



Original Research Article

Postharvest drying effect on quantity and quality of essential oil of the Black Tea-tree (*Melaleuca bracteata* F. Muell.)

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Abstract

Melaleuca bracteata F. Muell. (Family Myrtaceae) commonly known as black tea tree or river tea tree is a source of industrially important essential oil which contains methyl eugenol, (E)-methyl cinnamate, linalool and eugenol, like therapeutically active compounds. The present communication phytochemically analyzes the effect of the postharvest shade drying on the essential oil of *M. bracteata* cultivated in the foothills of Uttarakhand, providing all the agroclimatic conditions. The postharvest shade drying experiment was conducted for a period of 10 days. Overall, 11 compounds comprising 94.0 to 97.0% of the total composition were identified, mainly with dominance of phenylpropanoids (83.5–93.3%) followed by sesquiterpenoids (0.8–4.5%) and monoterpenoids (0.9–4.0%). GC and GC-MS analysis confirm methyl eugenol as the major compound constituting 80.4% of the total oil composition. The results of the post-harvest drying experiment showed qualitative and quantitative compositional variations with methyl eugenol (81.8–88.4%) as major constituent. Results indicated the potential utilization of the essential oil of dried leaves of *M. bracteata* as a natural source of methyl eugenol.

Keywords: Black tea tree, Drying, Essential oil, *Melaleuca bracteata*, Methyl eugenol.

Introduction

Melaleuca is one of the important genera of the Myrtle family, Myrtaceae. The family is comprised of about 130 to 150 genera with more than 3000 species distributed predominantly in tropical, subtropical, and warm temperate areas of the world (Reynerston et al., 2008). There are nearly 300 species of the *Melaleuca* genus distributed in Australia and South-East Asia. *Melaleuca bracteata* F. Muell. is an aromatic plant which belongs to the Myrtaceae family and is commonly known as the black tea-tree, river tea-tree, or mock olive. This tree is well suited for roadside or park plantings or other ornamental purposes. The production of numerous commercial essential oils (EOs) with potent aromas and a wide range of oil constituents (terpenoids, phenylpropanoids) of significant economic value is well recognised for *Melaleuca* species. *M. alternifolia* (tea tree oil), *M. quinquenervia* (niaouli oil), *M. cajuputi* (cajuput oil) are among the most popular and well-known plants in this genus from which EOs can be obtained for commercial usage (Brophy et al., 2013). Essential oil (EO) isolated from plants belonging to the *Melaleuca* genus

showed broad efficacy against bacteria and fungi and is used widely as a traditional medicine for a number of conditions, including acne, wounds, sores, dandruff, and skin lesions (Carson et al., 2006). The EOs from *Melaleuca* genus have demonstrated antibacterial (Goswami et al., 2017), anti-inflammatory (Kholiya et al., 2024), fungicidal (Bagg et al., 2006), acaricidal (Iori et al., 2005), antioxidant (Kholiya et al., 2024; Pino et al., 2010), antiviral properties (Minami et al., 2003) and herbicidal activities (Almarie et al., 2016).

The EOs of several *Melaleuca* species showed considerable compositional variability under different ecological and geographic conditions. There were mainly four chemotypes of *M. bracteata* on the basis of its essential oil composition. Among the four chemotypes, chemotype IV essential oil is rich in methyl eugenol (ME) content. Worldwide, the EO of this yellow-foliaged tree is often used for its medicinal properties (Brophy et al., 2013). Recent research (Choi et al., 2010) indicated that ME may have positive effects on human health as well. Based on their studies, ME may reduce cerebral ischemic injury through suppression of oxidative injury

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and inflammation. The various roles of ME in nature, especially related to the chemical defense of plants, such as antifungal, antibacterial, antinematode, or toxicant roles against pathogens and insect herbivores, as well as its functions as an insect antifeedant/repellent and in pollination, are reviewed (Tan & Nishida, 2012). The EO of *M. bracteata* from the foothills of North India may lead to an alternative source of ME for multiple industries.

A review of the literature revealed that the postharvest drying potentials of *M. bracteata* growing in India have not been explored to date. Therefore, the present communication aimed to investigate the effect of postharvest drying on the chemical composition of the essential oil of *M. bracteata* F. Muell. And the secondary aimed is to study how drying influences the essential oil quality and its optimum recovery, cultivated in the CSIR-CIMAP Research Center, Pantnagar. To the best of our knowledge, there is no literature report on the essential oil content of postharvest shade drying grown in the Tarai region of Uttarakhand Himalaya, India. The interpretation based on the chemical composition of the studied samples results in a better understanding of their oil extraction and its biological efficacy.

Materials and Methods

Plant material

Fresh leaves of *M. bracteata* were collected from the experimental field of CSIR-Central Institute of Medicinal and Aromatic Plants, Research Centre, Pantnagar, Uttarakhand (29.02°N latitude, 79.31°E longitude, altitude 243.8 m) in the month of September 2022. The maximum temperature ranges between 35 and 45 °C and the minimum between 2 and 5 °C with an average rainfall of 1350 mm during the year. The monsoon usually breaks in mid-June and continues up to September. The leaves of *M. bracteata* contain a number of oil glands, which makes them a rich source of essential oil and the leaves are available throughout the year for the extraction of essential oil. For this reason, we take leaves of *M. bracteata* for our postharvest shade drying experiment. A total of thirty-three homogenized samples, weighing 100 g each (fresh weight basis), were divided into eleven sets (three replicates per set). One set of samples was distilled on the day of harvesting (Day 0), while the remaining ten sets were kept in the shade for postharvest drying/storage studies (for 1,2,3... upto 10 days). The average temperature under shade is usually 4-5 °C lower than the outer temperature. The observations about moisture loss, EO content, and chemical composition were recorded at ten consecutive time periods of shade drying. Moisture loss (%) have been calculated by using formula:

Moisture loss (%) = [(Fresh weight – Dry weight)/Fresh weight] × 100

Extraction of essential oil

Fresh leaves of the plant were cleaned first and then carried to hydro-distillation in a Clevenger-type apparatus for 4 hours, for isolation of essential oil (European Pharmacopoeia, 2004). Triplicates of each set were hydrodistilled separately. EO was measured directly in the extraction burette, and contents (%) were calculated as the volume (mL) of essential oil per 100 g of fresh weight (v/w) of plant material. The EO was dehydrated over anhydrous Na₂SO₄ and kept in a refrigerator until the samples underwent GC-FID/GC-MS analysis.

GC-FID analysis

The 0.2 µL neat EOs were analyzed by using GC Thermo Fisher Trace-1300. The capillary column type was TG-5MS (30 m × 0.25 mm, 0.25 µm film thickness). The carrier gas was Nitrogen at a constant flow rate of 1.0 mL/min and an average velocity of 30 mL/min. The injector temperature was 240 °C, having split ratio 1:40 and the detector (Flame ionization detector, FID) temperature was 250 °C. The initial column oven temperature was set at 70 to 220 °C at the rate of 4 °C/min. The relative content of the constituent was calculated based on the %peak area (FID response) without using a correction factor.

Gas chromatography-mass spectrometry analysis

GC-MS analyses were carried on PerkinElmer turbo mass quadrupole mass spectrometer fitted with an Equity-5 fused silica capillary column (60 m × 0.32 mm i.d., film thickness 0.25 µm). The oven column temperature ranged from 70 to 250 °C; programmed at 3 °C min⁻¹ with initial and final hold time 2 minutes, using He as carrier gas at 1.0 mL min⁻¹. The injection volume was 0.02 µL neat with a split ratio of 1:30. The injector source and transfer line temperatures were 250 °C; the mode of ionization was electron impact ionization (EI), with ionization energy 70 eV and mass scan range of 40 to 400 amu. GC-FID and GC-MS analysis of the essential oil was done in a pooled manner.

Identification of constitutional compounds in essential oil

Identification of essential oil constituents was accomplished on the basis of retention index (RI, determined with reference to homologous series of n-alkanes, C₈–C₂₄; Supelco Analytical, Bellefonte PA, USA, under same temperature-programmed conditions), reference mass spectral library search (NIST/EPA/NIH version 2.1 and Wiley registry of mass spectral data 7th edition), and by comparison of mass spectra data with literature (Adams, 2012). The relative content of individual components of the oil is expressed as percent peak area relative to the total peak area of the GC/FID chromatogram, automated electronic integration without response factor correction.

Statistical Analysis

The analysis of variance (ANOVA) was performed using the TNAUSTAT-Statistical package with LSD type Statistical design. Statistical analyses were done, which were based on standard methods (Panse & Sukhatme, 1989; Singh & Chaudhary, 1985). The mean values of all the major components were subjected to correlation and path coefficient analyses (Dewey & Lu, 1959).

Results and Discussion

The data on shade drying duration and its impact on the EO yield of *M. bracteata* are presented in Table 1. The moisture loss (%) was found to be significant from the very first day of drying, reaching 53.7% after 10 days. Similarly, the essential oil content exhibited notable variation during shade drying, increasing from 0.9% in fresh plant material to 1.1% after 9 days. The oil yield remained constant at 0.9% for the first 4 days of drying, then gradually increased up to 10 days. The p -value < 0.05 in Table 1 clearly indicates the significance of the study. These findings clearly suggest that optimal oil recovery occurs when approximately half of the moisture is lost from the fresh plant material. Overall, the results in Table 1 showed the essential oil yield variation in post harvested shade dried leaves prior to distillation.

The chemical composition of postharvest shade drying of *M. bracteata* was determined by GC-FID and gas chromatography-mass spectrometry (GC-MS) methods. Figure 1 represents the gas chromatogram of EO, where higher peaks indicate major constituents of EO. The structure of major compounds along with their name are highlighted in Figure 2. The components in Table 2 were classified into three classes on the basis of their structural properties. Day 0 indicates a fresh sample, while day 4 indicates four days of shade drying the fresh sample. Overall, 11 compounds were identified in Table 2, forming total 94.0 to 97.0% of the total composition, among which phenyl propanoids (83.5–93.3%) dominated, all three categories of compounds, viz, sesquiterpenoids (0.8–4.5%) and monoterpenoids (0.9–4.0%). *M. bracteata* EO is rich in ME and (E)-methyl cinnamate, while linalool, eugenol, germacrene-D, (E)-methyl isoeugenol are also present. It was observed that shade drying resulted in variation in the content of its marker constituents. The composition of ME increases with the increase in the number of days for which the plants were dried under shade. On the other hand, the content of (E)-methyl cinnamate decreases with the increase in the number of days. It was observed that after six days of drying, the per cent composition of ME began to decrease, while (E)-methyl cinnamate started increasing after seven days of drying. The percentage composition of ME was highest on the sixth day (88.39%), whereas the percentage composition of

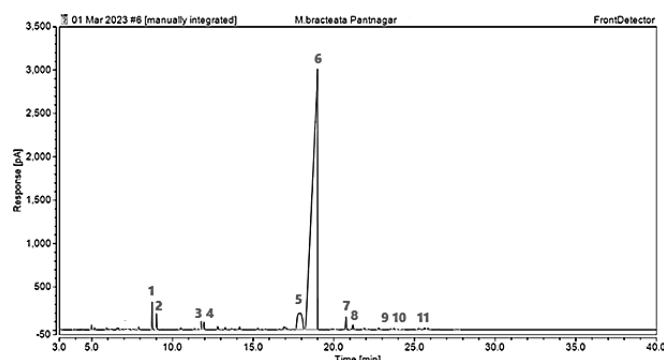


Figure 1: Gas chromatogram of essential oil of *M. bracteata*

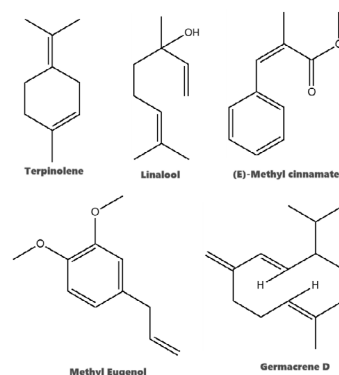


Figure 2: Structure of major compounds found in *M. bracteata* essential oil

Table 1: Influence of shade drying on essential oil content of *M. bracteata*

Days	Weight of sample (g)	Moisture loss (%)	Essential oil yield (%)
0	100 ± 0.0	0 ± 0.0	0.9 ± 0.1
1	86.0 ± 2.3	12.7 ± 1.3	0.9 ± 0.0
2	74.7 ± 1.2	26.1 ± 0.5	0.9 ± 0.0
3	65.3 ± 3.0	34.7 ± 3.0	0.9 ± 0.0
4	54.3 ± 0.7	45.9 ± 0.6	0.9 ± 0.2
5	55.0 ± 0.6	45.0 ± 0.6	1.0 ± 0.0
6	55.3 ± 2.4	44.7 ± 2.4	1.0 ± 0.0
7	54.0 ± 1.0	46.0 ± 1.0	1.0 ± 0.0
8	50.7 ± 1.8	49.3 ± 1.7	1.1 ± 0.0
9	51.3 ± 3.7	48.7 ± 3.7	1.1 ± 0.1
10	46.3 ± 2.6	53.7 ± 2.6	1.1 ± 0.1
C.D @5%	5.3	5.0	0.1
SE(m)	1.8	1.7	0.1
SE(d)	2.6	2.4	0.1
C.V.	5.0	7.9	8.1
p -value	0.027	0.020	0.002

* p -value < 0.05 significant; > 0.05 not significant

Table 2: Influence on major essential oil components of *M. bracteata* during pre-distillation shade drying

Peak No	Compounds	Retention index		Days of pre-distillation shade drying (% concentration)										
		<i>RI_{lit}</i>	<i>RI_{cal}</i>	0	1	2	3	4	5	6	7	8	9	10
1	Terpinolene	1086	1090	0.4	0.6	0.8	0.9	1.0	1.0	0.5	0.7	0.8	0.9	1.2
2	Linalool	1095	1094	0.5	1.1	1.0	1.0	1.1	1.1	0.8	0.8	1.0	0.9	1.4
3	Methyl chavicol	1195	1200	0.2	0.4	0.4	0.5	0.5	0.5	0.4	0.4	0.4	0.2	0.5
4	Eugenol	1356	1361	1.1	0.5	0.6	0.6	0.6	0.5	0.5	0.5	0.6	0.6	0.4
5	E- methyl cinnamate	1376	1397	7.0	6.6	5.6	5.3	5.7	5.4	5.0	5.0	6.0	6.3	6.0
6	Methyl eugenol	1403	1407	80.4	82.6	85.2	85.5	85.4	86.2	88.4	87.0	84.8	84.7	81.8
7	Germacrene-D	1480	1482	2.9	1.1	0.7	0.6	0.6	0.4	0.5	0.6	0.8	0.8	2.6
8	E- Methyl isoeugenol	1491	1495	1.1	0.4	0.4	0.3	0.3	0.2	0.3	0.4	0.4	0.4	0.4
9	Caryophyllene oxide	1582	1586	0.4	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2
10	α-Murolol	1644	1648	0.5	0.2	0.2	0.2	0.2	0.1	0.2	0.1	0.2	0.4	0.2
11	α-Cadinol	1652	1654	0.8	0.3	0.3	0.2	0.2	0.1	0.2	0.2	0.3	0.3	0.3
Class composition														
	Monoterpenoids (MT)			0.9	1.7	1.8	1.9	2.1	2.1	1.3	1.5	1.8	1.8	2.6
	Sesquiterpenoids (ST)			4.6	1.8	1.3	1.1	1.1	0.7	1	1	1.5	1.7	3.3
	Phenyl propanoids (PP)			89.8	90.5	92.2	92.2	92.5	92.8	94.6	93.3	92.2	92.2	89.1
	Total identified			95.3	94.0	95.3	95.2	95.7	95.6	96.9	95.8	95.5	95.7	95.0

* Mode of identification: RI (retention index), MS (mass spectrometry); and coinjection/comparison with standards and known essential oil constituents; *RI_{cal}*: retention index determined in TG-5 (30 m x 0.25 mm) using n-alkanes; *RI_{lit}*=Retention index data acquired from literature (Adams, 2007); MT = Monoterpenoids; ST= Sesquiterpenoids; PP= Phenyl propanoids.

(E)-methyl cinnamate was highest on the first day (7.0%). Among other compounds, eugenol, germacrene-D and E-methyl isoeugenol were present in the highest amounts on the first day (1.1, 2.9 and 1.1%, respectively), while terpinolene and linalool were present in the highest amounts at tenth day (1.2 and 1.4%, respectively) of drying. It can be observed that shade drying leads to increase the composition of the major compound ME and minor compounds such as terpinolene and linalool. The increment of major compound ME may be due to the lesser temp during shade drying, which leads to less evaporation of essential oil, whereas after six days, as the dryness increases, the absorption of temp increases and thus evaporation increases.

Recently, a study on EO of leaves of *M. bracteata* from China reports ME (66.68%) as the major compound (Wang et al., 2020). In another study, eugenol methyl ether (82.3%) was reported as the major compound (Siddique et al., 2017). Earlier, two studies from North India also reported ME-rich *M. bracteata* species. Our findings report higher content of ME than Joshi et al. (2021) and lower content than Goswami et al. (2017). This may be due to the increased climatic changes over the past few years (Wani et al., 2023). However, the essential oil yield is the same as reported by Goswami et al. (2017). A recent study

from Brazil reports that ME actively repels *Amblyomma sculptum* nymphs (Barrorzo et al., 2025), while another study from China suggests it repels *S. invicta* (He et al., 2023). Hazrati et al. (2021) discovered that drying processes had a substantial impact on EO content, with shade-drying yielding the maximum level of EO in *Stachys lavandulifolia*. In addition to the drying process, storage conditions also affect essential oil yield (Lisoba et al., 2018), which may be due to the fact that there is no regular/continuous pattern in EO as observed (Table 2). Several previous studies have evaluated the effect of drying and storage on the EO yield, such as *Ocimum x africanum* (Padalia et al., 2018), *Cannabis sativa* (Baek et al., 2025), *M. linariifolia* (Kholiya et al., 2024), and *M. leucadendron* (Kholiya et al., 2023). These studies have also suggested shade drying as one of the most suitable methods of drying herbs.

Conclusion

The current research has significant implications for profitable oil production. *M. bracteata* was found to be a rich source of eugenol and have ability to achieve a yield increase by modifying existing distillation practices to improve oil returns per tree. Furthermore, it is suggested that drying techniques for about a week may improve

the recovery of essential oils. However, the results of the present study may vary as essential oil composition depends on climatic conditions. Some of the bioactive compounds found in essential oil change depending on the drying duration. The percentage of eugenol is nearly the same from day 1 of shade drying to day 10. The composition of ME (88.4%) was high at sixth day of drying with 1.0% essential oil yield. The maximum methyl eugenol can be able to extract from the *M. bracteata* when the moisture content of it is 55.3% on wet basis. In terms of chemical class composition, phenylpropanoids (83.5–93.3%) were the most represented of the total oil. ME is a phenylpropanoid & major compound of essential oil. Phenylpropanoids are bioactive compounds and are highly used commercially for their insect repellent properties. The findings of the present study will be helpful for large scale/ commercial production of ME-rich essential oil.

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Author Contributions

Sushma Kholiya contributed to writing the original draft, investigation, and formal analysis. Amit Chauhan contributed to writing, review and editing, conceptualization, and methodology. Pragya Pandey contributed to formal analysis. Venkatesha K. T. contributed to data curation and formal analysis. R. K. Upadhyay contributed to writing and data analysis. R. C. Padalia contributed to supervision, resources, methodology, and writing, review and editing.

Conflict of Interest

The authors declare no conflict of interest.

References

- Adams, R. P. (2012). *Identification of essential oil components by gas chromatography/mass spectrometry*. Allured Publishing Corporation.
- Almarie, A., Mamat, A., & Rukunudin, I. (2016). Chemical composition and herbicidal effects of *Melaleuca bracteata* F. Muell. essential oil against some weedy species. *International Journal of Scientific & Engineering Research*, 7(1), 507–512. <http://www.ijser.org>
- Baek, Y., Grab, H., & Chen, C. (2025). Postharvest drying and curing affect cannabinoid contents and microbial levels in industrial hemp (*Cannabis sativa* L.). *Plants*, 14, 414. <https://doi.org/10.3390/plants14030414>
- Bagg, J., Jackson, M. S., Sweeney, M. P., Ramage, G., & Davies, A. N. (2006). Susceptibility to *Melaleuca alternifolia* (tea tree) oil of yeasts isolated from the mouths of patients with advanced cancer. *Oral Oncology*, 42(5), 487–492. <https://doi.org/10.1016/j.oraloncology.2005.10.002>
- Barrozo, M. M., Figueiredo, D., Bernardes, G., Santos, E. F., Carvalho, R. A., Silva, I. S., Vale, F. L., Martins, J., Luz, H. R., Ferreira, L. L., & Monteiro, C. (2025). Repellent activity of deet combined with botanical compounds against *Amblyomma sculptum* nymphs: laboratory and field evaluations. *Pathogens*, 14(5), 495–495. <https://doi.org/10.3390/pathogens14050495>
- Brophy, J. J., Craven, L. A., & Doran, J. C. (2013). *Melaleucas: Their botany, essential oils and uses*. Australian Centre for International Agricultural Research.
- Carson, C. F., Hammer, K. A., & Riley, T. V. (2006). *Melaleuca alternifolia* (tea tree) oil: A review of antimicrobial and other medicinal properties. *Clinical Microbiology Reviews*, 19(1), 50–62. <https://doi.org/10.1128/cmr.19.1.50-62.2006>
- Choi, Y. K., Cho, G. S., Hwang, S., Kim, B. W., Lim, J. H., Lee, J. C., Kim, H. C., Kim, W. K., & Kim, Y. S. (2010). Methyl eugenol reduces cerebral ischemic injury by suppression of oxidative injury and inflammation. *Free Radical Research*, 44, 925–935.
- Dewey, D. R., & Lu, K. H. (1959). A correlation and path-coefficient analysis of components of crested wheatgrass seed production. *Agronomy Journal*, 51(9), 515–518. <https://doi.org/10.2134/agronj1959.00021962005100090002x>
- European Pharmacopoeia. (2004). *European Pharmacopoeia* (4th ed., Version 4.08, pp. 3158–3159). European Directorate for the Quality of Medicines & HealthCare (EDQM).
- Goswami, P., Verma, S. K., Chauhan, A., Venkatesha, K. T., Verma, R. S., Singh, V. R., Darokar, M. P., Chanotiya, C. S., & Padalia, R. C. (2017). Chemical composition and antibacterial activity of *Melaleuca bracteata* essential oil from India: A natural source of methyl eugenol. *Natural Product Communications*, 12(6), 965–968. <https://doi.org/10.1177/1934578x1701200633>
- Hazrati, S., Lotfi, K., Govahi, M., & Ebadi, M. T. (2021). A comparative study: Influence of various drying methods on essential oil components and biological properties of *Stachys lavandulifolia*. *Food Science & Nutrition*, 9(5), 2612–2619. <https://doi.org/10.1002/fsn3.2218>
- He, Y., Zhang, J., Shen, L., Wang, L., Qian, C., Lyu, H., Yi, C., Cai, J., Chen, X., Wen, X., Wen, C., & Wang, C. (2022). Eugenol derivatives: Strong and long-lasting repellents against both undisturbed and disturbed red imported fire ants. *Journal of Pest Science*, 96(1), 327–344. <https://doi.org/10.1007/s10340-022-01501-8>
- Iori, A., Grazioli, D., Gentile, E., Marano, G., & Salvatore, G. (2005). Acaricidal properties of the essential oil

- of *Melaleuca alternifolia* Cheel (tea tree oil) against nymphs of *Ixodes ricinus*. *Veterinary Parasitology*, 129(1–2), 173–176. <https://doi.org/10.1016/j.vetpar.2004.11.035>
- Joshi, A., Kumar, R., Prakash, O., Szczepaniak, L., Pant, A. K., & Kucharska-Ambrozej, K. (2021). Methyl Eugenol, 1,8-cineole and Nerolidol rich essential oils with their biological activities from three melaleuca species growing in tarai region of north India. *Brazilian Archives Of Biology and Technology*, 64, 1–15. <https://doi.org/10.1590/1678-4324-2021210186>
- Kholiya, S., Bhatt, G., Chauhan, A., Kumar, D., Venkatesha, K. T., Upadhyay, R. K., & Padalia, R. C. (2024). Effect of seasons, storage and distillation times on essential oil composition of *Melaleuca leucadendra* (L.). *Indian Journal of Natural Product Resour*, 14(4), 611–616 (2023). <https://doi.org/10.56042/ijnpr.v14i4.5449>
- Kholiya, S., Pandey, H., Padalia, R. C., Tiwari, A., & Prakash, O. (2024). Phytochemical analysis, post-harvest shade drying, and biological activities of *Melaleuca linariifolia* Sm. from foothills of Kumaun Himalayas, India. *Biochemical Systematics and Ecology*, 114, 1–8 (2024). <https://doi.org/10.1016/j.bse.2024.104824>
- Lisboa, H. M., Maria, E. D., & Cavalcanti-Mata, M. A. (2018). Modeling of food drying processes in industrial spray dryers. *Food and Bioprocess Technology*, 107, 49–60. <https://doi.org/10.1016/j.fbp.2017.09.006>
- Minami, M., Kita, M., Nakaya, T., Yamamoto, T., Kuriyama, H., & Imanishi, J. (2003). The inhibitory effect of essential oils on herpes simplex virus type-1 replication in vitro. *Microbiology and Immunology*, 47(9), 681–684. <https://doi.org/10.1111/j.1348-0421.2003.tb03431.x>
- Padalia, R. C., Singh, V. R., Bhatt, G., Chauhan, A., Upadhyay, R. K., Verma, R. S., & Chanotiya, C. S. (2018). Optimization of harvesting and postharvest drying methods of *Ocimum x africanum* Lour. for production of quality essential oil. *Journal of Essential Oil Research*, 30, 437–443. <https://doi.org/10.1080/10412905.2018.1495110>
- Panase, V. G., & Sukhatme, P. V. (1989). Statistical methods for agricultural workers. Indian Council of Agricultural Research.
- Pino, J. A., Regalado, E. L., Rodríguez, J. L., & Fernández, M. D. (2010). Phytochemical analysis and in vitro free-radical-scavenging activities of the essential oils from leaf and fruit of *Melaleuca leucadendra* L. *Chemistry & Biodiversity*, 7(9), 2281–2288. <https://doi.org/10.1002/cbdv.200900162>
- Reynertson, K. A., Yang, H., Jiang, B., Basile, J. M., & Kennelly, E. J. (2008). Quantitative analysis of antiradical phenolic constituents from fourteen edible Myrtaceae fruits. *Food Chemistry*, 109, 883–890. <https://doi.org/10.1016/j.foodchem.2008.01.021>
- Siddique, S., Parveen, Z., Bareen, F., & Mazhar, S. (2017). Chemical composition, antibacterial and antioxidant activities of essential oils from leaves of three *Melaleuca* species of Pakistani flora. *Arabian Journal of Chemistry*, 13, 67–74. <https://doi.org/10.1016/j.arabjc.2017.01.018>
- Singh, R. K., & Chaudhary, B. D. (1985). *Biometrics in Quantitative Genetics Analysis*. Kalayani Publishers, New Delhi, India.
- Tan, K. H., & Nishida, R. (2012). Methyl eugenol: Its occurrence, distribution, and role in nature, especially in relation to insect behavior and pollination. *Journal of Insect Science*, 12(56), 1–6074, 2012. <https://doi.org/10.1673/031.012.5601>
- Wang, L. Y., How, W. C., Shen, T. A., Rong, D., & Luo, Y. (2020). Chemical composition, antioxidant and bioactivities of essential oils from *Melaleuca bracteata* leaves. *Plant Protection Science*, 56(1), 18–29. <https://doi.org/10.17221/38/2019-pps>
- Wani, Z. A., Fatima, T., Verma, O., Sharma, V., & Pant, S. (2023). Impacts of climate change on plants with special reference to the Himalayan region. In S. Sharma, J. C. Kuniyal, P. Chand, & P. Singh (Eds.), *Climate change adaptation, risk management and sustainable practices in the Himalaya* (pp. 237–251). Springer Nature.