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RESEARCH ARTICLE

Quality modulation of essential oils in lemongrass and citronella through *Melia dubia* Cav.-*Cymbopogon* agroforestry

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Abstract

Although quantitative data regarding *Melia dubia* Cav.-*Cymbopogon* interactions remains limited, silvi-aromatic agroforestry systems are progressively recognized for their ability to enhance land-use efficiency, agricultural income and sustainability by modifying microclimates and regulating secondary metabolism in aromatic crops. This research employed a replicated split-plot design with five replications over three harvests from 2024 to 2025 to evaluate the performance of two *M. dubia* clones (MTP-1 and MTP-2) intercropped with lemongrass (*Cymbopogon citratus*) and citronella (*Cymbopogon nardus*) at the University of Agricultural Sciences, GKVK, Bengaluru, India (13°04′ N; 77°35′ E). We assessed growth parameters, forage output, oil yield and oil content. We employed GC-MS to analyse the composition of the essential oil, utilizing spectral libraries and authentic standards for chemical identification. MTP-1 consistently surpassed MTP-2 in vegetative growth and biomass production during all harvests. At the third harvest, plants cultivated with MTP-1 measured 138.65 cm in height and produced 135.65 tillers. Plants cultivated with MTP-2 attained a height of only 88.15 cm and produced 67.75 tillers. The MTP-1 system produced greater quantities of fresh and dried herbage and oil (44.37 vs. 29.96 kg ha^{-1}), with the MTP-1 and lemongrass combination yielding the maximum oil output (46.36 kg ha^{-1}). The MTP-2 × citronella combination had a higher oil content (2.12 % compared to 1.76 %), indicating a trade-off between biomass accumulation and oil concentration. In citronella oil, shady conditions decreased citronellal while increasing geranyl acetate. The citral (geranial + neral) concentration in lemongrass oil was increased. Agroforestry systems with *M. dubia* enhance growth and oil yield while altering the composition of essential oils. This renders them beneficial for both the environment and the economy and they can be utilized to achieve market and quality objectives.

Keywords: aromatic grasses; biomass productivity; canopy microclimate; monoterpene profile; oil yield; silvi-aromatic integration

Introduction

Aromatic grasses of the genus *Cymbopogon* produce essential oils that are significant in the global essential oil market. Due to their aroma and several biological benefits, these oils are highly beneficial in perfumery, cosmetics, medicine, food preservation and agriculture. Lemongrass (*Cymbopogon citratus* (DC.) Stapf) and citronella (*Cymbopogon nardus* (L.) Rendle) are two significant grasses due to their high demand and diverse use. The primary constituents of lemongrass oil are citral (comprising E-citral and Z-citral) and neral. These compounds impart a citrous aroma to the oil and are celebrated for their antibacterial, antioxidant and anti-inflammatory properties (1-3). Citronella oil comprises citronellal, geraniol and citronellol, recognised for their efficacy in repelling insects and enhancing the fragrance of other substances (4, 5).

Genetic, agronomic and environmental factors influence the output and composition of essential oils. Studies demonstrate that distillation methods, the processing of botanical substances and harvest timing significantly affect the quality and composition of essential oils (6, 7). For instance, citral consistently ranks highest in lemongrass oils, regardless of the pretreatment methods employed. In citronella oils, citronellal consistently serves as the primary indicator, irrespective of the extraction method employed (3, 4). Additional research indicates that soil nutrient composition, irrigation methods and planting techniques can influence both the quantity and variety of essential oils produced (8, 9).

Agroforestry systems have recently garnered interest as sustainable land-use models that integrate trees with intercrops, hence enhancing resource utilisation efficiency and ecological resilience (10, 11). *Melia dubia*, a rapidly growing tree with diverse applications, has emerged as a viable component of these systems

due to its swift growth, short rotation period and compatibility with aromatic crops (12-14). Intercropping essential oil-producing grasses like lemongrass and citronella under *Melia dubia augments* farmer revenue, boosts land productivity and fosters soil health (15, 16). Despite the existence of these benefits, there is a lack of adequate data concerning the influence of tree-based agroforestry systems on the essential oil composition of citronella and lemongrass.

Previous research focused mainly on improving oil yield, extraction efficiency and the therapeutic qualities of lemongrass and citronella oils (1-3). Nevertheless, there are few similar studies evaluating the influence of solitary cropping versus tree-based intercropping on essential oil quality. Agroforestry can alter the biosynthesis of terpenoids and esters by modifying light exposure, shading and microclimatic conditions (17, 18), making it essential to thoroughly examine oil profiles in these contexts.

This study aimed to evaluate the effects of sole cropping and *Melia dubia*-based agroforestry systems on the essential oil composition of lemongrass and citronella via GC-MS analysis, specifically targeting the quantification of changes in key bioactive constituents of industrial significance. The hypothesis proposed that integrating these aromatic grasses into a *Melia dubia* agroforestry system modifies the crop microenvironment, consequently affecting secondary metabolite biosynthesis and leading to notable, species-specific differences in the relative abundance of essential oil constituents such as citral, neral, citronellal, geraniol and geranyl acetate, compared to monoculture cultivation.

Materials and Methods

Plant materials

The lemongrass leaves and citronella leaves utilised for essential oil production were sourced from experimental plots established at Agroforestry unit, 'M' block, University of Agricultural Sciences, GKVK, Bengaluru, India (13°04′ N; 77°35′ E). The plants were severed at 5–6 months of age, with the shoots excised at 50 cm above the root zone. We exclusively utilised fresh, green and intact leaves for the analysis. The mean moisture content was 74.75 ± 0.05 %. The Bioenergy Research and Quality Assurance Laboratory, UAS, GKVK, Bengaluru employed the analysis of given samples of essential oils through Gas Chromatography-Mass Spectrometry. We utilised the citral analytical standard for GC-MS compound identification, which exhibited a purity of 98.3 % (cis-citral 49.2 % and trans-citral 49.1 %).

Experimental design

A split-plot experiment was conducted to examine the influence of *Melia dubia* clones and aromatic crop type on growth, yield and essential oil quality. The primary plot variable was the *M. dubia* clones, consisting of M_1 (MTP-1) and M_2 (MTP-2). The fragrant crop served as the sub-plot variable: S_1=lemongrass and S_2 = citronella. The plots were arranged in a random sequence suitable for split-plot design. The primary plots were designated for *M. dubia* clones, with sub-plots incorporated within each main plot. Throughout the cropping cycle, three harvests occurred: the first, second and third.

Experimental site

The research was conducted at the "M" block of the Agroforestry unit under the Zonal Agricultural Research Station (ZARS), Bengaluru, GKVK. Prior to the establishment, composite soil samples (0-15 cm) were analysed for pH, electrical conductivity, organic carbon, available nitrogen, phosphorus, potassium and texture. The site saw standard land preparation, with baseline fertilisation and irrigation protocols consistently applied across treatments in compliance with local regulations for *Cymbopogon* spp.

Lemongrass and citronella grass

Certified slips of S_1 (Lemongrass) and S_2 (Citronella) were relocated to an area measuring 5.0 m × 5.0 m. Aromatic grass rows in multi-crop plots were situated 0.6 m from the tree line. The *M. dubia* trees were spaced 5.0 m apart in rows and 5.0 m apart between plants. Weed management, earthing-up and watering were executed uniformly. Nutrient management relied on soil analyses, including the division of nitrogen application following each harvest. Insect and disease control adhered to integrated pest management protocols and was uniform across all treatments. Pruning in M_1 and M_2 was conducted in accordance with the established regulations for each system (19).

Growth and yield assessment

Quantified plant height (from the soil to the apex of the highest leaf collar), the number of tillers per clump and the number of leaves per clump at each harvest. We accomplished this by labelling the central plants inside each plot. The average of two perpendicular diameters was employed to assess the canopy spread along the east-west and north-south directions. To obtain the fresh herb yield in kg ha^{-1}, we harvested the above-ground biomass from the net plot area and converted it to a hectare basis (20).

A representative sub-sample was dried in an oven at 60 ± 2 °C until a consistent weight was achieved to determine the dry herb yield (kg ha^{-1}) and moisture content (21).

Oil content (%) by examining the dry weight (g oil per 100 dry herbage) and the oil yield (kg ha^{-1}) by analysing:

$$\text{Oil yield} = \frac{(\text{Oil content (\%)} \times \text{Dry herb yield (Kg/ha)}) \; (\text{Oil content (\%)} \times \text{Dry herb yield (Kg/ha)}}{100} \quad \ldots (1)$$

Oil extraction

A Clevenger apparatus was employed to hydro distillation the essential oils. Over a duration of 3 hr, 2 L of distilled water were employed to distil around 500 g of fresh leaves. The recovered oil was extracted from the aqueous layer, desiccated using anhydrous sodium sulphate and stored in amber vials at 4 °C until subsequent testing. We calculated the oil yields based on the fresh weight and recorded them as a percentage (v/w) (22).

Gas Chromatography-Mass Spectrometry (GC-MS) analysis and component identification

We employed a Shimadzu QP2020 series gas chromatograph equipped with an SH-Rxi-5Sil capillary column (30 m × 0.25 mm × 0.25 µm) to identify the chemical constituents of the essential oils. The carrier gas utilised was helium, which flowed at a constant rate of 1.20 mL min^{-1}. The injector possessed a volume of 1.0 µL, a split ratio of 1:50 and a pressure of 68.3 kPa.

The oven temperature protocol commenced with a 2 min hold at 50 °C, subsequently increased to 220 °C at a rate of 10 °C min^{-1} and ultimately ascended to 310 °C at a rate of 15 °C min^{-1}, followed by a 5 min wait. A flame ionisation detector (FID) maintained at 320 °C was employed to detect the signal. We correlated the mass spectra

of the identified compounds with the NIST/EPA/NIH Mass Spectral Library and subsequently validated them against authentic standards, including citral (Sigma-Aldrich, 98.3 % purity) (23).

Statistical analysis

An experiment was conducted in triplicate and the results were reported as mean ± standard deviation. A one-way analysis of variance (ANOVA) was employed to evaluate changes in primary chemicals between cropping regimes. Split plot design was employed at a 5 % significance level to differentiate the means (24).

Results and Discussion

Growth attribute

Aromatic crops grown under the MTP-1 clone of *Melia dubia* consistently exhibited superior vegetative growth compared to MTP-2 in all harvests (Table 1). Plants cultivated under M_1 attained a height of 138.65 cm by the third harvest, representing an increase of about 58 % compared to those under M_2 (88.15 cm; $p < 0.05$). During each harvest, lemongrass (S_1) consistently exhibited greater height than citronella (S_2). The interaction adhered to a distinct sequence ($M_1S_1 > M_1S_2 > M_2S_1 > M_2S_2$), with M_1S_1 attaining a peak height of 146.80 cm during the third harvest. The substantial growth advantage associated with MTP-1 likely arises from the clone's ability to establish a superior microclimate and resource environment, characterized by reduced radiation, enhanced soil conditions from litter inputs and improved water-use efficiency. These circumstances are recognized for promoting vegetative growth and canopy development in C_4 grasses such as *Cymbopogon* when cultivated in silvi-aromatic systems rather than in monoculture cropping.

A similar trend was observed for tillering (Table 1). The quantity of tillers per clump increased consistently from the first to the third harvest. M_1 exhibited nearly double the number of tillers (135.65 clump^{-1}) compared to M_2 (67.75 clump^{-1}; $p < 0.05$). Lemongrass consistently outperformed citronella across all harvests, with the interaction ranking remaining unchanged ($M_1S_1 > M_1S_2 > M_2S_1 > M_2S_2$), where M_1S_1 exhibited the highest number of tillers (146.40 clump^{-1}). Enhanced light diffusion and reduced heat stress beneath the tree canopy resulted in superior tillering in MTP-1. These conditions are conducive to initiating and sustaining tiller viability, as observed in *Melia dubia–Cymbopogon* agroforestry systems (25).

The pattern of leaf development was analogous to that of tillering (Table 1). M_1 documented 59.40 leaves per clump by the third harvest, but M_2 documented 37.55 leaves per clump. This indicates that M_1 possessed 58 % more leaves ($p < 0.05$). Lemongrass had a greater leaf count than citronella, with the M_1S_1 interaction yielding the highest number of leaves (61.20 clump^{-1}). The increased leaf area under MTP-1 likely enhanced photosynthetic capacity, resulting in greater biomass accumulation. This aligns with previous reports regarding moderated-light agroforestry systems with lemon grass (26).

As the crops matured, the canopy expansion (east–west and north–south) increased. It consistently exceeded under M_1 compared to M_2 (Table 2). During the third observation, M_1 exhibited canopy spreads of 87.0 cm (E–W) and 76.8 cm (N-S), which were 25-32 % more than those of M_2 ($p < 0.05$). M_1S_2 demonstrated the most pronounced canopy expansion among the interactions. The responses indicate that *M. dubia* alters light absorption and influences plant growth in space. This corroborates research indicating that canopy density, leaf orientation and diurnal light distribution significantly influence the structure of understory crops (27, 28).

Yield attribute

The yields of fresh and dry herbs increased with each harvest, significantly above those under M_1 compared to M_2 (Tables 3). During the third harvest, the yield of fresh herbs under M_1 (2519 kg ha^{-1}) exceeded that of M_2 (1503 kg ha^{-1}) by over 68 % ($p < 0.05$). Lemongrass consistently outperformed citronella, with the highest interaction yield recorded at M_1S_1 (2667 kg ha^{-1}). A comparable trend was observed in the yield of desiccated herbs, with M_1 outperforming M_2 by over 65 % and M_1S_1 yielding the highest dry biomass at 1289 kg ha^{-1}. The yield gains stem directly from enhanced vegetative characteristics, including increased tiller density, greater leaf count and an expanded canopy spread. Collectively, these characteristics enhanced photosynthetic efficiency and augmented biomass output under MTP-1, aligning with prior studies on lemongrass-based intercropping and agroforestry systems (29-31).

Oil yield and composition

The oil content percentage exhibited an inverse relationship with biomass output (Tables 4). M_2 and S_2 exhibited higher oil content, particularly during the third harvest (M_2 = 2.12 %; S_2 = 2.27 %). The maximum value was seen in M_2S_2 (2.75 %). M1 and lemongrass (S_1) exhibited reduced oil percentages. This disparity illustrates a fundamental trade-off between biomass and concentration: M_1's rapid growth and greater dry matter accumulation resulted in a diminished oil concentration percentage, whereas M_2's reduced biomass yielded a higher oil concentration. Reports indicate that light-mediated dilution effects on essential oil content occur, with

Table 1. Growth parameters of aromatic crops as influenced by *Melia dubia* clones under agroforestry system

Main Plot (*Melia dubia* clones)	Plant height (cm)			Number of tillers per clump			Number of leaves per clump		
	1st harvest	2st harvest	3rd harvest	1st harvest	2st harvest	3rd harvest	1st harvest	2st harvest	3rd harvest
M_1: MTP-1	117.85	132.50	138.65	97.55	111.40	135.65	48.45	56.25	59.40
M_2: MTP-2	72.50	81.70	88.15	54.35	61.60	67.75	29.15	34.10	37.55
S.Em ±	**0.64**	**2.23**	**1.96**	**0.42**	**0.28**	**2.65**	**0.57**	**0.63**	**0.25**
CD (*p*=0.05)	**3.87**	**13.54**	**11.94**	**2.53**	**1.70**	**16.15**	**3.47**	**3.84**	**1.50**
Sub plot (aromatic crops)									
S_1: Lemon grass	98.35	111.60	119.75	84.10	95.45	111.40	42.80	48.00	51.00
S_2: Citronella grass	92.00	102.60	107.05	67.80	77.55	92.00	34.80	42.35	45.95
S.Em ±	**0.19**	**0.58**	**0.70**	**0.13**	**0.15**	**0.05**	**0.10**	**0.24**	**0.22**
CD (*p*=0.05)	**0.76**	**2.27**	**2.74**	**0.51**	**0.59**	**0.21**	**0.38**	**0.96**	**0.85**
Interaction effect (M×S)									
M_1S_1: MTP-1+ Lemon grass	121.50	138.70	146.80	106.80	121.20	146.40	52.10	58.40	61.20
M_1S_2: MTP-1+ Citronella grass	114.20	126.30	130.50	88.30	101.60	124.90	44.80	54.10	57.60
M_2S_1: MTP-2+ Lemon grass	75.20	84.50	92.70	61.40	69.70	76.40	33.50	37.60	40.80
M_2S_2: MTP-2+ Citronella grass	69.80	78.90	83.60	47.30	53.50	59.10	24.80	30.60	34.30
S.Em ±	**0.27**	**0.82**	**0.99**	**0.18**	**0.21**	**0.08**	**0.14**	**0.34**	**0.31**
CD (*p*=0.05)	**1.08**	**3.21**	**3.87**	**0.72**	**0.83**	**0.30**	**0.53**	**1.35**	**1.21**

Table 2. Plant spread (cm^2) of aromatic crops as influenced by *Melia dubia* clones under agroforestry system

Main Plot (*Melia dubia* clones)	Treatments					
	1st harvest		2nd harvest		3rd harvest	
	E-W	N-S	E-W	N-S	E-W	N-S
M_1: MTP-1	76.60	67.80	82.35	71.90	87.00	76.80
M_2: MTP-2	61.95	51.80	65.65	55.35	69.40	58.20
S.Em ±	**0.63**	**0.69**	**0.35**	**1.14**	**0.21**	**0.31**
CD (*p*=0.05)	**3.81**	**4.20**	**2.15**	**6.92**	**1.26**	**1.89**
Sub Plot (aromatic crops)						
S_1: Lemon grass	64.50	55.85	68.80	58.80	72.60	62.80
S_2: Citronella grass	74.05	63.75	79.20	68.45	83.80	72.20
S.Em ±	**0.30**	**0.34**	**0.66**	**0.48**	**0.92**	**0.54**
CD (*p*=0.05)	**1.18**	**1.35**	**2.58**	**1.88**	**3.62**	**2.13**
Interaction effect (M×S)						
M_1S_1: MTP-1+ Lemon grass	70.80	62.40	74.50	64.00	76.40	68.70
M_1S_2: MTP-1+ Citronella grass	82.40	73.20	90.20	79.80	97.60	84.90
M_2S_1: MTP-2+ Lemon grass	58.20	49.30	63.10	53.60	68.80	56.90
M_2S_2: MTP-2+ Citronella grass	65.70	54.30	68.20	57.10	70.00	59.50
S.Em ±	**0.42**	**0.49**	**0.93**	**0.68**	**1.31**	**0.77**
CD (*p*=0.05)	**1.66**	**1.91**	**3.65**	**2.66**	**5.13**	**3.01**

Table 3. Fresh herb yield (kg ha^{-1}) and dry herb yield (kg ha^{-1}) of aromatic crops as influenced by *Melia dubia* clones under agroforestry system

Main Plot (*Melia dubia* clones)	Treatments					
	Fresh herb yield (kg ha^{-1})			Dry herb yield (kg ha^{-1})		
	1st harvest	2st harvest	3rd harvest	1st harvest	2st harvest	3rd harvest
M_1: MTP-1	1610	2078	2519	854.9	1036.5	1227.6
M_2: MTP-2	996	1258	1503	487.7	624.1	744.2
S.Em ±	**7**	**26**	**21**	**5.43**	**3.05**	**4.92**
CD (*p*=0.05)	**43**	**156**	**132**	**33.05**	**18.56**	**29.96**
Sub Plot (aromatic crops)						
S_1: Lemon grass	1467	1839	2233	788.0	916.8	1088.1
S_2: Citronella grass	1139	1498	1789	554.6	743.9	883.7
S.Em ±	**7**	**9**	**20**	**7.29**	**7.34**	**14.52**
CD (*p*=0.05)	**28**	**35**	**80**	**28.61**	**28.83**	**57.00**
Interaction effect (M×S)						
M_1S_1: MTP-1+ Lemon grass	1733	2133	2667	987.1	1061.6	1289.3
M_1S_2: MTP-1+ Citronella grass	1487	2023	2372	722.8	1011.5	1165.9
M_2S_1: MTP-2+ Lemon grass	1200	1544	1800	589.0	772.0	887.0
M_2S_2: MTP-2+ Citronella grass	792	973	1207	386.5	476.3	601.5
S.Em ±	**10**	**13**	**29**	**10.31**	**10.38**	**20.53**
CD (*p*=0.05)	**39**	**50**	**113**	**40.46**	**40.77**	**80.61**

Table 4. Oil content (%) and oil yield (kg ha^{-1}) of aromatic crops as influenced by *Melia dubia* clones under agroforestry system

Main Plot (*Melia dubia* clones)	Treatments					
	Oil content (%)			Oil yield (kg ha^{-1})		
	1st harvest	2nd harvest	3rd harvest	1st harvest	2nd harvest	3rd harvest
M_1: MTP-1	1.77	1.79	1.76	28.68	37.13	44.37
M_2: MTP-2	1.50	1.82	2.12	15.01	20.63	29.96
S.Em ±	**0.01**	**0.00**	**0.02**	**0.40**	**0.57**	**0.30**
CD (*p*=0.05)	**0.09**	**0.02**	**0.13**	**2.43**	**3.49**	**1.84**
Sub Plot (aromatic crops)						
S_1: Lemon grass	1.71	1.73	1.61	25.61	30.64	36.56
S_2: Citronella grass	1.55	1.88	2.27	18.08	27.12	37.77
S.Em ±	**0.01**	**0.02**	**0.01**	**0.13**	**0.37**	**0.23**
CD (*p*=0.05)	**0.05**	**0.08**	**0.04**	**0.51**	**1.47**	**0.91**
Interaction (M×S)						
M_1S_1: MTP-1+ Lemon grass	1.88	1.88	1.74	32.73	40.05	46.36
M_1S_2: MTP-1+ Citronella grass	1.65	1.69	1.78	24.62	34.20	42.37
M_2S_1: MTP-2+ Lemon grass	1.54	1.57	1.48	18.48	21.22	26.76
M_2S_2: MTP-2+ Citronella grass	1.45	2.06	2.75	11.54	20.04	33.16
S.Em ±	**0.02**	**0.03**	**0.01**	**0.18**	**0.53**	**0.33**
CD (*p*=0.05)	**0.07**	**0.12**	**0.05**	**0.72**	**2.07**	**1.29**

optimal irradiance enhancing overall oil yield, while excessive or insufficient light alters oil concentration (32).

Despite the reduced oil percentages, the total oil yield (kg ha^{-1}) was significantly greater under M_1 due to increased biomass production. M_1 yielded 44.37 kg ha^{-1} of oil at the third harvest, whereas M_2 yielded just 29.96 kg ha^{-1}, representing an increase of nearly 48 % ($p < 0.05$). M_1S_1 exhibited the maximum oil output at 46.36 kg ha^{-1}. This indicates that systems emphasizing productivity derive greater benefits from enhanced biomass accumulation than from elevated oil concentration alone.

GC-MS analysis of the essential oil composition

GC-MS analysis revealed that the treatment significantly altered the composition of the essential oils (Tables 5, Fig. 1). Citral isomers constitute most of the oils in lemongrass. In sole cropping, citral constituted 39.22 % and neral constituted 27.80 % of the oils, respectively. The concentrations of these compounds increased significantly under *Melia dubia* (citral 45.33 %; neral 33.80 %), whereas geranyl acetate decreased from 11.54 % to 2.73 %. When cultivated in isolation, citronella exhibited high concentrations of citronellal (45.60 %) and geraniol (20.32 %); but, under arboreal conditions, citronellal decreased to 38.31 %, while geranyl acetate increased to 10.45 %. The alterations in composition indicate that shade generated by *M. dubia* and modifications in light quality influence terpene production. In lemongrass, this results in an increased concentration of aldehyde fractions, whereas in citronella, it promotes greater ester formation. Numerous results indicate light-induced metabolic reprogramming of monoterpene pathways in *Cymbopogon* and other aromatic crops (33, 34). This natural diversity primarily arises from genetics and environment (35-38).

Conclusion

Intercropping *Melia dubia* in the MTP-1 configuration enhanced plant growth, biomass production and essential oil yield. Lemongrass consistently exceeded citronella in height, tillering, biomass output and overall oil yield. In contrast, citronella and the MTP-2 system demonstrated increased oil content, indicating a trade-off between biomass output and oil concentration. Tree-based intercropping altered the composition of essential oils by increasing citral concentrations in lemongrass and decreasing citronellal levels in citronella. This illustrates the varying responses of different species to alterations in microclimatic conditions. Economically, systems emphasizing elevated biomass and oil yield may benefit from MTP-1-lemongrass combinations, whereas markets demanding higher oil concentration or certain quality characteristics may gain from citronella-based systems. *M. dubia* can contribute to sustainable land use by optimizing resource utilization, regulating the microclimate and providing farmers with additional income opportunities. Future research should focus on the long-term efficacy of the system, its scalability across agroecological zones and comprehensive economic assessments to validate the viability of *Melia dubia*-based silvi-aromatic systems at commercial scales.

Table 5. Major compounds of lemongrass as influenced by *Melia dubia* clones under agroforestry system

Peak	RT (min)	Compound Name	Area %	Height	Main function
		Sole lemongrass			
1	8.78	(1R)-2,6,6-Trimethylbicyclo [3.1.1]hept-2-ene	0.14	0.49	Terpene
2	9.42	Camphene	1.07	3.21	Terpene
4	12.88	D-Limonene	0.46	1.35	Monoterpene (Flavour)
6	16.33	Linalool	2.07	4.91	Alcohol, Aroma
11	19.11	Isoneral	0.32	0.85	Isomer of neral/citral
16	23.06	Nersal	27.80	17.64	Major aromatic aldehyde
18	23.86	Geraniol	3.64	5.61	Alcohol, Fragrance
19	24.59	Citral	39.22	20.35	Key essential oil compound
28	29.10	Geranyl acetate	11.54	14.84	Ester (fixative)
		Lemon grass under *Melia dubia*			
1	9.42	Camphene	0.1	0.41	Terpene
3	12.88	D-Limonene	0.27	0.89	Monoterpene
7	16.33	Linalool	1.7	4.62	Alcohol
12	19.12	Isoneral	0.74	2.2	Isomer of neral/citral
15	23.14	Neral	33.8	21.07	Main aldehyde
16	23.88	Geraniol	1.87	3.75	Alcohol
17	24.67	Citral	45.33	23.62	Major essential oil component
26	29.00	Geranyl acetate	2.73	7.11	Ester
		Sole Citronella grass			
4	19.17	Citronellal	45.60	24.53	Major aldehyde responsible for citronella's lemon scent
8	23.74	Geraniol	20.32	16.57	Alcohol with pleasant floral smell
6	22.55	Citronellol	14.26	14.71	Monoterpenoid alcohol
11	27.78	6-Octen-1-ol,3,7-dimethyl-,acetate	4.81	8.07	Ester
13	29.00	Geranyl acetate	4.18	9.52	Ester often found in citronella oils
1	12.93	D-Limonene	4.55	10.78	Monoterpene contributing citrus-like aroma
7	22.75	Neral	0.84	2.30	Isomer of citral involved in aroma
		Citronella grass under *Melia dubia*			
4	19.10	Citronellal	38.31	21.74	Major aldehyde responsible for citronella's lemon scent
7	23.74	Geraniol	20.61	15.45	Alcohol with pleasant floral smell
5	22.52	Citronellol	12.44	13.18	Monoterpenoid alcohol
12	29.08	Geranyl acetate	10.45	14.52	Ester
10	27.80	6-Octen-1-ol,3,7-dimethyl-,acetate	8.03	11.11	Ester often found in citronella oils
1	12.91	D-Limonene	2.47	6.52	Monoterpene contributing citrus-like aroma
6	22.75	Neral	1.42	3.31	Isomer of citral involved in aroma

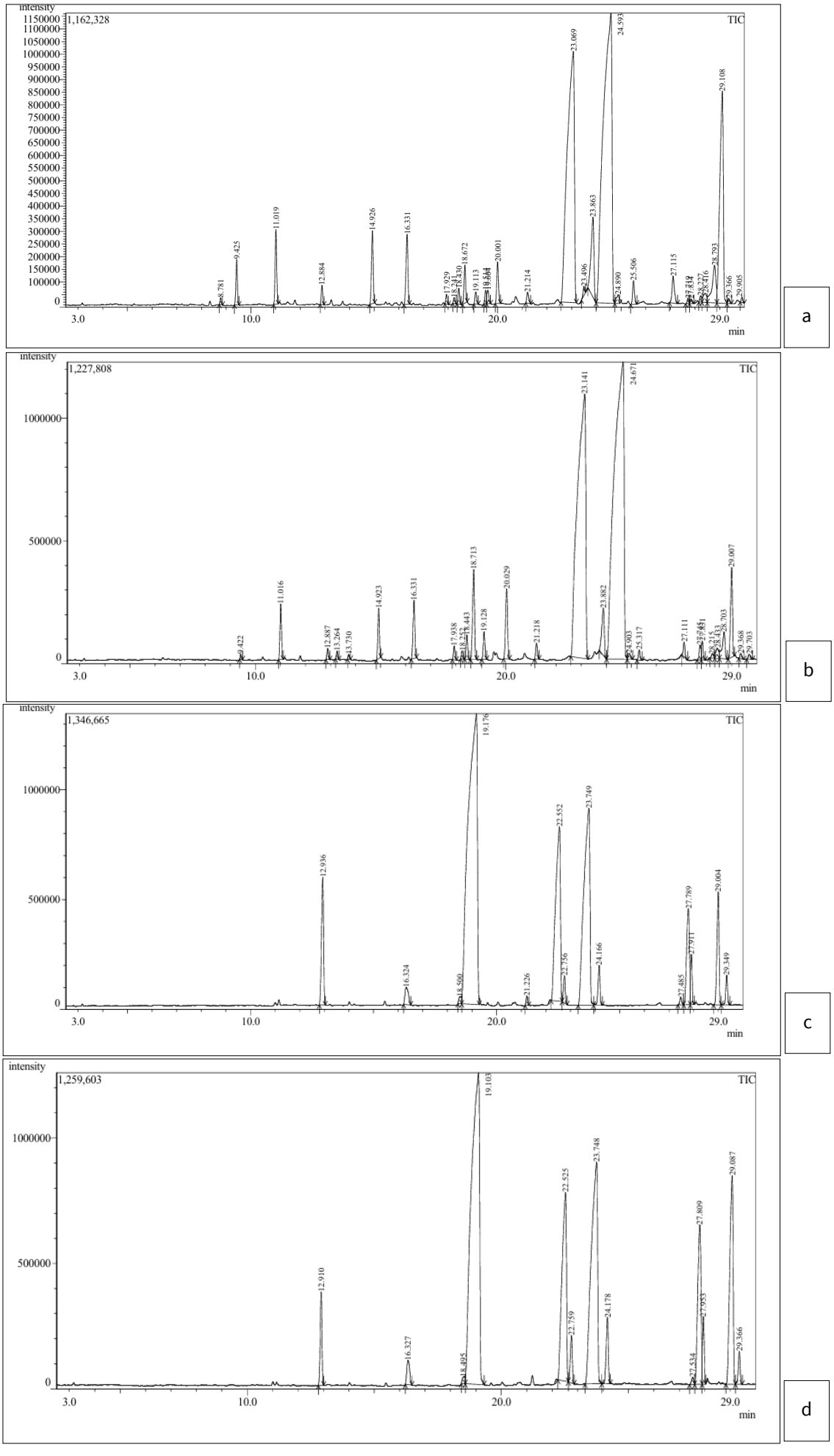

Fig. 1. Chromatogram of **a.** Sole lemongrass **b.** Lemongrass under *Melia dubia* **c.** Sole citronella **d.** Citronella under *Melia dubia*.

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Authors' contributions

PP carried out the experiment, collected data, analysed data and writing of original manuscript. HDC conceptualized the study, helped in designing, supervision and writing of drafted manuscript. PR helped in essential oil analysis (GC-MS) of aromatic crops. VM participated in the design of the study and helped in statistical analysis. MM helped in conceptualization of experiments and advisory. UKSN participated in conducting field experiment. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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