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Selection of Superior Quality *Cymbopogon nardus* (L.) Rendle (Poaceae) Populations by Means of Quantity and Quality of Essential Oils

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Abstract The main aim of the research was to evaluate essential oil content and composition of four different population samples (P1 - P4) of *Cymbopogon nardus* (L.) Rendle for the superior quality production of essential oil. The essential oil content and composition of different parts of *C. nardus* populations were determined using steam distillation in Clevenger type apparatus and GC-MS respectively. Findings revealed that essential oil content was significantly higher in leaves of all four populations of *C. nardus* followed by sheath, flowers and roots. Populations P-3 & P-4 demonstrated higher oil content compared to the four populations tested. The major compounds present in the leaf oil were geraniol, DL - limonene, citronellal, β - citronellol and geranyl acetate were common to all the four populations tested. Moreover, geraniol content was varied from 16%-58% and the highest geraniol content was recorded in the leaf oil of population P-4 (58.87%). Therefore, populations P-3 and P-4 with their greater oil contents and superior oil composition can be recommended for commercial cultivation to rejuvenate essential oil industry.

Keywords: *Cymbopogon nardus, essential oil, citronella, Poaceae, geranial, citronellal*

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1. Introduction

Cymbopogon nardus (L.) Rendle (Citronella) is an industrially important, essential oil-bearing perennial plant which is cultivated throughout the hotter parts of India, Burma, Malay Peninsula, Sri Lanka and Seychelles [1,2]. It is a tall herb, usually 1.5 to 2.1 m in height, copiously branched and forming a large decomposed nodding panicle [3]. Its oil is called citronella oil and well known for its variety of properties. Essential oils are a mixture of several aroma compounds produced by specialized secretory structures such as glandular trichomes and oil or resin ducts. Essential oils of Citronella contain many industrially important bioactive compounds, such as geraniol, citronellal, terpenes, methyl eugenol, L-borneol, methyl heptanone, farnesol and sesquiterpenes [4]. Moreover, these compounds have exhibited their potential in an array of therapeutic activities such as antimicrobial activity and antioxidant activity [5,6,7,8] and insect and pest repellent activity [9,10,11,12,13,14]. Therefore, citronella essential oil extensively used as an ingredient in natural insect and control products, flavour and fragrance industry, cosmetics industry as well as the pharmaceutical industry [10,15]. Further, it is necessary to have high-quality planting materials to ensure the greater economic benefits of a cultivated crop. Even though Sri Lanka was famous for its "Ceylon citronella oil", and earned considerable foreign exchange in 1900s, but currently, the contribution of Citronella essential oil to the essential oil industry is 2-3%. This downward variation is mainly due to unavailability of superior quality varieties that are with high essential oil content and composition for commercial cultivation of citronella [16]. It is assumed that there are super quality citronella populations which are not yet exploited for their quality parameters. Therefore, the current study aims to evaluate available citronella populations by means of morphology, essential oil content and composition in order to select potential superior quality variety/ populations of citronella for commercial cultivation.

2. Materials and Methods

2.1 Collection of Mother Stocks

Planting materials of four *C. nardus* populations (two *Maha Pangiri* populations and two *Heen Pangiri* populations) were obtained from previously authenticated mother plant stocks maintained by the Department of Export Agriculture, Sri Lanka. These mother plants were cultivated in the same soil and climatic conditions in institutional research plots.

- Population No 1 (P_1) -Maha Pangiri population 1
- Population No 2 (P_2)- Maha Pangiri population 2
- Population No 3 (P_3)- Heen Pangiri population 1
- Population No 4 (P_4)- Heen Pangiri population 2.

2.2. Morphological Observations of Growth Performance

Fifty plants of each population were grown in the institutional research field under the same soil and environmental conditions and maintained for 6 months following controlled agronomic practices. Morphological observations were carried out and necessary data were recorded for each population of *C nardus*. Since the main aim was to screen the physical and chemical yield of four populations, parameters concerning the economic importance, growth parameters such as bush size, bush diameter, leaf and sheath parameters of each population were collected. The voucher specimens of Population No 1 - 4 were prepared and deposited in the institutional herbarium (HP1-HP4). Twenty individuals per population were used to record morphological data.

2.3. Harvesting and Sample Preparation

Six months old plants which were cultivated under the same soil and climatic conditions were uprooted carefully without disturbing the roots. Then the plant parts were carefully separated as roots, leaves, sheaths, flowers and cut into 2-3 cm pieces using secateurs. 350 g of each plant part sample (roots, leaves, sheaths and flowers) was used to prepare separate samples for distillation.

2.4. Distillation of Essential Oil

Previously prepared samples (350g per each) of different parts of *C. nardus*, harvested from the four populations, were steam distilled in a Clevenger-type apparatus separately for 5 hrs. The extracted volatile oils were dried over anhydrous sodium sulphate and stored in sealed vials at 4 ˚C in a refrigerator until GC-MS analysis is performed. The oil content of different parts of the plant was calculated using following formula.

$$Yield\ of essential\ oil = \frac{Volumn\ of\ essential\ oil(ml) obtained}{Mass\ of\ raw\ materials(g) used} \times 100.$$

Results were presented as means of triplicate and standard deviation.

2.5. Observation for Organoleptic Properties of Oil

The colour, aroma and the oil content was observed of each essential oil derived from different parts (leaf, sheath, root and flower) of *C. nardus*.

2.6. GC-MS Analysis of Essential Oils

Essential oils obtained from different parts (leaf, sheath, root and flower) of *C. nardus* were subjected to GC-MS analysis. The oil analysis was carried out using GC-MS. The GC apparatus was Agilent Technology 6890 series, capillary column of HP-5MS (30 m×0.25 mm, film thickness 0.25 μm). The oven temperature program was initiated at 50°C, held for 5 min then raised up to 280 °C at a rate of 5 °C /min held for 10 min. Helium was used as the carrier gas at a flow rate 0.9 mL/min. The injector temperature was 250°C. GC-MS analysis was conducted on a HP 6890 GC system coupled with 5973 network mass selective detector with a capillary column as same as above, carrier gas helium with flow rate 0.9 mL/min with a split less injection mode, injector and oven temperature programmed was identical to GC. The compounds present in the oil were identified by comparison of their retention indices (RI), mass spectra fragmentation available in Wiley W9N08 database and NIST (National Institute of Standards and Technology) database.

2.7. Statistical Analysis

Data were statistically analyzed using Analysis of Variance (ANOVA) and means were compared using Tukey test. Statistical analysis was performed with Minitab 17 software.

3. Result & Discussion

3.1. Morphology of the Selected four Populations of *C. nardus* - Growth Performance

As demonstrated in Table 1 and Figure 1, population 1 and population 2 possess significantly higher variation in important yield performances such as bush size, bush height, leaf length and leaf width compared to population No. 3 & 4. Moreover, based on the results tested 4 populations were clearly separated into 2 clusters; Population 1&2 vs. population 3&4. As all four populations were grown under similar environmental and agronomic conditions the impact of environmental factors and agronomical practices on the growth performance was minimized. Therefore, the observed results depict the true phenotypic variation of selected *C. nardus* populations. Earlier studies conducted by [17], demonstrated that there are two morphologically different citronella types ‘Lenabatu’ and ‘Mahapengiri’ which were derived from *Cymbopogon nardus* (L.) Rendle and *Cymbopogon winterianus* Jowitt respectively. When morphological characters of *Mahapangiri* described by [17] are compared with present observations, a close relationship with populations No 1 & 2 is clearly observed. Similarly, populations No 3 & 4 also exhibited a morphological relationship with variety *Lenabatu*. Therefore, it is in agreement with the assumption that populations No 1&2 have derived from “Type” *Maha pangiri* while Populations No 3 & 4 derived from “Type” *Lenabatu*.

Table 1. Morphology of four populations of *Cymbopogon nardus*

Character	Population 1	Population 2	Population 3	Population 4
Bush Height (m)	1.68 ± 0.09 [a]	1.53 ± 0.14 [a]	0.98 ± 0.07 [b]	0.85 ± 0.7 [b]
Bush Diameter (cm)	17.31 ± 0.86 [a]	16.12 ± 1.64 [a]	12.45 ± 2.15 [b]	10.25 ± 1.24 [c]
Leaf length (m)	1.62 ± 0.054 [a]	1.48 ± 0.04 [a]	0.92 ± 0.02 [b]	0.81 ± 0.023 [b]
Leaf width (cm)	1.75 ± 0.052 [a]	1.48 ± 0.248 [b]	1.32 ± 0.158 [b]	1.18 ± 0.078 [c]
Leaf colour	Grayish green	Silvery green	Grayish green	Grayish green
Sheath length (cm)	10.15± 0.03 [a]	9.82± 0.04 [a]	7.64± 0.03 [b]	7.13± 0.02 [b]
Sheath colour	Reddish green	Reddish green	Reddish green	Reddish green

Figure 1. Four populations of *Cymbopogon nardus* (**A**. Population 1; **B**. Population 2; **C.** Population 3; **D.** Population 4)

3.2. Essential Oil Content and Organoleptic Properties

As presented in Table 2, plant parts of all four tested *C. nardus* populations (leaf, sheath, root and flower) possess marked content of essential oil. Moreover, essential oils extracted from each part exhibited strong lemony aroma inherited to *C. nardus* and oil colour was varied from yellow to pale yellow or colourless. The significantly higher essential oil content was observed from leaves of population No 4 (1.22 ± 0.32a). Order of increment of leaf essential oil content variation was population No 4 > population No 3 > population No 1 > population No 2. Moreover, available essential oil content in different parts of the four populations of *C. nardus* was varied sequentially as, leaf > sheath > flower > root. Currently, essential oil industry of *C. nardus* practices distillation of only leaves for the extraction of essential oils. However, the results of our study revealed the possibility of extracting essential oils productively not only from leaves but also from other parts such as sheath, flowers and roots of *C. nardus*. This would definitely contribute to increase the yield and quality of essential oils and to reduce the wastage. Our results on the essential oil content of leaves of *C. nardus* population No 4 is in agreement with [18] and [19] regarding the essential oil content, who also reported that essential oil content of leaves of Java citronella varied from 0.12% to 2.18%. Moreover, [20] have obtained a higher percentage of oil from the leaves when comparing to sheaths of *C. nardus*.

Table 2. Essential oil content and organoleptic properties of essential oil extracted from different parts of *Cymbopogon nardus* (Mean of 3 treatments, followed by the same letter do not differ by Tukey test at P < 0.05)

Plant Part	Population	Oil Yield % (v/w)	Oil Colour	Oil Aroma
Leaves	Population 1	0.68 ± 0.03[c]	Yellow	Strong Aroma
	Population 2	0.35 ± 0.01[d]	Yellow	Strong Aroma
	Population 3	0.93 ± 0.05[b]	Pale Yellow	Strong Aroma
	Population 4	1.22 ± 0.32[a]	Pale Yellow	Strong Aroma
Sheath	Population 1	0.38 ± 0.03[b]	Pale Yellow	Strong Aroma
	Population 2	0.36± 0.02[c]	Pale Yellow	Strong Aroma
	Population 3	0.41 ± 0.15[b]	Pale Yellow	Strong Aroma
	Population 4	0.56 ± 0.07[a]	Pale Yellow	Strong Aroma
Roots	Population 1	0.14 ± 0.04[c]	Pale Yellow	Strong Aroma
	Population 2	0.30± 0.01[d]	Pale Yellow	Strong Aroma
	Population 3	0.25 ± 0.06[b]	Pale Yellow	Strong Aroma
	Population 4	0.22 ± 0.03[b]	Pale Yellow	Strong Aroma
Flowers	Population 1	0.37 ± 0.04[a]	Colour less to pale yellow	Strong Aroma
	Population 2	0.32 ± 0.01[b]	Colour less to pale yellow	Strong Aroma
	Population 3	0.38 ± 0.05[a]	Colour less to pale yellow	Strong Aroma
	Population 4	0.40 ± 0.01[a]	Colour less to pale yellow	Strong Aroma

3.3. Essential Oil Composition

3.3.1. Essential Oil Composition of Leaves of Four Populations of *Cymbopogan nardus*

As demonstrated in Table 3 the essential oil composition of leaf samples of four populations (Populations No 1 -4) were identified representing 96.7%, 99.7%, 91.6% and 96.5% of total essential oil profiles respectively. The number of compounds present in leaf essential oil of four populations was varied from 15 to 28. The highest number of compounds observed in leaf essential oil of population No 2. The major constituents and their contents present in essential oil of the four populations of *C. nardus* were geraniol (16.04% -58.87%), DL-limonene (2.81% - 8.07%), citronellal (2.45%-18.58%), β - citronellol (3.59 %-12.1%), geranyl acetate (1.28%-4.87%) and Cis ocimine (0.56%-3.87%). Findings of the current study on the number of compounds and their content in each population are in agreement with the previous study conducted by Wijesekera *et al.*, *[17]*, who reported that citronellal, geraniol, DL-limonene, citronellol and geranyl acetate as major compounds present in the two "Types" of citronella grown in Sri Lanka. However, geraniol content reported in the previous study of two tested citronella varieties was comparatively lesser (18.0% to 23.9%) compared to the present study (16.04%-58.87%). Moreover, results on individual compounds and their percentages of four *C. nardus* populations presented in the current study are in agreements with several previous studies [21,22].

Table 3. Essential oil composition of leaves of four populations of *Cymbopogan nardus*

R.T.	Compound	Percentage of total oil profile			
		P 1	P 2	P 3	P 4
10.120	α- Pinene	ND	2.68	ND	ND
11.328	β -Myrcene	ND	0.64	ND	ND
10.523	Camphene	ND	9.41	ND	ND
10.826	α- Terpinene	1.01	ND	ND	ND
12.157	DL -Limonene	7.77	8.08	5.12	2.81
12.228	cis ocimine	1.93	0.56	3.87	1.06
12.406	β -Ocimine	1.08	0.34	2.17	0.71
13.956	4- Nonanone	ND	ND	0.74	0.49
14.057	Linalool	ND	0.76	0.81	1.15
14.135	Camphor	ND	0.95	ND	ND
14.230	Citronellal	18.58	9.17	2.45	8.81
14.632	Borneol	ND	9.26	ND	ND
14.715	4- Terpineol	ND	0.89	ND	ND
14.940	β -Fenchyl alcohol	ND	1.79	ND	ND
15.438	β - Citronellol	12.01	3.59	9.06	9.27
15.615	z-Citral	ND	0.69	ND	ND
16.030	Geraniol	26.22	16.04	53.22	58.87
16.113	α- Citral	ND	0.76	ND	ND
16.314	Bornyl acetate	ND	0.51	ND	ND
16.734	Citrinellyl acetate	1.52	ND	1.36	0.92
17.015	Methyleugenol	ND	ND	3.57	3.02
17.522	Geranyl acetate	2.69	1.28	4.88	4.61
17.724	β -Elemene	ND	0.61	ND	ND
18.150	Caryophyllene	ND	0.86	1.84	0.67

R.T.	Compound	Percentage of total oil profile			
		P 1	P 2	P 3	P 4
18.542	Zingeiberine	ND	ND	ND	2.39
18.955	α- Farnesene	1.34	4.23	3.34	ND
19.121	Methyl isoeugenol	0.9	5.32	ND	ND
19.370	δ- Cadinene	0.63	ND	ND	2.85
19.476	α- Pachoulene	ND	ND	ND	0.73
19.552	Methyl trans isoeugenol	14.22	ND	ND	ND
19.370	α- Amorphene	ND	ND	2.83	ND
19.488	γ -Bisabolene	ND	ND	0.58	ND
19.749	Elemol	ND	ND	0.57	ND
20.223	Caryophyllene oxide	ND	0.92	0.29	0.89
20.270	Trans-isoelemicin	0.82	0.81	ND	ND
20.381	α- Cadinol	0.89	ND	ND	ND
20.459	Benzaldehyde	ND	1.56	ND	ND
20.767	γ -Eudesmol	ND	1.15	ND	ND
20.969	Cis asarone	ND	12.51	ND	ND
21.075	α- Eudesmol	ND	1.08	ND	ND
22.710	Neophytadiene	ND	ND	ND	0.42
Total %		91.6	96.53	96.72	99.69

ND- Not Detected (< 0.05)
*values are the average of triplicates.

3.3.2. Essential oil Composition of Sheaths of Four Populations of *Cymbopogan nardus*

As presented in Table 4, major compounds found in essential oils of sheath samples of four populations were calculated as representing 94.3%, 85.1%, 96.3% and 88.1% of total essential oil profiles respectively. It is interesting to note that, in addition to the major compounds present in leaf essential oil, some other important compounds such as elimicin, methyl eugenol, endoborneol and linalool which were not detected in leaf essential oils were present in sheath essential oil in marked amounts. Moreover, geraniol was observed as the major compound in sheath essential oils of all four populations of *C. nardus* studied. Geraniol content ranges between 20.33% - 37.78% in the sheath oil.

Table 4. Essential oil composition of sheath of four populations of *Cymbopogan nardus*

R.T.	Compound	Percentage of total oil profile			
		P 1	P 2	P 3	P 4
12.086	α- pinene	0.99	1.16	3.33	ND
12.631	Camphene	2.66	2.33	7.54	ND
14.549	α - Terpinene	5.16	1.03	ND	ND
15.568	DL - Limonene	5.12	5.77	5.98	1.23
15.923	α -ocimene	ND	3.53	ND	ND
16.243	β -ocimene	1	1.89	6.76	ND
17.984	Linalool	0.72	2.06	1.43	1.58
19.63	Citronellal	4.44	3.97	2.28	1.65
20.08	endo-Borneol	1.74	2.24	6.37	3.68
21.337	α - terpineol	1.18	0.53	1.47	ND
21.928	β- Citronellol	5.12	4.04	1.81	3.24
22.236	z- citral (neral)	0.99	1.297	1.25	1.024
22.852	Geraniol	23.41	20.33	32.14	37.78
23.112	Citral	1.38	1.71	ND	2.03
25.232	Phenol	0.53	1.52	ND	2.18
25.861	Citronellyl acetate	0.87	ND	2.17	ND
26.121	Geranyl acetate	2.14	6.63	19.75	ND
26.725	Methyleugenol	4.34	4.05	ND	4.57
27.768	Caryophyllene	0.72	ND	ND	ND
27.962	Isoeugenol	ND	0.66	ND	ND
29.034	Methyl Isoeugenol	ND	3.00	ND	3.04
29.296	Germacrene- D	0.55	ND	ND	ND
30.291	δ- cadinene	2.214	ND	0.98	0.74
30.491	Elemicin	16.59	9.65	ND	18.27
31.699	Zingiberene	ND	1.084	ND	ND
32.09	γ-Curcumene	ND	1.338	ND	ND
32.623	Isoelemicin	ND	3.26	ND	4.85
32.671	Selina-6- en-4-ol	5.36	ND	ND	ND
33.133	t- cadinol	6.03	ND	3.03	ND
33.392	α - Bisabolene	ND	1.95	ND	2.15
34.353	Juniper campor	1.04	ND	ND	ND
Total %		94.32	85.13	96.31	88.05

ND- Not Detected (< 0.05)
*values are the average of triplicates.

Table 5. Essential oil composition of roots of four populations of *Cymbopogan nardus*

R.T.	Compound	Percentage of total oil profile			
		P 1	P 2	P 3	P 4
12.086	α- pinene	1.2	ND	ND	0.28
12.631	Camphene	ND	ND	ND	0.97
14.549	α - Terpinene	1.19	ND	ND	ND
15.568	DL - Limonene	0.80	1.08	ND	1.37
17.984	Linalool	ND	ND	ND	0.25
19.63	Citronellal	ND	1.16	ND	0.23
20.08	endo-Borneol	ND	ND	1.05	1.97
21.337	α - terpineol	ND	ND	ND	0.57
21.928	β- Citronellol	0.77	3.22	ND	ND
22.852	Geraniol	ND	9.329	1.67	0.68
23.112	Citral	ND	1.66	ND	ND
23.125	piperitone	2.06	ND	ND	ND
25.232	Phenol	ND	12.15	ND	ND
26.725	Methyleugenol	ND	1.92	31.39	ND
27.768	Caryophyllene	2.49	1.18	3.86	0.27
29.034	Methyl Isoeugenol	ND	1.58	ND	ND
29.296	Germacrene- D	ND	ND	ND	1.65
30.291	δ- cadinene	5.86	ND	3.53	0.61
30.491	Elemicin	20.59	6.39	ND	ND
31.699	Zingiberene	ND	1.42	ND	ND
32.09	γ-Curcumene	ND	2.00	ND	ND
32.588	4,6- Guaiadiene	14.64	ND	ND	ND
32.623	Isoelemicin	ND	2.48	ND	ND
33.074	α- cadinol	11.85	ND	ND	ND
33.133	t- cadinol	19.81	ND	15.13	ND
34.353	Juniper campor	2.62	ND	ND	ND
32.883	Patchouli alcohol	ND	17.46	ND	ND
26.298	β -Elemene	ND	ND	ND	1.73
28.584	germacrene	ND	ND	ND	1.654
30.372	Elemol	ND	ND	17.69	19.74
31.391	Hedycaryol	ND	ND	ND	2.37
31.947	γ-eudesmol	ND	ND	ND	3.98
32.883	γ- cadinene	ND	ND	ND	2.10
Total %		83.92	63.10	74.32	40.48

ND- Not Detected (< 0.05)
*values are the average of triplicates.

3.3.3. Essential Oil Composition of Roots of Four Populations of *Cymbopogan nardus*

As shown in Table 5, major compounds present in root samples of four populations were identified representing 83.9%, 63.1%, 74.3% and 40.5% of total essential oil profiles respectively. Results revealed that individual compounds identified in essential oils of roots were greatly varied. Moreover, the availability of common compounds which were observed in essential oils of leaf and sheath were found in lesser amounts in root essential oils of all four populations. However, availability of the greater amount of industrially important compounds such as methyl eugenol (31.39%) in population P-3, patchouli alcohol (**17.46%)** in population P-2, and elevated amounts of elemol (**17.69 and 19.79%)** in population P-3 & P-4 clearly demonstrate the industrial potential of essential oils in roots of *C. nardus*.

3.3.4. Essential Oil Composition of Flowers of Four Populations of *Cymbopogan nardus*

Essential oil composition of flowers of four different populations of *C. nardus* was demonstrated in Table 6. Major compounds present in flower samples of four populations (Population P-1, Population P -2, Population P-3 and Population P-4) were calculated as representing 74.07%, 72.20%, 80.48% and 71.52% of total essential oil profiles respectively.

As shown in Table 6, the flower essential oil of four populations of *C. nardus* was a mixture of a total of 31 individual compounds. The major compounds observed in essential oils of flowers of 4 populations were α- pinene, camphene, DL - limonene, endo-borneol, α - terpineol, β- citronellol, Z-citral, geraniol, citral, geranyl acetate, caryophyllene, γ- selinene, t- cadinol and germacrene- D. The highest number of individual compounds observed in flowers of population P-1 (26), followed by population P-2 (23), population P-4 (17) and population P-3 (15) respectively. Further, there were 12 compounds common for all four populations while compounds like t- cadinol, α- cadinol, γ- selinene, Elemicin, δ- cadinene and methyl eugenol, were only detected in Population P-1 &P-2.

In the 1990s, Sri Lanka was well famous for its 'Ceylon citronella' essential oil. However, this reputation was gradually declined due to the lack of high-quality planting materials and inferior quality of essential oil compositions in existing varieties [16]. Therefore, the current study was

aimed to select superior quality citronella variety/s based on essential oil content and composition of existing populations for commercial cultivation. So in the current study, all four citronella populations maintained under similar soil, climatic conditions and agronomic practices and were evaluated for their essential oil content and composition. Among tested citronella populations, leaf, sheath and flowers, belong to populations P- 3 and P-4 exhibited marked contents of essential oil. Moreover, the economical value of citronella essential oil is mainly determined by the content of its active constituents such as geraniol, geranial acetate, citral, citronellal, α- pinene, camphene, limonene and caryophyllene etc. [4,23]. Among tested populations and their different plant parts such as leaves, sheath and flowers, populations No 3 & 4 contained a marked content of geraniol, geranial acetate as well as α- pinene, camphene, limonene and caryophyllene (Table 3 to Table 6). Moreover, roots essential oils of population No 3 contained a higher amount of methyl eugenol (31.39%), while rich content of elemol (19%) observed in root essential oils of population No 4.

Table 6. Essential oil composition of flowers of four populations of *Cymbopogan nardus*

R.T.	Compound	Percentage of total oil profile			
		P 1	P 2	P 3	P 4
12.086	α- pinene	1.64	1.02	3.25	3.13
12.631	Camphene	3.81	4.15	8.55	11.66
14.549	α - Terpinene	2.87	0.45	ND	ND
15.568	DL - Limonene	7.00	6.15	8.28	9.28
15.923	α -ocimene	0.53	ND	ND	ND
16.243	β -ocimene	0.25	1.25	1.01	ND
17.984	Linalool	0.31	ND	ND	1.17
19.63	Citronellal	2.03	ND	ND	ND
20.08	endo-Borneol	1.03	2.15	6.84	7.09
21.337	α - terpineol	0.86	0.45	1.68	1.15
21.928	β- Citronellol	2.43	1.49	2.21	1.64
22.236	z- citral (neral)	0.39	0.86	1.30	1.41
22.852	Geraniol	2.55	1.97	14.47	7.94
23.112	Citral	0.69	2.45	2.24	3.65
25.861	Citronellyl acetate	1.88	2.47	ND	ND
26.121	Geranyl acetate	2.32	1.25	2.06	4.42
26.725	Methyleugenol	2.60	2.04	ND	ND
27.768	Caryophyllene	4.08	3.17	5.39	4.75
29.034	Methyl Isoeugenol	ND	7.25	9.61	ND
29.296	Germacrene- D	1.56	0.52	2.24	1.48
30.291	δ- cadinene	3.28	2.94	ND	ND
30.491	Elemicin	9.80	8.46	ND	ND
31.629	Germacrene D-4-ol	4.89	3.74	ND	ND
31.959	γ- selinene	5.85	4.12	ND	ND
32.623	Isoelemicin	ND	ND	11.28	ND
33.074	α- cadinol	4.01	5.15	ND	ND
33.133	t- cadinol	5.93	7.56	ND	0.96
34.353	Juniper campor	1.36	1.02	ND	ND
20.767	α - terpineol	ND	ND	ND	1.15
26.263	Linalool oxide	ND	ND	ND	5.84
31.083	Caryophyllene oxide	ND	ND	ND	4.72
Total %		74.06	72.20	80.48	71.52

ND- Not Detected (< 0.05)
*values are the average of triplicates.

4. Conclusion

All tested parts of four *C. nardus* populations contained marked amount of essential oils and the highest essential oil content was observed in the leaves of Population P-4 and followed by Population P- 3, Population P-1 and Population P-2 respectively. Presence of the higher oil content in leaves scientifically validate the traditional claim of harvesting of leaves of *C. nardus* for commercial production of citronella oil. According to the results of the current study, the marked content of oil and their individual compounds responsible for the economic value of essential oils were present in greater amounts in leaves as well as other tested plant parts. Therefore, populations P- 3 & 4 with their greater oil contents and superior oil composition could be recommended for commercial cultivation to rejuvenate the citronella essential oil industry. Further studies on the variation of oil content and composition under different soil and climatic conditions are suggested.

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