

**IMPROVISATION OF THE PROCESS FOR EXTRACTION OF
ESSENTIAL OILS FROM AROMATIC WOODS
(*CEDRUS DEODARA* & *SANTALUM ALBUM*)**

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**CENTRE FOR RURAL DEVELOPMENT & TECHNOLOGY
INDIAN INSTITUTE OF TECHNOLOGY DELHI
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by

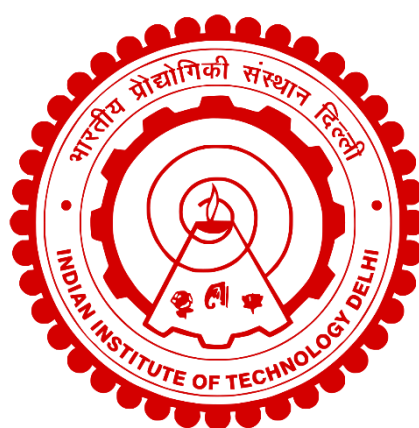
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Submitted

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to the



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Dedicated to
My Parents

CERTIFICATE

This is to certify that the thesis entitled “**Improvisation of the process for extraction of essential oils from aromatic woods (*Cedrus deodara & Santalum album*)**”, being submitted by **Ms. Shreya Tripathi** to the **Indian Institute of Technology Delhi** for the award of “**Doctor of Philosophy**” is a record of bonafide research work carried out by her. She has worked under our guidance and supervision and has fulfilled the requirements for the submission of this thesis. To the best of our knowledge, the results contained in this thesis have not been submitted in part or full to any other university or institute for the award of any degree or diploma.



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by

Shreya Tripathi

ABSTRACT

The present study focuses on two valuable essential oils extracted from aromatic woods cedarwood and sandalwood belonging to the genus *Cedrus* and *Santalum*, respectively. There are various species of these plants found in different parts of the world. However, for both of these aromatic woods, the essential oils extracted from the species grown in India are established to be of superior quality. The Indian cedarwood belongs to *C. deodara* and sandalwood belongs to *S. album*.

India is a vast country with varied climatic conditions prevailing in different states which can cause significant variations in the yield and chemical composition of essential oils. Therefore, the samples of cedarwood and sandalwood were procured from different states of India to analyze the variation in the yield and chemical composition of the essential oil extracted. Cedarwood is mainly grown at high altitudes, hence the samples were obtained from Himachal Pradesh and Uttarakhand. Hydrodistillation of these woodchips provided 3.6% and 4.9% of essential oils in 10-11 h respectively. The chemical profile of the essential oils was similar with variation only in percentage composition. The total percentage of sesquiterpene hydrocarbons in cedarwood oil from Himachal Pradesh and Uttarakhand were 20.6% and 13.9%, respectively. Whereas, the total percentage of oxygenated sesquiterpenoids were 73.5% and 76.5%, respectively. A significantly high difference was observed in the amount of (*E*)- α -atlantone concentration in the two oils. Sandalwood samples were procured from Maharashtra (Western India), Odisha (Eastern India), and Karnataka (Southern India). Hydrodistillation of these woodchips provided 1.5% (Maharashtra), 3.2% (Odisha), and 5.1% (Karnataka) sandalwood oil in 14 h. The chemical profile of these oils was similar with variation in percentage composition. The total sesquiterpene hydrocarbon content in sandalwood oil from Maharashtra, Odisha, and Karnataka was 1.2%, 3.4% and 4.0%, respectively. The total content of oxygenated sesquiterpenoids was 78.2%, 87.6%, and 87.8%, respectively. The santalol content in these oils was 73.1%, 78.1%, and 81.9%, respectively.

The chemical composition of cedarwood and sandalwood oil reveals the presence of sesquiterpenoids which are relatively difficult to extract in comparison to monoterpenoids. The essential oil yield for this aromatic wood is low and requires a large amount of energy and time for the separation of oil from the wood. This causes an increased demand for raw materials leading to extensive deforestation. Therefore, to increase oil yield, the current study attempts three

different techniques for the pretreatment of these woodchips before subjecting them to hydrodistillation. These pretreatment techniques were selected based on their ability to disrupt the lignocellulosic linkage within the plant material causing the opening of oil glands and thereby facilitating the extraction of essential oils. The selected pretreatment techniques were: subcritical water and hydrolytic enzymes. The process variables for these two pretreatment techniques were optimized for both aromatic woods. Integration of the two pretreatment processes at optimized conditions was also attempted. The results suggest the success of all three pretreatment processes providing improved cedarwood and sandalwood oil yield with respect to the control (untreated woodchips). These pretreatments led to a 40-50% reduction in extraction time which is a very crucial aspect of production at a commercial scale.

The hydrodistillation of fresh cedarwood yielded 3.6% essential oil. The optimized parameters achieved for the subcritical water pretreatment of cedarwood were: a temperature of 150°C, a time of 30 min, a solid-to-solvent ratio of 1:12. The cedarwood oil yield at these optimized conditions was 4.8%. The optimized parameters for the enzymatic pretreatment of cedarwood were: temperature 50°C, pH 5, incubation time 90 min, and enzyme loading 1.2 mg/mL. The cedarwood oil yield at these optimized conditions was 6.6%. Besides, the combination of these two pretreatment processes led to an oil yield of 5.8%. Interestingly, it was observed that pretreatment of woodchips also led to improved extraction of (*E*)- α -atlantone, which exhibits high antimicrobial activity as established by some studies.

The hydrodistillation of fresh sandalwood yielded 5.1% essential oil. The optimum conditions obtained for subcritical water pretreatment of sandalwood were the same as cedarwood and led to an oil yield of 6.0%. The optimum conditions for enzymatic pretreatment of sandalwood were: temperature of 50°C, pH 5, incubation time of 120 min, and enzyme loading of 1.5 mg/mL, yielding 6.8% sandalwood oil. The required incubation time and enzyme loading were higher than the cedarwood. The integrated pretreatment led to a 6.3% oil yield. It was observed that these pretreatments also led to an improved percentage of santalol in the extracted oil. Santalol is established as the most valuable constituent of sandalwood oil deciding its quality and market price.

The results of the present work suggest the superiority of the low-temperature enzymatic-treatment process over others for the pretreatment of the selected aromatic woods for obtaining higher yields and improved quality of essential oil. The cedarwood and sandalwood oil obtained via enzymatic-assisted hydrodistillation were investigated for their antimicrobial activity against selected bacterial and fungal strains by the disc diffusion assay process. For cedarwood oil, a significant improvement in antimicrobial activity was observed for oil extracted from pretreated wood. This can be attributed to an increase in the content of oxygenated sesquiterpenoids responsible for the antimicrobial property of cedarwood oil. For sandalwood oil also, a slight improvement in activity against selected strains was observed.

Further, the most suitable enzymatic-pretreated cedarwood and sandalwood were subjected to liquid-CO₂, which is a green extraction process with high selectivity towards valuable volatile terpenoids. The results reveal that liquid-CO₂ is suitable for the profitable isolation of volatile terpenoids from both kinds of wood with an improved yield at lesser extraction time. For cedarwood, the yield of terpenoids was increased up to 8.1% in 4 h in liquid-CO₂ as compared to the prolonged hydrodistillation (10-11 h) for extraction of essential oil (3.6%). For sandalwood, when enzymatically pretreated woodchips were used for extraction of volatiles via liquid-CO₂ the yield was increased to 7.3% in 4 h as compared to the essential oil (5.1%) isolated in 14 h. The percentage of valuable terpenoids viz. (*E*)- α -atlantone in cedarwood and santalol in sandalwood were also drastically enhanced in the pretreated woods. Besides, both cedarwood and sandalwood oil from pretreated wood displayed significantly improved antimicrobial activities in comparison to essential oil extracted from fresh wood.

The essential oils from aromatic woods can generally be categorized as a sesquiterpenoids class of compounds, which are less volatile. Therefore, these essential oils can be used as a fragrance base to provide a middle note of the formulations and fetch higher prices which often attracts adulteration by illegal traders. The practiced quality control evaluation of essential oil is associated with its appearance, olfactory, physicochemical attributes, GC-FID, and GC/MS analysis. To overcome these key steps, experienced illegal practitioners use low-volatile or non-volatile liquid adulterants. The most common adulterants detected in commercial samples are vegetable oils which are ideal for mixing with these wood essential oils due to their non-toxic nature, immiscibility in water, low-cost and abundant availability. These oils exhibit homogeneous

mixing with wood essential oils because of nearly identical density. To find a practical solution to this real issue, many researchers are engaged in the exploitation of different spectroscopic techniques to segregate vegetable oils/liquid biopolymers from natural oils. Though some initial success in this field has been attained, it needs skilled manpower as well as quantitative estimation of adulterants is a challenging task. Therefore, our group has been the first to develop a handy analytical technique for qualitative as well as quantitative estimation of high boiler adulterants through thermogravimetric analysis (TGA). It is a novel, rapid and precise method to detect the high boiler adulterants in sandalwood and cedarwood essential oil. For process optimization, different proportions of (5%, 10%, 15%, and 30%,) selected high-boiler adulterants such as castor oil, coconut oil, and polyethylene glycol 400 were mixed with cedarwood and sandalwood oil. The adulterated samples were analyzed for their physical properties such as refractive index and specific gravity. No significant change in comparison to pure essential oil was observed. The adulterated and pure (control) oil samples were then subjected to thermogravimetric analysis. A clear-cut distinction in the TGA pattern was observed, which was exactly quantified. The pure essential oil sample exhibited a single-stage volatilization pattern in a low-temperature region corresponding to sesquiterpenoids. Whereas, the adulterated samples exhibited a two-stage volatilization pattern corresponding to the presence of both essential oil (low temperature) and adulterant (high temperature). Further by use of the TGA software precise determination of the amount of adulterant was estimated by their weight loss patterns corresponding to the two volatilization zones.

In addition, the phytochemical investigations of the essential oils were carried out. The isolation of major terpenoids in the essential oils was carried out by column chromatography. (*E*)- α -atlantone was isolated from cedarwood essential oil, and (*Z*)- α -santalol was isolated from the sandalwood essential oil. The isolated compounds were characterized by spectroscopic techniques such as GC/MS and NMR. Further, the spent wood obtained after hydrodistillation was utilized for the preparation of incense sticks. These woods are very highly recognized for worship purposes; hence the prepared incense sticks can fetch a decent price and help in the generation of income through MSME schemes. It was observed that the required binder for pretreated wood was low in comparison to untreated wood. This can lead to the utilization of waste for providing alternate employment opportunities to rural society along with solving a crucial issue of waste disposal.

सारांश

वर्तमान अनुसंधान कार्य , देवदार और चंदन की सुगन्धित लकड़ी से निष्कर्षित किये जाने वाले दो मूल्यवान गंध प्रदान करने वाले तेलों पर केंद्रित है, जो क्रमशः जीनस *Cedrus* तथा *Santalum* के अंतर्गत आते हैं। दुनिया के विभिन्न हिस्सों में इन पौधों की विभिन्न प्रजातियां पाई जाती हैं। हालाँकि, इन दोनों सुगन्धित लकड़ियों के लिए, भारत में उगाई जाने वाली प्रजातियों से निकाले जाने वाले तेल बेहतर गुणवत्ता के हैं। भारतीय देवदार *C. deodara* प्रजाति तथा चंदन *S. album* प्रजाति के होते हैं।

भारत एक विशाल देश है जहां विभिन्न राज्यों में विभिन्न जलवायु परिस्थितियां प्रचलित हैं, जो इन तेलों की उपज (yield) और रासायनिक संरचना में महत्वपूर्ण बदलाव ला सकती हैं। इसलिए, निष्कर्षित किये गए तेल की उपज और रासायनिक संरचना में भिन्नता का विश्लेषण करने के लिए भारत के विभिन्न राज्यों से देवदार और चंदन के नमूने प्राप्त किए गए थे। देवदार की लकड़ी मुख्य रूप से उच्च ऊंचाई पर उगाई जाती है, इसलिए नमूने हिमाचल प्रदेश और उत्तराखंड से प्राप्त किए गए थे। इन वुडचिप्स के हाइड्रोडिस्टिलेशन ने १०-११ घंटे में क्रमशः ३.६% और ४.९% तेल प्रदान किए। हिमाचल प्रदेश और उत्तराखंड से प्राप्त की हुई।

देवदार की लकड़ी से निष्कर्षित तेल में सेसक्विटरपीन हाइड्रोकार्बन का कुल प्रतिशत क्रमशः २०.६% और १३.९% था। जबकि, ऑक्सीजन युक्त sesquiterpenoids का कुल प्रतिशत क्रमशः ७३.५% और ७६.५% था। दोनों तेलों में (E)- α -atlantone की मात्रा में काफी महत्वपूर्ण अंतर देखा गया। चंदन के नमूने महाराष्ट्र (पश्चिमी भारत), ओडिशा (पूर्वी भारत) और कर्नाटक (दक्षिणी भारत) से प्राप्त किए गए थे। इन वुडचिप्स के हाइड्रोडिस्टिलेशन ने १४ में १.५% (महाराष्ट्र), ३.२% (ओडिशा), और ५.१% (कर्नाटक) चंदन का तेल प्रदान किया। इन तेलों की रासायनिक रूपरेखा समान थी, केवल

compounds की प्रतिशत संरचना में भिन्नता थी। महाराष्ट्र, ओडिशा और कर्नाटक से ली गयी लकड़ी से प्राप्त चंदन के तेल में कुल sesquiterpene हाइड्रोकार्बन की मात्रा क्रमशः १.२%, ३.४% और ४.०% थी। ऑक्सीजन युक्त sesquiterpenoids की कुल सामग्री क्रमशः ७.८२%, ८७.२% और ८७.८% थी। इन तेलों में santalol की मात्रा क्रमशः ७३.१%, ७.८१ और ८१.९% थी।

देवदार और चंदन के तेल की रासायनिक संरचना के विश्लेषण से इन में sesquiterpenoids की उपस्थिति का पता चलता है जो मोनोटेरपेनोइड्स की अपेक्षाकृत निकालने में अधिक कठिन होते हैं। इन सुगंधित लकड़ी से निकाले गए तेलों की yield कम है और लकड़ी से तेल को अलग करने के लिए बड़ी मात्रा में ऊर्जा और समय की आवश्यकता होती है। इससे कच्चे माल (देवदार और चंदन की लकड़ी) की बढ़ती मांग के कारण व्यापक वनों की कटाई होती है। इसलिए, yield बढ़ाने के उद्देश्य से वर्तमान अनुसंधान में, हाइड्रोडिस्टिलेशन करने से पहले, इन वुडचिप्स का तीन अलग-अलग तकनीकों द्वारा प्रीट्रीटमेंट करने का प्रयास किया गया है।

इन प्रीट्रीटमेंट तकनीकों का चयन पादप सामग्री के भीतर लिग्नोसेल्यूलोसिक लिंकेज को बाधित करने की उनकी क्षमता के आधार पर किया गया था, जिससे तेल ग्रंथियां खुल जाती हैं और इस तरह तेलों के निष्कर्षण में आसानी होती है। चयनित प्रीट्रीटमेंट तकनीकें थीं: सबक्रिटिकल वाटर और हाइड्रोलाइटिक एंजाइम। इन दो प्रीट्रीटमेंट तकनीकों के लिए अनुकूलित प्रक्रिया स्थितियों का अध्ययन किया गया। अनुकूलित परिस्थितियों में दोनों प्रीट्रीटमेंट प्रक्रियाओं के एकीकरण का भी प्रयास किया गया था। प्रयोग के परिणाम से यह सिद्ध होता है कि नियंत्रण (अनुपचारित लकड़ी) की तुलना में तीनों ही प्रीट्रीटमेंट तकनीकों के द्वारा बेहतर देवदार और चंदन के तेल की उपज प्रदान की जा रही है। इन के कारण निष्कर्षण समय में ४० - ५०% की कमी आई जो कि व्यावसायिक पैमाने पर उत्पादन का एक बहुत ही महत्वपूर्ण पहलू है।

ताजा देवदार की लकड़ी के हाइड्रोडिस्टिलेशन से ३.६% तेल प्राप्त हुआ। देवदार की लकड़ियों के सबक्रिटिकल वाटर प्रीट्रीटमेंट के लिए प्राप्त अनुकूलित पैरामीटर थे: १५० डिग्री सेल्सियस का तापमान, ३० मिनट का समय, और सॉलिड टू सॉल्वेंट अनुपात १:१२। इन अनुकूलित परिस्थितियों में देवदार के तेल की उपज ५.८% थी। देवदार की लकड़ी के एंजाइमेटिक प्रीट्रीटमेंट के लिए अनुकूलित पैरामीटर थे: तापमान ५० डिग्री सेल्सियस, पीएच ५, ऊष्मायन समय १० मिनट, और एंजाइम लोडिंग १.२ मिलीग्राम/एमएल। इन अनुकूलित परिस्थितियों में देवदार के तेल की उपज ६.६% थी। इसके अलावा, इन दो प्रीट्रीटमेंट प्रक्रियाओं के संयोजन से ५.८% तेल का निष्कर्षण हुआ। यह देखा गया कि वुडचिप्स के प्रीट्रीटमेंट से (ई)- α -एटलांटोन का बेहतर निष्कर्षण हुआ, जो कुछ अध्ययनों द्वारा स्थापित उच्च रोगाणुरोधी गतिविधि को प्रदर्शित करता है।

ताजे चंदन के हाइड्रोडिस्टिलेशन से ५.१% तेल प्राप्त होता है। चंदन के सबक्रिटिकल वाटर प्रीट्रीटमेंट के लिए प्राप्त इष्टतम स्थितियां देवदार की लकड़ी के समान थीं और इससे तेल की पैदावार ६.०% हुई। चंदन के एंजाइमेटिक प्रीट्रीटमेंट के लिए इष्टतम स्थितियां थीं: ५० डिग्री सेल्सियस का तापमान, पीएच ५, १२० मिनट का ऊष्मायन समय, और १.५ मिलीग्राम / एमएल की एंजाइम लोडिंग, जिन्से ६.८% चंदन का तेल प्राप्त हुआ। आवश्यक ऊष्मायन समय और एंजाइम लोडिंग देवदार की लकड़ी से अधिक थीं। एकीकृत प्रीट्रीटमेंट के कारण ६.३% तेल का निष्कर्षण हुआ। यह देखा गया कि इन पूर्व उपचारों से निकाले गए तेल में santalol का प्रतिशत भी बेहतर हुआ। santalol को चंदन के तेल की गुणवत्ता और बाजार मूल्य तय करने वाले सर्वाधिक मूल्यवान घटक के रूप में स्थापित किया गया है।

वर्तमान अनुसंधान कार्य के परिणाम तेल की उच्च निष्कर्षण मात्रा और बेहतर गुणवत्ता प्राप्त करने के लिए चयनित सुगंधित लकड़ी के पूर्व उपचार हेतु कम तापमान एंजाइमेटिक-उपचार प्रक्रिया को

अन्य तकनीको की तुलना में श्रेष्ठ बताते हैं। एंजाइम-सहायता प्राप्त हाइड्रोडिस्टीलेशन के माध्यम से प्राप्त देवदार और चंदन के तेल की जांच डिस्क प्रसार परख प्रक्रिया द्वारा चयनित बैक्टीरिया और कवक उपभेदों के खिलाफ उनकी रोगाणुरोधी गतिविधि के लिए की गई। देवदार के तेल के लिए, पूर्व-उपचारित लकड़ी से निकाले गए तेल के लिए रोगाणुरोधी गतिविधि में एक महत्वपूर्ण सुधार देखा गया। देवदार के तेल की रोगाणुरोधी संपत्ति में वृद्धि के लिए ऑक्सीजन युक्त sesquiterpenoids की मात्रा में वृद्धि को जिम्मेदार ठहराया जा सकता है। चंदन के तेल के लिए भी, चयनित उपभेदों के खिलाफ गतिविधि में सुधार देखा गया।

इसके अलावा, सबसे उपयुक्त एंजाइमेटिक-प्रीट्रीटेड देवदार और चंदन की लकड़ी से तरल कार्बन डाइऑक्साइड के द्वारा तेल का निष्कर्षण किया गया। तरल कार्बन डाइऑक्साइड एक हरी पर्यावरण अनुकूल प्रक्रिया है जो कि मूल्यवान वाष्पशील टेरपेनोइड्स के निष्कर्षण के लिए उच्च चयनात्मकता दिखाती है। परिणामों से पता चलता है कि तरल कार्बन डाइऑक्साइड कम समय में बेहतर मात्रा के साथ दोनों प्रकार की लकड़ी से वाष्पशील टेरपेनोइड्स के लाभदायक निष्कर्षण के लिए उपयुक्त है। देवदार की लकड़ी के हाइड्रोडिस्टीलेशन से लंबे समय (१०-११ घंटे) में केवल ३.६% तेल की तुलना में तरल- कार्बन डाइऑक्साइड द्वारा ४ घंटे में टेरपेनोइड्स की उपज ८.१% तक बढ़ गई थी। चंदन के लिए, जब तरल- कार्बन डाइऑक्साइड के माध्यम से वाष्पशील के निष्कर्षण के लिए एंजाइमेटिक रूप से प्रेट्रीटेड वुडचिप्स का उपयोग किया गया था, तो ४ घंटे में ७.३% तक तेल प्राप्त हुआ जो कि पारंपरिक हाइड्रोडिस्टीलेशन द्वारा १४ घंटे में निष्कर्षित तेल (५.१%) की तुलना में अधिक है। उपचारित देवदार और चंदन की लकड़ी से निष्कर्षित तेल में (ई)- α -atlantone तथा santalol की मात्रा भी काफी बढ़ा गई थी। इसके अलावा, उपचारित देवदार और चंदन की लकड़ी से निष्कर्षित तेल ताजी लकड़ी से निकाले गए तेल की तुलना में बेहतर रोगाणुरोधी गतिविधियाँ प्रदर्शित करता है।

सुगंधित लकड़ी से निष्कर्षित तेलों को आम तौर पर sesquiterpenoids वर्ग के रूप में वर्गीकृत किया जा सकता है, जो कम-वाष्पशील होते हैं। इसलिए, इन तेलों का उपयोग फॉर्मूलेशन के मध्य नोट प्रदान करने और उच्च मूल्य प्राप्त करने के लिए सुगंध आधार के रूप में किया जा सकता है, जो अक्सर अवैध व्यापारियों द्वारा मिलावट को आकर्षित करता है। तेल की गुणवत्ता नियंत्रण और मूल्यांकन इसकी दिखावट, घाण, भौतिक, रासायनिक विशेषताओं, GC-FID और जीसी/एमएस (GC/MS) विश्लेषण से जुड़ा है। इनसे बचने के लिए अनुभवी अवैध चिकित्सक कम-वाष्पशील या गैर-वाष्पशील तरल मिलावट का उपयोग करते हैं। वाणिज्यिक नमूनों में पाए जाने वाले सबसे आम मिलावट पदार्थ वनस्पति तेल हैं। वनस्पति तेलों की गैर-विषाक्त प्रकृति, पानी में अमिश्रणता, कम लागत और प्रचुर-मात्रा में उपलब्धता इनहे लकड़ी के तेलों के साथ मिश्रण के लिए आदर्श बनाती है। ये तेल लगभग समान घनत्व के कारण लकड़ी के तेलों के साथ सजातीय मिश्रण प्रदर्शित करते हैं। इस वास्तविक मुद्दे का एक व्यावहारिक समाधान खोजने के लिए, कई शोधकर्ता वनस्पति तेलों/तरल बायोपॉलिमर को इन तेलों से अलग करने के लिए विभिन्न स्पेक्ट्रोस्कोपिक तकनीकों के दोहन में लगे हुए हैं। यद्यपि इस क्षेत्र में कुछ प्रारंभिक सफलता प्राप्त हुई है, इसके लिए कुशल जनशक्ति की आवश्यकता है और साथ ही मिलावटों का मात्रात्मक आकलन एक चुनौतीपूर्ण कार्य है। इसलिए, हमने पहली बार थर्मोग्रेविमेट्रिक विश्लेषण (टीजीए) के माध्यम से उच्च बॉयलर मिलावट के गुणात्मक और मात्रात्मक आकलन के लिए एक आसान विश्लेषणात्मक तकनीक विकसित करने करने का प्रयास किया। यह चंदन और देवदार के तेल में उच्च बॉयलर मिलावटी पदार्थ का पता लगाने के लिए एक नया, तेज़ और सटीक तरीका है। प्रक्रिया के अनुकूलन के लिए, विभिन्न अनुपात में (5%, 10%, 15% और 30%) चयनित उच्च-बॉयलर मिलावटी पदार्थ जैसे कि अरंडी (Castor) का तेल, नारियल का तेल और पोलाइथिलीन ग्लाइकॉल 400 को देवदार और चंदन के तेल के साथ मिलाया गया था। मिलावटी नमूनों का उनके भौतिक गुणों जैसे अपवर्तनांक और विशिष्ट गुरुत्व

के लिए विश्लेषण किया गया था। इन में शुद्ध आवश्यक तेल की तुलना में कोई महत्वपूर्ण परिवर्तन नहीं देखा गया। इसके पश्चात, मिलावटी और शुद्ध (नियंत्रण) तेल के नमूनों का थर्मोगैविमेट्रिक विश्लेषण किया गया। टीजीए पैटर्न में एक स्पष्ट अंतर देखा गया था, जिसे सटीक रूप से परिमाणित किया गया था। शुद्ध तेल के नमूने ने sesquiterpenoids के अनुरूप कम तापमान वाले क्षेत्र में एकल-चरण वाष्पीकरण पैटर्न का प्रदर्शन किया। जबकि, मिलावटी नमूनों में तेल (कम तापमान) और मिलावट (उच्च तापमान) दोनों की उपस्थिति के अनुरूप दो चरणों वाला वाष्पीकरण पैटर्न प्रदर्शित किया गया था। इसके अलावा टीजीए सॉफ्टवेयर के उपयोग से मिलावट की मात्रा का सटीक निर्धारण उनके वजन घटाने के पैटर्न द्वारा दो वाष्पीकरण क्षेत्रों के अनुरूप किया गया था।

इसके अलावा, तेलों की फाइटोकेमिकल जांच की गई। स्तंभ क्रोमैटोग्राफी द्वारा तेलों में प्रमुख टेरपेनोइड्स का अलगाव किया गया था। (ई)- α -atlantone को देवदार के आवश्यक तेल से अलग किया गया था, और (Z)- α -santalol को चंदन के आवश्यक तेल से अलग किया गया था। पृथक यौगिकों की पहचान जीसी/एमएस और एनएमआर जैसी स्पेक्ट्रोस्कोपिक तकनीकों से की गई। इसके अलावा, हाइड्रोडिस्टिलेशन के बाद प्राप्त की गई लकड़ी का उपयोग अगरबत्ती तैयार करने के लिए किया गया था। इन लकड़ियों को पूजा के उद्देश्यों के लिए बहुत मान्यता प्राप्त है, इसलिए तैयार अगरबत्तियां एक अच्छी कीमत प्राप्त कर सकती हैं और एमएसएमई योजनाओं के माध्यम से आय उत्पन्न करने में मदद कर सकती हैं। यह देखा गया कि उपचारित लकड़ी के लिए आवश्यक बाइंडर अनुपचारित लकड़ी की तुलना में कम था। इससे अपशिष्ट निपटान के एक महत्वपूर्ण मुद्दे को हल करने के साथ-साथ ग्रामीण समाज को वैकल्पिक रोजगार के अवसर प्रदान करने के लिए कचरे का उपयोग हो सकता है।

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List of Symbols

Symbol	Description
T	Temperature
t	Time
Min	Minute
L	Liter
Kg	Kilogram
G	Gram
mg	Milligram
%	Percentage

List of Abbreviations

Syntax	Description
CWEO	Cedarwood essential oil
SEO	Sandalwood essential oil
Liq-CO ₂	Liquid carbon dioxide
SC-CO ₂	Supercritical carbon dioxide
SD	Steam distillation
HD	Hydrodistillation
MAE	Microwave-assisted extraction
M-AHD	Microwave-air hydrodistillation
CO	Castor oil
Coco	Coconut oil
PEG	Polyethylene glycol
nD	Not determined