

Review Article



Biotechnological Enhancement of Aromatic Siddha Medicinal Plants for Sustainable Aromatherapy: Current Advances and Future Perspectives

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ABSTRACT

Background: Mental health disorders, including stress, anxiety, depression, and insomnia, have emerged as major public health concerns worldwide. Aromatherapy, utilizing volatile phytoconstituents derived from medicinal plants, has gained increasing attention as a complementary therapeutic approach for promoting psychological well-being. Siddha medicine encompasses numerous aromatic medicinal plants possessing neuroprotective, anxiolytic, antidepressant, and adaptogenic properties. However, conventional essential oil production methods are often associated with limitations such as low yields, seasonal variability, poor standardization, and reduced bioavailability. Recent advances in biotechnology have provided innovative strategies to overcome these challenges and enhance the therapeutic potential of aromatherapy.

Objective: To comprehensively review the role of biotechnology in improving the production, standardisation, delivery, and therapeutic efficacy of aromatic Siddha medicinal plants used in aromatherapy for mental health management.

Methods: A comprehensive literature review was conducted using scientific databases, including PubMed, Scopus, Web of Science, ScienceDirect, and Google Scholar. Relevant literature pertaining to Siddha aromatic medicinal plants, essential oils, biotechnology, tissue culture, metabolic engineering, nanotechnology, and mental health applications was critically analyzed.

Results: Biotechnological interventions, including plant tissue culture, hairy root culture, microbial biotransformation, metabolic engineering, and nanoencapsulation, significantly improve essential oil yield, consistency, and bioavailability. Aromatic Siddha medicinal plants such as Vallarai (*Centella asiatica*), Tulsi (*Ocimum tenuiflorum*), Vetiver (*Vetiveria zizanioides*), Sandalwood (*Santalum album*), Lemon Grass (*Cymbopogon citratus*), and Lavangam (*Syzygium aromaticum*) exhibit promising therapeutic effects against stress, anxiety, depression, and sleep disorders. Nanotechnology-based delivery systems further enhance the stability and controlled release of volatile compounds.

Conclusion: The integration of biotechnology with Siddha aromatherapy offers sustainable solutions for large-scale production and improved therapeutic efficacy of essential oils. Future research focusing on artificial intelligence-assisted cultivation, synthetic biology, and personalised aromatherapy may establish new paradigms in mental health management.

Keywords: Aromatherapy, Siddha Medicine, Biotechnology, Mental Health, Nanotechnology, Sustainable Production.

INTRODUCTION

Mental health disorders have become one of the major public health concerns of the twenty-first century. Increasing urbanization, demanding work environments, lifestyle changes, and social isolation have contributed to a steady rise in conditions such as stress, anxiety, depression, insomnia, and cognitive impairment. These disorders not only reduce quality of life but also place a considerable burden on healthcare systems and society. Although conventional psychotropic medications remain the cornerstone of treatment, their long-term use is often associated with adverse effects, drug dependence, and poor patient adherence. As a result, there is growing interest in complementary approaches that can support mental well-being with fewer side effects.

Aromatherapy has gained increasing attention as one such complementary therapy. Aromatherapy has been widely used to manage a broad range of health conditions⁽¹⁾. It involves the use of essential oils extracted from aromatic

medicinal plants through inhalation, massage, topical application, or diffusion to promote psychological and emotional well-being. It's the ancient tradition of herbal medicine². Once inhaled, volatile compounds stimulate the olfactory system and activate regions of the limbic system involved in emotion, memory, and stress regulation. This interaction influences several neurochemical pathways associated with mood, relaxation, and cognitive function, providing a biological basis for the therapeutic use of essential oils in mental health.

The Siddha system of medicine has long recognized the value of aromatic medicinal plants in maintaining mental and neurological health³. Plants such as *Centella asiatica* (Vallarai)⁴, *Ocimum tenuiflorum* (Tulsi)⁵, *Vetiveria zizanioides* (Vetiver)⁶, *Santalum album* (Sandalwood)⁷, *Cymbopogon citratus* (Lemongrass)⁸, and *Syzygium aromaticum* (Clove)⁹ have traditionally been used to relieve mental fatigue, improve memory, promote restful sleep, and restore emotional balance. These therapeutic effects are attributed to a diverse range of bioactive constituents,



including terpenoids¹⁰, phenylpropanoids¹¹, flavonoids¹², and essential oils, many of which have demonstrated neuroprotective, antioxidant, and anxiolytic properties in recent pharmacological studies.

Despite their therapeutic potential, the wider application of aromatic Siddha medicinal plants faces several practical challenges. Essential oil yield and composition are influenced by climatic conditions, geographical location, seasonal variation, cultivation practices, and extraction methods, resulting in inconsistencies in quality and therapeutic efficacy¹³. In addition, the volatile nature of essential oils, their limited stability, and relatively low bioavailability can restrict their clinical effectiveness and make product standardization difficult.

Recent advances in biotechnology provide promising solutions to many of these limitations. Techniques such as plant tissue culture, metabolic engineering, microbial biosynthesis, and nanotechnology offer opportunities to improve essential oil yield, maintain phytochemical consistency, conserve valuable medicinal plants, and develop more efficient delivery systems. These innovations have the potential to bridge traditional Siddha knowledge with modern pharmaceutical science, enabling the development of standardized and evidence-based aromatherapy products.

This review discusses the role of aromatic Siddha medicinal plants in mental health management, examines the challenges associated with conventional essential oil production, and highlights recent biotechnological advances that can improve their quality, sustainability, and therapeutic application. It also explores future directions that may support the integration of Siddha aromatherapy into evidence-based mental healthcare.

1. Aromatherapy and Mental Health

Mental health is fundamental to emotional, psychological, and social well-being, influencing how individuals cope with daily challenges, build relationships, and maintain overall quality of life. The increasing prevalence of stress, anxiety, depression, insomnia, and cognitive disorders has renewed interest in complementary therapies that can be used alongside conventional treatment¹⁴. Among these, aromatherapy has attracted considerable attention because of its non-invasive nature and its ability to influence both psychological and physiological responses¹⁵.

Aromatherapy uses essential oils extracted from aromatic plants, which contain a complex mixture of volatile compounds such as monoterpenes, sesquiterpenes, phenols, aldehydes, esters, and alcohols. Following inhalation, these molecules stimulate olfactory receptors that transmit signals to the limbic system, particularly the amygdala, hippocampus, and hypothalamus¹⁶. These brain regions regulate emotion, memory, and stress responses, and their activation can influence neurotransmitters including serotonin, dopamine, and gamma-aminobutyric acid (GABA). Aromatherapy has also been reported to

modulate the hypothalamic–pituitary–adrenal (HPA) axis, reducing cortisol levels and promoting relaxation. In addition, topical application allows certain constituents to be absorbed through the skin, contributing to antioxidant, anti-inflammatory, and neuroprotective effects¹⁷.

2. Aromatic plants:

Several aromatic plants traditionally used in Siddha medicine have demonstrated promising effects on mental health. Vetiver (*Vetiveria zizanioides*)⁶ and Sandalwood (*Santalum album*) are valued for their calming properties and are commonly used to reduce stress and improve sleep quality. Tulsi (*Ocimum tenuiflorum*)⁵, rich in eugenol and other phenolic compounds, exhibits adaptogenic, anxiolytic, and antidepressant activities, while Lemongrass (*Cymbopogon citratus*)⁸ has shown mood-enhancing effects through modulation of serotonergic and dopaminergic pathways. Vallarai (*Centella asiatica*)⁴ is particularly recognized for supporting cognitive function, with bioactive constituents such as asiaticoside and madecassoside promoting neuronal regeneration, enhancing synaptic plasticity, and protecting against oxidative stress.

Overall, current evidence suggests that aromatherapy may serve as a valuable complementary approach for managing stress, anxiety, depression, insomnia, and cognitive dysfunction¹⁸. The integration of traditional Siddha knowledge with advances in biotechnology—including improved cultivation methods, phytochemical standardization, and innovative delivery systems—offers new opportunities to develop safer, more consistent, and clinically relevant aromatherapy formulations. Nevertheless, further well-designed clinical studies are required to establish standardized treatment protocols and strengthen the evidence supporting their use in mental health care.

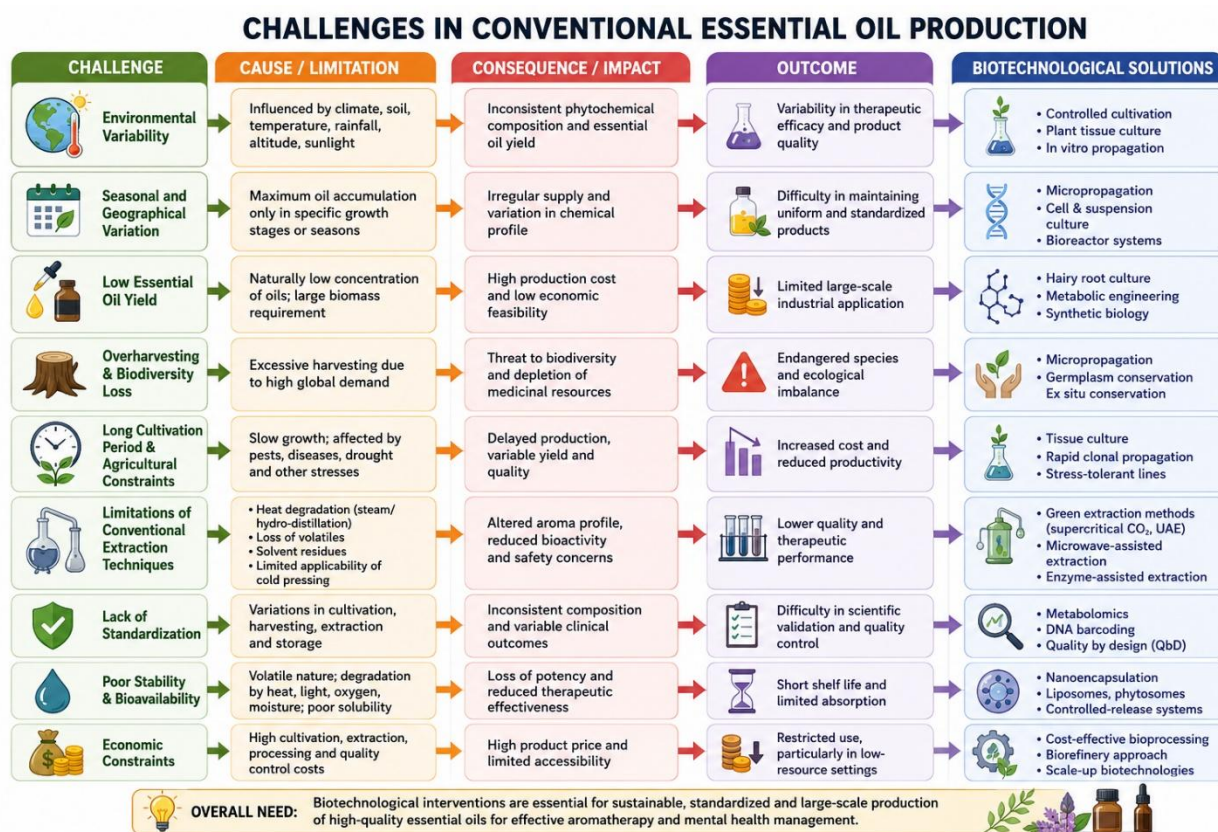
3. Challenges in Conventional Essential Oil Production

Essential oils are the primary therapeutic constituents used in aromatherapy and are responsible for the characteristic fragrance and biological activities of aromatic medicinal plants. They are traditionally extracted from various plant parts, including leaves, flowers, roots, bark, seeds, and fruits, using conventional techniques such as hydro-distillation, steam distillation, solvent extraction, and cold pressing¹⁹. Although these methods have been practiced for centuries and continue to be widely used, they are associated with several limitations that affect the yield, quality, consistency, and commercial production of essential oils²⁰. Conventional extraction methods may also result in the loss or degradation of heat-sensitive volatile compounds, while the inherent volatility, poor stability, limited bioavailability²¹. Together, these challenges highlight the need for innovative and sustainable approaches to improve essential oil production, standardization, and clinical applicability, paving the way for the application of modern biotechnological strategies as shown in Figure 1.



Table 1: Aromatic plants and their uses:

Plant	Major bioactive constituents	Principal mental health benefits	Biotechnological approaches
<i>Centella asiatica</i> (Vallarai)	Asiaticoside, madecassoside	Neuroprotective, memory enhancement, anxiolytic	Tissue culture, cell suspension, hairy root culture
<i>Ocimum tenuiflorum</i> (Tulsi)	Eugenol, linalool, rosmarinic acid	Adaptogenic, anxiolytic, antidepressant	Micropropagation, metabolic engineering
<i>Vetiveria zizanioides</i> (Vetiver)	Vetiverol, khusimol, vetivone	Sedative, stress reduction, sleep promotion	In vitro root culture, bioreactors
<i>Santalum album</i> (Sandalwood)	α -Santalol, β -santalol	Anxiolytic, relaxation, improved sleep	Tissue culture, micropropagation
<i>Cymbopogon citratus</i> (Lemongrass)	Citral, geraniol, myrcene	Mood enhancement, antioxidant, anxiolytic	Micropropagation, metabolic engineering
<i>Syzygium aromaticum</i> (Clove)	Eugenol, eugenyl acetate	Neuroprotective, cognitive support	Tissue culture and improved propagation
<i>Citrus limon</i> (Lemon)	Limonene, β -pinene, γ -terpinene	Mood enhancement, stress reduction	Micropropagation and optimized extraction

Figure 1: Challenges in conventional essential oil production

Source: Author created figure

4. Biotechnological Strategies for Enhancing Essential Oil Production

The increasing demand for high-quality essential oils in aromatherapy has highlighted the limitations of conventional cultivation and extraction methods, including low metabolite yield, seasonal variability, and inconsistent phytochemical composition. In recent years, biotechnology has emerged as a sustainable solution to improve the production, quality, and standardization of essential oils derived from aromatic Siddha medicinal plants. The integration of plant biotechnology with metabolic

engineering and microbial approaches not only enhances the biosynthesis of valuable aromatic compounds but also supports biodiversity conservation, sustainable cultivation, and year-round production.

4.1 Plant Tissue Culture²²

Plant tissue culture is widely recognized as an efficient technique for the rapid propagation of aromatic medicinal plants under controlled conditions. In vitro culture enables the production of genetically uniform, disease-free planting material while minimizing the influence of seasonal and

environmental variations. This approach has been successfully applied to aromatic species such as *Ocimum tenuiflorum* (Tulsi), *Cymbopogon citratus* (Lemongrass), and *Santalum album* (Sandalwood), resulting in consistent biomass production and improved phytochemical uniformity. In addition to large-scale propagation, tissue culture plays an important role in conserving endangered medicinal plants and ensuring a continuous supply of quality raw materials for essential oil production.

4.2 Cell Suspension²³ and Hairy Root Culture²⁴

Cell suspension and hairy root cultures provide effective alternatives to conventional cultivation for the production of secondary metabolites. Cell suspension cultures facilitate the continuous production of valuable aromatic compounds under controlled laboratory conditions, whereas hairy root cultures, induced by *Agrobacterium rhizogenes*, exhibit rapid growth, genetic stability, and enhanced metabolite accumulation. These in vitro culture systems have demonstrated significant potential for improving the production of bioactive constituents in medicinal plants such as *Centella asiatica*, *Ocimum tenuiflorum*, and *Vetiveria zizanioides*, making them promising platforms for sustainable essential oil production.

4.3 Metabolic Engineering²⁵ and Elicitation²⁶

Advances in metabolic engineering have enabled the targeted enhancement of essential oil biosynthesis by manipulating key enzymes involved in the mevalonate (MVA) and methylerythritol phosphate (MEP) pathways. Such modifications promote the accumulation of commercially important aromatic compounds, including linalool, eugenol, citral, geraniol, and santalols. In addition, elicitation strategies using biotic and abiotic elicitors, such as jasmonic acid, salicylic acid, yeast extract, and ultraviolet radiation, further stimulate secondary metabolite production. Together, these approaches offer an effective strategy for improving both the yield and therapeutic quality of essential oils.

4.4 Synthetic Biology²⁷ and Microbial Biosynthesis²⁸

Synthetic biology has opened new avenues for producing plant-derived aromatic compounds independent of conventional cultivation. Through metabolic pathway engineering, microorganisms such as *Escherichia coli* and *Saccharomyces cerevisiae* can be engineered to synthesize valuable terpenoids, including linalool, geraniol, limonene, and citral. This approach provides a sustainable and scalable alternative for producing high-value phytochemicals while reducing pressure on natural plant resources. Although its application to Siddha medicinal plants is still evolving, microbial biosynthesis holds considerable promise for the future production of standardized aromatherapy products.

4.5 Bioreactor-Based Production Systems²⁹

The successful transition from laboratory-scale cultures to commercial production relies heavily on bioreactor technology. Modern bioreactors provide controlled environments for cultivating plant cells, tissues, hairy roots,

and engineered microorganisms, resulting in improved productivity, reduced contamination, and greater process consistency. Systems such as stirred-tank, air-lift, and temporary immersion bioreactors support the large-scale production of essential oils and bioactive metabolites while maintaining consistent quality. Their integration with advanced biotechnological approaches is expected to facilitate the industrial production of aromatic compounds for pharmaceutical and aromatherapy applications.

4.6 Future Outlook

The integration of biotechnology into Siddha medicinal plant research has the potential to transform conventional essential oil production into a more sustainable, standardized, and commercially viable process. By addressing challenges such as low yield, environmental variability, and overexploitation of medicinal plants, these technologies can ensure a reliable supply of high-quality aromatic compounds for evidence-based aromatherapy. Future advances in genome editing³⁰, multi-omics technologies³¹, artificial intelligence, and precision bioprocessing are expected to further optimize metabolite production and strengthen the global acceptance of Siddha-based aromatherapy for mental health management as shown in Figure 2.

5. Nanotechnology-Based Delivery Systems for Essential Oils³²

Despite their considerable therapeutic potential, the clinical application of essential oils remains limited by several physicochemical challenges. To address these limitations, nanotechnology-based delivery systems have emerged as a promising approach to improve the stability, bioavailability, and overall therapeutic performance of essential oils.

Key Challenges of Conventional Essential Oils

- High volatility, resulting in rapid evaporation.
- Poor aqueous solubility and limited bioavailability.
- Susceptibility to degradation caused by heat, light, oxygen, and moisture.
- Short biological half-life due to rapid degradation.
- Limited penetration across biological membranes, including the blood–brain barrier (BBB).
- Variability in therapeutic efficacy and difficulties in formulation standardization.

Nanotechnology-Based Solutions:

- Nanoemulsions: Enhance the solubility, stability, absorption, and controlled release of essential oils.
- Liposomes: Protect volatile constituents, improve membrane permeability, and enable sustained release.
- Polymeric nanoparticles: Increase stability, prolong circulation time, and facilitate targeted drug delivery.

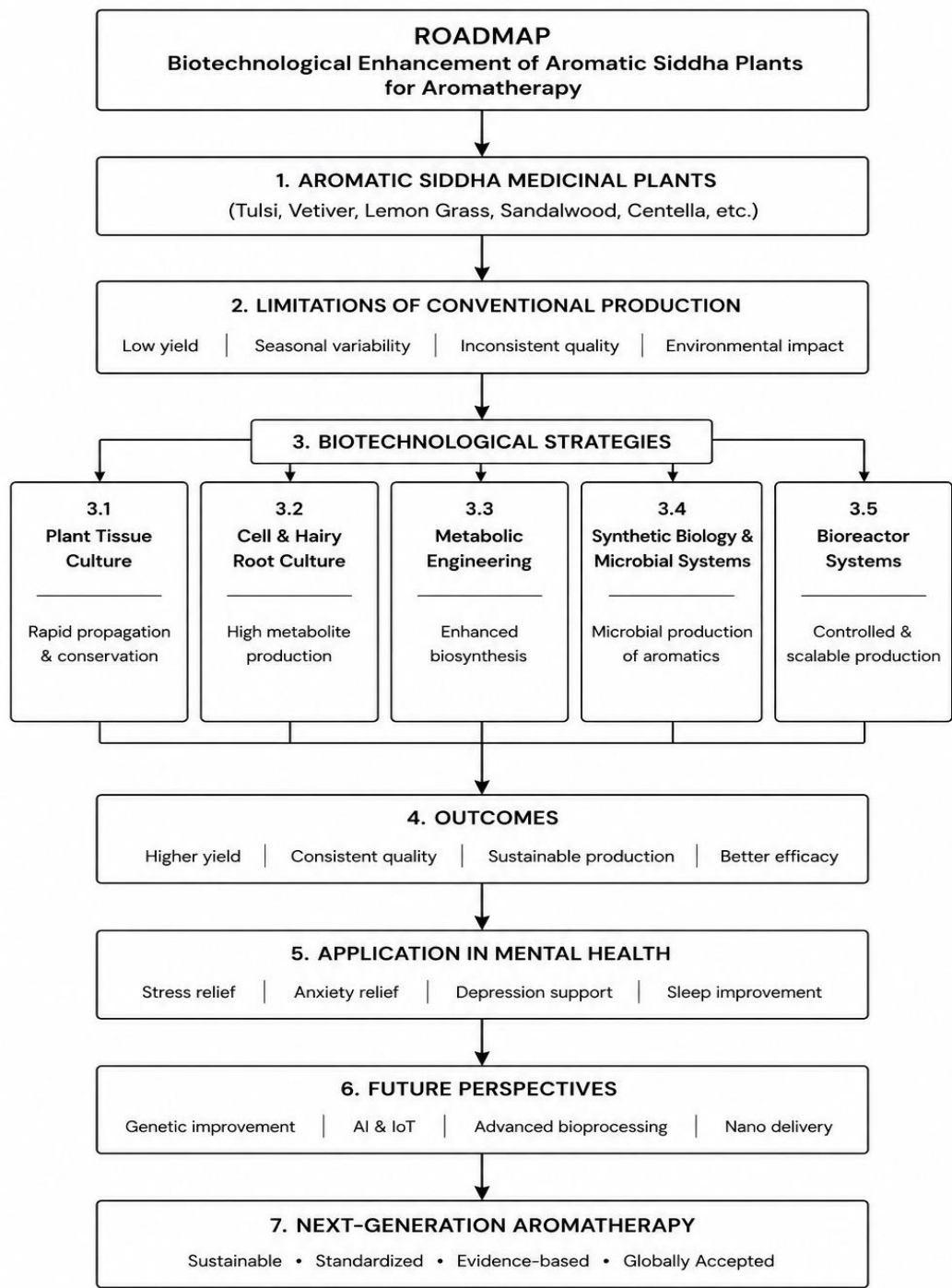


- Solid lipid nanoparticles (SLNs) and nanostructured lipid carriers (NLCs): Improve drug-loading capacity, storage stability, bioavailability, and controlled release.
- Cyclodextrin inclusion complexes: Enhance solubility and chemical stability while reducing the volatility of essential oils.
- Nanofiber and wearable delivery systems: Support prolonged and controlled aromatherapy through patches, masks, and smart textile-based platforms.

Future Perspectives:

Nanotechnology offers exciting opportunities for targeted brain delivery of essential oils, thereby enhancing their therapeutic potential in stress, anxiety, depression, insomnia, and neurodegenerative disorders³³. Its integration with biotechnology is expected to accelerate the development of standardized, sustainable, and evidence-based aromatherapy formulations derived from Siddha medicinal plants, ultimately supporting their broader clinical application and global acceptance.

Figure 2: Roadmap of Biotechnological enhancements in Aromatic Therapy:



Source: Author created figure



6. Emerging Technologies and Future Perspectives:

The future of aromatherapy lies in the successful integration of traditional Siddha knowledge with emerging technologies that improve essential oil production, quality, and therapeutic application. Innovations such as artificial intelligence (AI), precision agriculture, synthetic biology, CRISPR-based genome editing, and advanced bioprocess engineering have the potential to optimize the cultivation of aromatic medicinal plants through better growth management, predictive yield analysis, and real-time quality

monitoring. At the same time, microbial biosynthesis, smart bioreactors, and Internet of Things (IoT)-enabled cultivation systems offer sustainable alternatives for large-scale production while reducing environmental impact³⁴. Collectively, these technologies can address major challenges associated with conventional essential oil production, including low yield, seasonal variation, and inconsistencies in phytochemical composition, thereby supporting the development of standardized and evidence-based aromatherapy products.

Table 2: Emerging technology in Aromatherapy:

Emerging technology	Potential application	Expected impact
Artificial Intelligence (AI)	Predictive cultivation, harvest optimization, quality assessment	Increased essential oil yield and consistency
Precision aromatherapy	Personalized essential oil selection	Improved therapeutic outcomes
Biomarker-guided therapy	Cortisol, HRV, inflammatory markers	Individualized mental health interventions
Synthetic biology	Microbial production of aromatic compounds	Sustainable, large-scale manufacturing
CRISPR genome editing	Enhanced metabolite biosynthesis	High-yield elite medicinal plant varieties
Smart bioreactors	Automated metabolite production	Consistent commercial-scale production
Internet of Things (IoT)	Precision farming and crop monitoring	Improved cultivation efficiency
Green biotechnology	Eco-friendly production and conservation	Sustainable utilization of medicinal plants
Nanotechnology integration	Targeted and controlled essential oil delivery	Enhanced bioavailability and brain targeting

DISCUSSION

Mental health disorders continue to pose a major global health challenge, driving the search for complementary therapeutic approaches that are both effective and safe. In recent years, aromatherapy has gained increasing scientific attention due to its ability to influence emotional and cognitive functions through olfactory stimulation and neurochemical modulation. The interaction of volatile phytochemicals with the limbic system and the hypothalamic–pituitary–adrenal (HPA) axis provides a plausible biological basis for their anxiolytic, antidepressant, and neuroprotective effects^{14–18}. Within this context, the Siddha system of medicine offers a rich repository of aromatic medicinal plants that have traditionally been used to improve memory, reduce stress, promote sleep, and restore emotional balance. Modern pharmacological studies have increasingly validated these traditional claims by demonstrating the antioxidant, anti-inflammatory, adaptogenic, and neurotransmitter-modulating activities of bioactive constituents such as asiaticoside, eugenol, citral, linalool, and santalols^{4–18}. These findings highlight the relevance of integrating traditional Siddha knowledge with contemporary scientific research to develop evidence-based interventions for mental health.

Despite these promising therapeutic attributes, several challenges continue to limit the wider clinical application of essential oils. Conventional cultivation and extraction methods remain highly dependent on environmental conditions, geographical location, seasonal variation, and harvesting practices, leading to significant variability in

essential oil yield and phytochemical composition^{13,19–21}. Such inconsistencies not only affect therapeutic efficacy but also complicate product standardization, quality control, and regulatory approval. Furthermore, the overexploitation of commercially valuable aromatic species such as sandalwood has raised concerns regarding biodiversity conservation and the long-term sustainability of medicinal plant resources. These limitations underscore the need for innovative production strategies capable of ensuring consistent quality while reducing dependence on natural populations. Consequently, biotechnology has emerged as a key enabling discipline for overcoming these barriers and supporting the sustainable utilization of aromatic Siddha medicinal plants.

Among the various biotechnological approaches discussed in this review, plant tissue culture, cell suspension culture, hairy root culture, metabolic engineering, microbial biosynthesis, and bioreactor-based production systems offer significant advantages over conventional cultivation^{22–31}. These technologies enable the controlled production of valuable secondary metabolites independent of climatic fluctuations while improving metabolite yield, genetic uniformity, and phytochemical consistency. Tissue culture techniques have already demonstrated considerable success in the rapid propagation and conservation of medicinal plants such as *Ocimum tenuiflorum*, *Santalum album*, and *Cymbopogon citratus*, whereas hairy root cultures and metabolic engineering have enhanced the accumulation of commercially important aromatic compounds^{22–29}. Similarly, advances in synthetic biology and microbial biosynthesis have created opportunities to



produce plant-derived terpenoids through engineered microbial systems, thereby reducing harvesting pressure on medicinal plants and providing scalable alternatives for industrial production^{27–29}. Collectively, these approaches represent a shift from traditional plant-based extraction toward more sustainable and standardized manufacturing systems that are better suited to pharmaceutical and aromatherapy applications.

Another important advancement highlighted in this review is the application of nanotechnology to improve the therapeutic performance of essential oils. Although essential oils possess remarkable biological activity, their volatility, poor aqueous solubility, susceptibility to oxidation, and limited bioavailability often reduce their clinical effectiveness³². Nanotechnology-based delivery systems, including nanoemulsions, liposomes, polymeric nanoparticles, solid lipid nanoparticles, and nanostructured lipid carriers, have demonstrated considerable potential in protecting volatile constituents, improving stability, enhancing membrane permeability, and enabling sustained or targeted release^{32,33}. These systems are particularly relevant for mental health applications because they may facilitate improved delivery of neuroactive compounds across biological barriers, including the blood–brain barrier, thereby enhancing therapeutic efficacy in stress-related disorders, anxiety, depression, insomnia, and neurodegenerative diseases³³. The convergence of biotechnology and nanotechnology therefore represents a significant step toward the development of standardized, clinically relevant aromatherapy formulations with improved safety, reproducibility, and patient compliance.

Although considerable progress has been achieved, important research gaps remain before Siddha-based aromatherapy can be fully integrated into mainstream healthcare. Much of the available evidence is derived from in vitro experiments, animal studies, or small clinical investigations, while robust multicentre randomized controlled trials evaluating efficacy, safety, dosage, and long-term outcomes are still limited. In addition, internationally accepted standards for essential oil quality, formulation, and clinical use remain inadequate, creating challenges for regulatory approval and widespread clinical adoption. Future research should therefore emphasize multidisciplinary collaboration involving phytochemistry, biotechnology, nanotechnology, systems biology, artificial intelligence, multi-omics approaches, and precision medicine to optimize essential oil production and personalize aromatherapy interventions^{30–34}. Such integrated research strategies will strengthen the scientific evidence supporting Siddha medicine, facilitate the development of standardized aromatherapy products, and enhance their global acceptance as sustainable complementary interventions for mental health management.

KEY FINDINGS

The evidence reviewed in this article indicates that aromatic Siddha medicinal plants have considerable potential as

complementary agents for promoting mental health and emotional well-being. Plants such as *Centella asiatica*, *Ocimum tenuiflorum*, *Vetiveria zizanioides*, *Santalum album*, and *Cymbopogon citratus* contain diverse bioactive constituents that have demonstrated anxiolytic, antidepressant, neuroprotective, adaptogenic, and cognitive-enhancing activities. These phytochemicals influence multiple biological pathways involved in stress regulation, neurotransmitter modulation, antioxidant defense, and neuroprotection, supporting the traditional use of these plants in Siddha medicine.

The review also highlights several challenges associated with the conventional production of essential oils, including low yield, seasonal and geographical variability, inconsistent phytochemical composition, poor stability, and limited bioavailability. Such limitations often affect the quality, reproducibility, and therapeutic effectiveness of aromatherapy products, emphasizing the need for more reliable production methods.

Recent advances in biotechnology provide practical solutions to many of these challenges. Techniques such as plant tissue culture, cell suspension and hairy root culture, metabolic engineering, synthetic biology, microbial biosynthesis, and bioreactor-based production have shown significant potential for improving essential oil yield, phytochemical consistency, and sustainable production. In addition, nanotechnology-based delivery systems enhance the stability, bioavailability, and targeted delivery of essential oils, while emerging technologies including artificial intelligence and genome-editing approaches are expected to further advance the development of standardized and evidence-based aromatherapy products.

CONCLUSION

Aromatic Siddha medicinal plants represent an important source of bioactive compounds with significant therapeutic potential for promoting mental health and emotional well-being. Traditional knowledge supported by contemporary pharmacological evidence suggests that these plants possess anxiolytic, antidepressant, neuroprotective, adaptogenic, and cognitive-enhancing properties, making them promising complementary interventions for stress-related and neuropsychiatric disorders. However, the successful translation of these therapeutic benefits into routine clinical practice remains constrained by limitations associated with conventional essential oil production, including low yield, environmental variability, inconsistent phytochemical composition, poor stability, and limited bioavailability.

The findings of this review highlight biotechnology as a transformative approach for overcoming these challenges. Modern strategies such as plant tissue culture, metabolic engineering, microbial biosynthesis, hairy root culture, and bioreactor-based production can improve the sustainable production and standardization of essential oils, while nanotechnology-based delivery systems enhance their stability, absorption, and therapeutic performance.



Together, these innovations provide a scientific framework for developing high-quality, reproducible, and clinically relevant aromatherapy formulations derived from Siddha medicinal plants.

Future progress in this field will depend on interdisciplinary collaboration integrating traditional Siddha knowledge with biotechnology, nanotechnology, artificial intelligence, precision medicine, and systems biology. Equally important is the generation of robust clinical evidence through well-designed randomized controlled trials, standardized quality-control protocols, and harmonized regulatory guidelines. Such efforts will strengthen the scientific credibility of Siddha aromatherapy, facilitate its wider acceptance in integrative healthcare, and support the development of sustainable, evidence-based therapeutic strategies for improving global mental health.

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