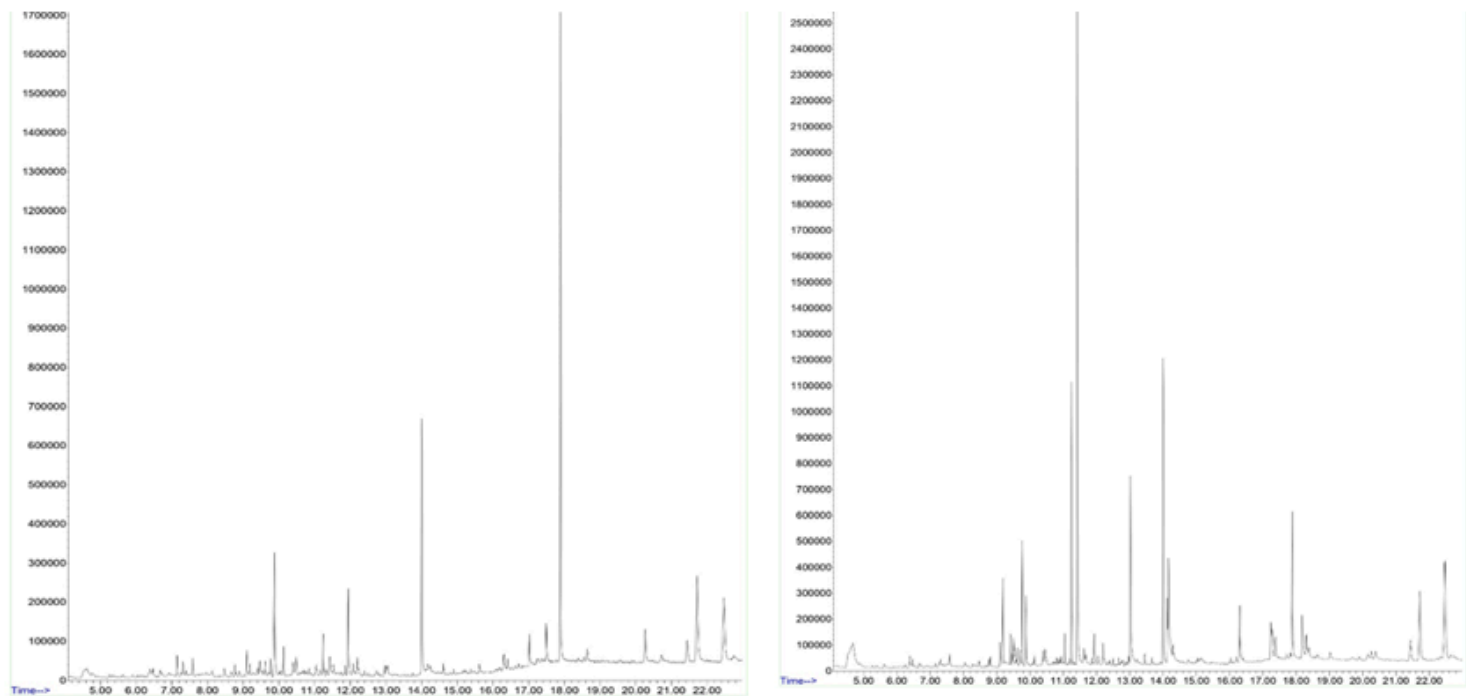


Figure 2

GC-MS chromatogram of identified bioactive compounds in *P. cablin* grown as intercrop and sole crop