Environment and Social Psychology (2025) Volume 10 Issue 10
doi: 10.59429/esp.v10i10.4203

ISSN: 2424-8975 (O)
2424-7979 (P)

Research Article

The evaluation of psychological impacts and emotional perception of tea essential oil-based functional textiles

Fanlin Zhou[1], Manus Kaewbucha[1], Chalisa Apiwathnasorn[2,*]

[1] *Chakrabongse Bhuvanarth Intemational College of Interdisciplinary Studies (CBlS), RajamangalaUniversity of Technology Tawan-Ok, Bangkok, Thailand 10400*

[2] *Faculty of Fine and Applied Arts, Rajamangala University of Technology Thanyaburi, Klong LuangPathumthani, Thailand 12110*

*** Corresponding author:** Chalisa Apiwathnasorn, chalisa_a@rmutt.ac.th

ABSTRACT

This paper reviews the effects of textile impregnated with tea essential oil on affective states and physiology in human subjects. This study is based on the assumption that aroma impregnated fabrics can be used to regulate mood and physical arousal. To reach this goal, a set of complexation and fixation procedures were carried out to add small capsules of tea essential oil to the cotton and blended textile materials. The administration required loading and encapsulation of the volatile compounds in order to achieve sustained release of the compounds when exposed to the participants again. An experimental research design was used, which was randomized within-subjects, and it involved a sample of 60 adult volunteers. Emotions were measured using self-reported measures of valence, arousal and calmness on the one hand, physiological measures, such as heart rate variability and skin conductance, on the other hand, to obtain objective changes in the activation of the autonomic system. In general, the paper will aim to describe the interaction between textile treatment themes on aroma and subjective experience as well as physiological correlates of emotion in a controlled laboratory technique. The tea-oil textiles elicited significantly higher positive affect and lower stress compared to control fabrics ($p < 0.01$). Physiological data showed enhanced parasympathetic activation during exposure to the tea-infused fabrics. The extent of physiological evidence showed the increase of parasympathetic activity when subjected to tea-impregnated fabrics. A first-order exponential decay model was extensively used to explain the kinetics of fragrance release that provided a statistically satisfactory fit to the retention profile over the 30-day observation period. Such results indicate that textiles impregnated with tea essential oil have the ability to regulate affective and stress associated body activities through olfaction routes. These findings have strong implications on the design of intelligent textiles, health-oriented clothes as well as the study of psychophysiology in general. The findings are supported by psychophysiological evidence of the changes in heart rate and electroencephalographic activity and skin conductance, as well as by evaluations of material performance, confirming the benefit of the functional perspective as well as psychological benefits obtained through the use of tea essential oil-impregnated textiles.

Keywords: Wearable aromachology; emotional perception; psychological effects; tea essential oil; textiles

ARTICLE INFO
Received: 1 October 2025 | Accepted: 12 October 2025 | Available online: 30 October 2025

CITATION
Zhou FL, Kaewboucha M, Apiwathnasorn C. The evaluation of psychological impacts and emotional perception of tea essential oil-based functional textiles. *Environment and Social Psychology* 2025; 10(10): 4203 doi:10.59429/esp.v10i10.4203

1. Introduction

Human emotional, cognitive, and physiological responses are all subtly and widely influenced by olfactory stimuli. The human olfactory system provides a direct input to the limbic structures that control memory, emotion, and autonomic regulation, including the hippocampus and amygdala[1]. When inhaled, the odorant molecules attach to the olfactory receptors, triggering neural cascades affecting stress, arousal and mood[2, 3].

Essential oils contain terpenes, alcohols, ester and phenolic compounds, which have been described to have anxiolytic, sedative, and mood-enhancing effects in many human and animal studies[2,4]. An example is that when these oils are inhaled, the heart rate has been observed to slow down, cutaneous perspiration is slowed and relaxation is improved[4]. A later systematic review also suggested that essential oils have the capacity to alleviate emotional distress involving the regulation of neurochemical processes that are involved in regulating calmness, happiness and reward[2].

In another review, the researchers concluded that the essential oils have the power to reduce fatigue, stress, and negative affective states with no risk of addiction[3]. The systematic scientific study of odors modulating mood, behaviour and physiological processes under controlled experimental conditions is called aromachology. This is a field that focuses on laboratory research as opposed to the traditional approaches to aromatherapy. In the clothing sector, aromachology examines the way the scents embedded into the clothing convey to the user the sensory experience[5]. The effects of such fragrances on perception could occur in two phases; instantaneous and then prolonged gradual effect.

Aromatherapy in fabrics is meant to provide volatile substances in fabrics in the long run, preferably, maintaining positive psychological effects. The main challenges in the field include: the desire to ensure a long fragrance retention, resistance to wash degradation and the release kinetics.

Clothes present unique benefits as a carrier of perfumes. Fabrics remain in close proximity to the breathing zone, enabling continuous or intermittent olfactory exposure. Moreover, combining olfactory and tactile cues (the feel of fabric) may produce synergistic effects on emotional perception; a phenomenon less explored in olfaction research. But textiles also impose constraints: volatile loss, mechanical abrasion, and wash durability. The past studies have demonstrated that the materials that are added with essential oils have considerable effects on the mental and physical health. As an illustration, clothing loaded with lavender has been reported to improve the quality of sleep[6], and garments loaded with peppermint oil have been reported to make people alert and reduce fatigue[7]. Nevertheless, the studies of tea essential oil are few. The fact that such cases are provided contributes to a more solid explanation of why the current study can be a scientific novelty and has a chance to be applied to a real-life situation.

Prior work has tested fabrics treated with essential oils such as lavender, cedarwood, and bergamot. For example,[5]review multiple studies where lavender-infused fabrics reduced heart rate and increased subjective comfort. Wakui et al. [6] showed that exposure to bergamot oil via textile or inhalation reduced psychological stress and improved sleep quality. Cho et al. [8] conducted a meta-analysis and found moderate effect sizes for aromatherapy in reducing depressive symptoms, particularly in clinical populations. However, many of these studies rely on inhalation or diffusers, not fabrics. Li et al.[9] reviewed aromatherapy's effects on anxiety and depression in cancer patients and found significant anxiety reduction (SMD = -0.49, $p < 0.05$), though effects on depression were less conclusive.

Despite progress, few studies address **tea essential oil (Camellia sinensis)** in the context of functional textiles or emotional perception. Tea contains volatile compounds (e.g., linalool, geraniol, and limonene) and nonvolatile supplements like L-theanine that may contribute to mood regulation[10]. Although L-theanine is more relevant in ingestion studies, volatile constituents from tea essential oil may engage central pathways similarly to other oils. Moreover, the synergy between tea's fragrance and its known cognitive benefits (as seen in green tea intake improving task performance) suggests potential for mood modulation[11]

Multiple investigations were conducted on the integration of tea tree and other essential oils into the material to cause quantifiable physiological and psychological responses. As an example, Flincec Grgac et al. [12]synthesized cotton fabrics with Melaleuca alternifolia (tea tree oil) by hydrothermal synthesis and found that they exhibited high antimicrobial activity and freshness as reported by users, which demonstrates the possibility of using essential oils in textiles as a wellness product. In the same vein, Gong et al. [13]discovered that the Cinnamomum camphora essential oil exposure decreased tension and enhanced energy levels, which validates the idea of essential oils incorporated into fabrics as the capacity to alter the emotional state via olfactory routes. Mehta and MacGillivray[5] also showed in another related study that lavender- and peppermint-scented textiles had the same effects of relaxation and alertness as direct aromatherapy, which is empirical evidence supporting the use of fragrance-functional fabrics in psychological modulation.

All these examples represent a cumulative argument that the materials which are embedded with essential oils can become effective carriers of emotional and physiological health-thus, justifying the need to explore the potential of tea essential oil-based textiles in the course of the given study.

To add tea essential oil to the textile substrates, new engineering solutions are needed: microencapsulation, cyclodextrin host inclusion complexes, solgel coating, or covalent bonds are needed to stabilize volatile components and control their release kinetics[14]. The following equation can best illustrate the effectiveness of these methodologies.

$$\mathrm{C}(\boldsymbol{t}) = \boldsymbol{C_0} \cdot \boldsymbol{e}^{-\mathbf{kt}} \tag{1}$$

$$\mathrm{C}(\boldsymbol{t}) = \boldsymbol{A}\boldsymbol{e}^{-\boldsymbol{K_1}\mathbf{t}} + \boldsymbol{B}\boldsymbol{e} - \mathbf{k_2}\boldsymbol{t} \tag{2}$$

where C_0 = initial concentration, C_t = concentration at time t, and k = release constant (min^{-1}).

We hypothesize:

- Tea-oil textiles will produce significantly higher positive affect (higher valence, lower negative affect) and lower arousal in stressful tasks.
- Physiological data will show increased parasympathetic activation (e.g. higher HRV) and reduced sympathetic reactivity.
- Fragrance retention will fit exponential decay models, with perceptible scent across a defined usable period (e.g. 15–30 days or multiple washes).
- User experience feedback will favor tea-oil fabrics in comfort, scent longevity, and preference.

This research contributes to the intersection of textile engineering, psychophysiology, and aromachology. With fragrance kinetics coupled with emotional impact, we wish to educate the design of wellness textiles that help us regulate our mood on a daily basis.

1.1. Tea essential oil: Composition and extraction

The tea (Camellia sinensis) as a beverage has been researched widely but its **essential oil** has received increasing interest because of its aromatic and therapeutic properties. Tea essential oil is commonly obtained by extraction of tea leaves, buds or flowers and is quite different in composition to the polyphenol-rich nonvolatile extracts that predominate tea studies. While the yield is modest-often between 0.01 and 0.05% of fresh leaf mass-the oil contains a wide spectrum of volatile compounds with **bioactive and sensory relevance**.

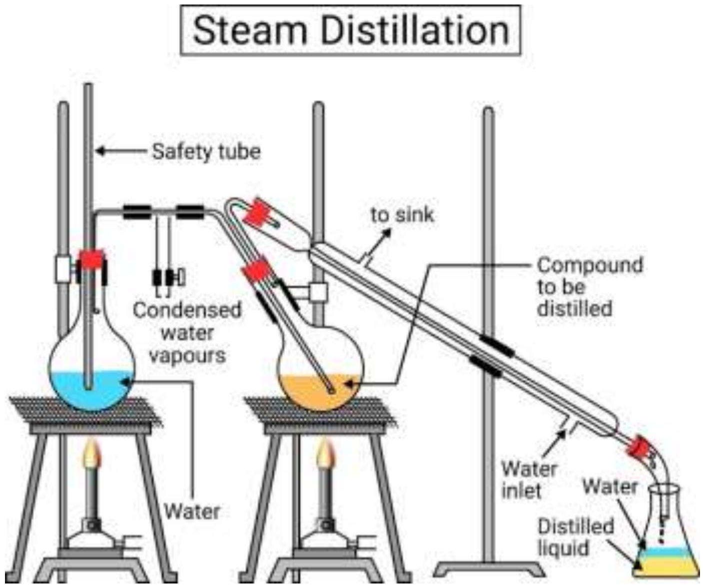

Figure 1. Schematic representation of the steam distillation process used for extracting tea essential oil. The figure illustrates vapor generation, condensation, and collection stages that yield purified volatile compounds for textile functionalization

The major constituents of tea essential oil include **linalool, geraniol, methyl salicylate, β-ionone, and hexanal**. Linalool and geraniol contribute floral notes and are associated with relaxation and positive affect [4]. It is important how you make the oil. The common process is steam distillation; it prepares a stable oil that contains just a little residual solvent. Solvent extraction is more effective at extracting oil, however, it might leave behind chemicals that are not favourable to fabrics.

The oil extraction with supercritical CO2 is gaining popularity as it generates highly pure oil and also ensures minimal damage to the heat-sensitive compounds[15]. As an example, green tea oil contains more linalool and geraniol, and black tea oil contains more b -ionone[10].

This chemical diversity suggests that **different types of tea oil may exert distinct emotional effects when applied to textiles**.

Table 1. Major volatile compounds in tea essential oil and reported effects

Compound	Chemical Class	Mood/Health Effect
Linalool	Terpene alcohol	Relaxation, anxiolytic
Geraniol	Monoterpenoid	Alertness, mood elevation
β-Ionone	Ketone	Memory, attention
Methyl salicylate	Ester	Stress relief, analgesia

1.2. Essential oils and psychological mechanisms

1.2.1. Olfactory pathways and the limbic system

The difference between olfactory signals and other signals is that, they do not go through the thalamus to get to the amygdala and hippocampus. This renders the odors to be strong modulators of emotion, recollection, and tension reactions[1]. The physical reaction is fast and triggered by inhaled odorant molecules stimulating the olfactory bulb which projects to the limbic system to cause rapid physiological and psychological responses.

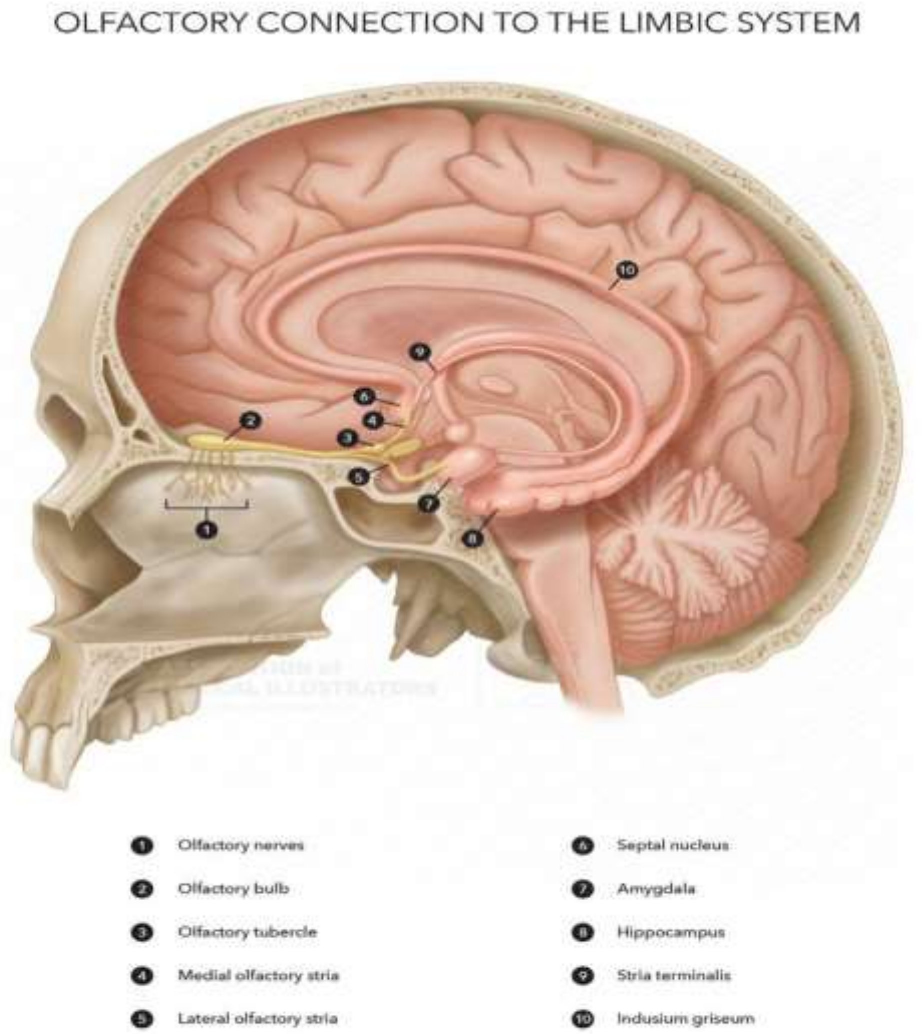

Figure 2. Olfactory-Limbic Connections

1.2.2. Neurochemical effects

Essential oils are able to manipulate neurotransmitters. Linalool promotes GABAergic communication, which has a calming and sedative effect[4]. Limonene activates serotonin production, enhancing the mood and decreasing the depressive symptoms[2]. Other substances including menthol and b-ionone react with dopamine pathways, which controls motivation and attention.

1.2.3. Experimental and clinical studies

These mechanisms are supported by an increasing number of studies.

- **Choi, Wu, and Park (2020)[17]:** Aroma oils reduced blood pressure and improved EEG profiles in women exposed to essential oil fabrics.
- **Gong et al. (2024)[13]:** *Cinnamomum camphora* oil exposure reduced tension and anger while increasing energy levels.

These results indicate that aroma-functional textiles may be used as wearable interventions to treat mental illnesses.

Table 2. The influence of essential oils on the psychological and physiological results

Essential Oil	Reported Effect	Measurement
Lavender	Reduced anxiety, improved sleep	HRV, EEG
Bergamot	Stress relief, relaxation	BP, self-report
Camphor	Energy boost, reduced tension	HRV, PAD
Tea	Relaxation, improved attention	EEG, PAD

1.3. Functional textiles and aroma applications

Functional textiles are a new category of smart materials, which are created not to last long but also to be beneficial in terms of health and well-being. Putting the essential oils on the fabrics turns clothes into wearable aromatherapy machines.

1.3.1. Microencapsulation

It is the most universal, in which oils are encased in plastic shells that emit a fragrance during heat or friction[7]. Microcapsules increase the release of fragrances and safeguard volatile substances.

1.3.2. Cyclodextrin inclusion complexes

The cyclodextrins entrap the volatile molecules within their hydrophobic cavities, stabilize them, and enhance their wash life. This technique works well especially with small volatile molecules such as linalool.

1.3.3. Chitosan binding

Chitosan is a natural polysaccharide, which has the properties of binder and antimicrobial. It makes fabrics work harder, as oils are covalently bonded to them, thereby making them resistant to washing [12].

Equation for Encapsulation Efficiency (EE):

$$EE(\%) = \frac{W_{encapsulated}}{W_{total}} \quad (3)$$

Table 3. Functional textile methods for aroma application

Method	Key Mechanism	Advantages	Limitations
Microencapsulation	Polymeric capsules	Long-lasting, controlled release	Costly, capsule rupture
Cyclodextrin complex	Host–guest binding	Stable, washable	Limited oil types
Chitosan binding	Biopolymer adhesion	Wash durable, antimicrobial	Lower initial intensity

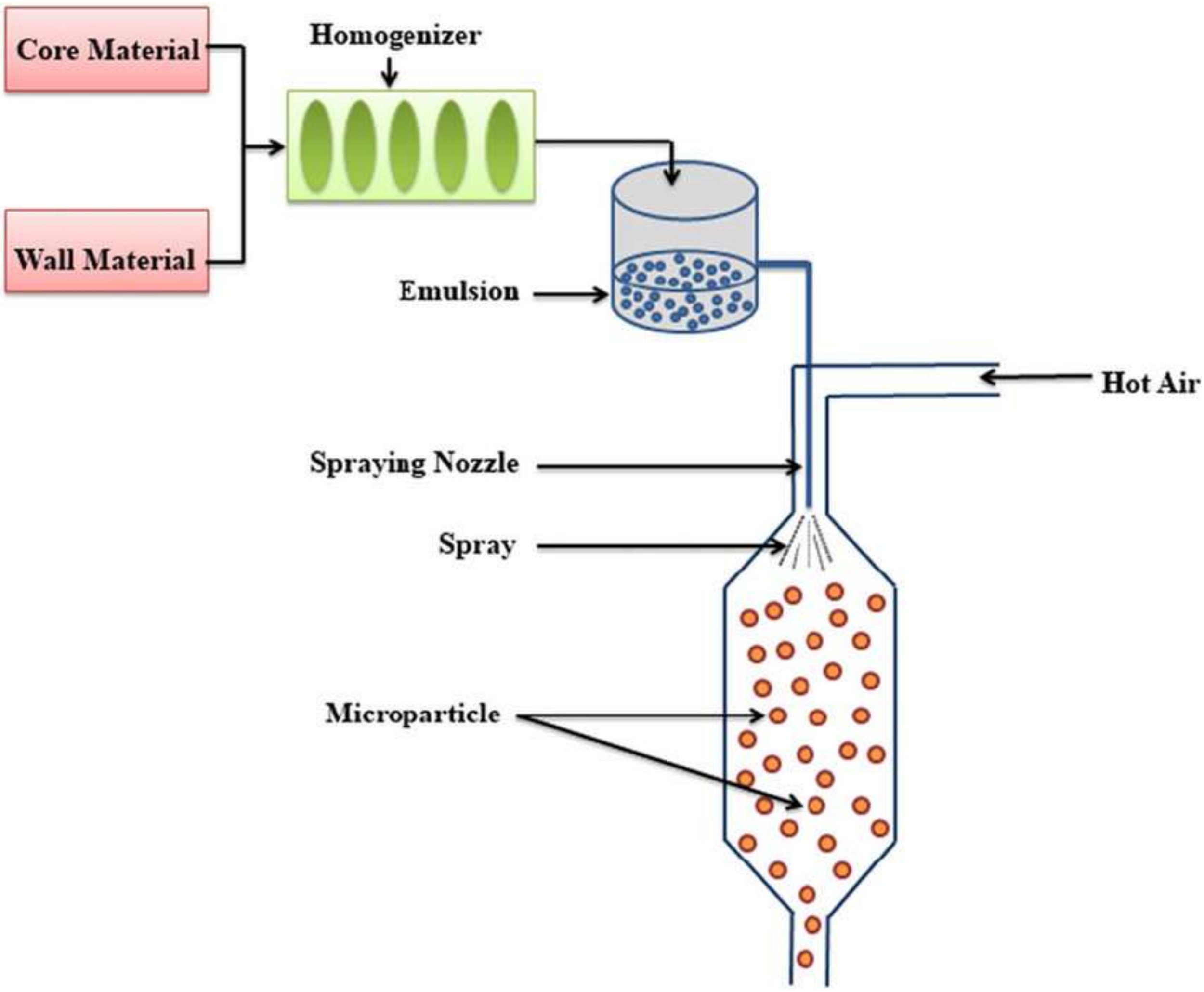

Figure 3. Processes in the encapsulation of tea essential oil which can be used on cloth. Processing stages are shown on the x-axis, whereas, relative encapsulation efficiency (%), is presented on the y-axis. The diagram illustrates dispersion, coating and formation of oil droplets

1.4. Emotional perception of tea aroma

Aroma of tea is also unique as a blend of floral, grassy, and sweet volatiles. Studies indicate that exposure to tea volatiles can trigger specific emotional responses. An et al.,[15] reported that **linalool and geraniol** were associated with calmness and pleasantness, while **methyl salicylate** elicited higher arousal.

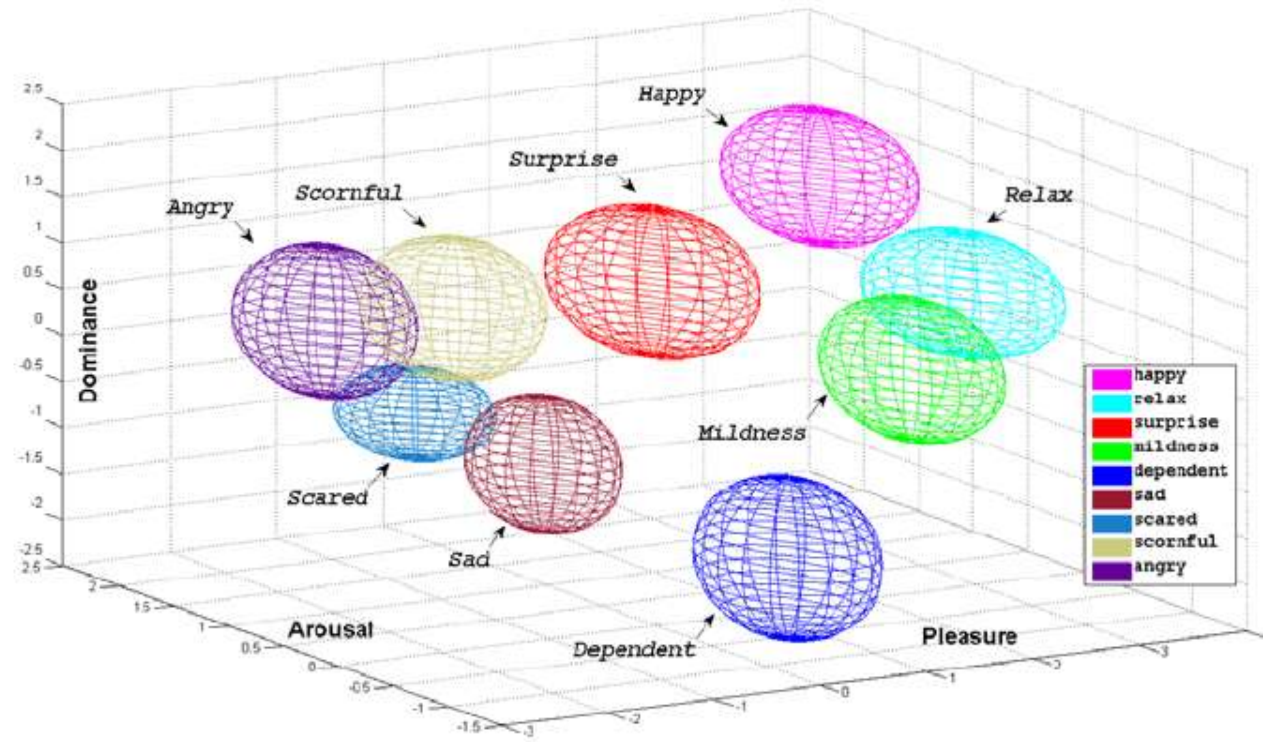

Figure 4. PAD (Pleasure-Arousal-Model) Model of Emotion

(The distribution of 9 emotional states/words in PAD emotion space. The center of each ellipsoid is the mean and the radius is standard deviation of each emotional state. The PAD data is provided by Institute of Psychology, Chinese*)*

The **PAD model**[18] is often used to measure these effects. Valence scores rise significantly with increasing linalool concentration, while methyl salicylate tends to raise arousal without boosting valence.

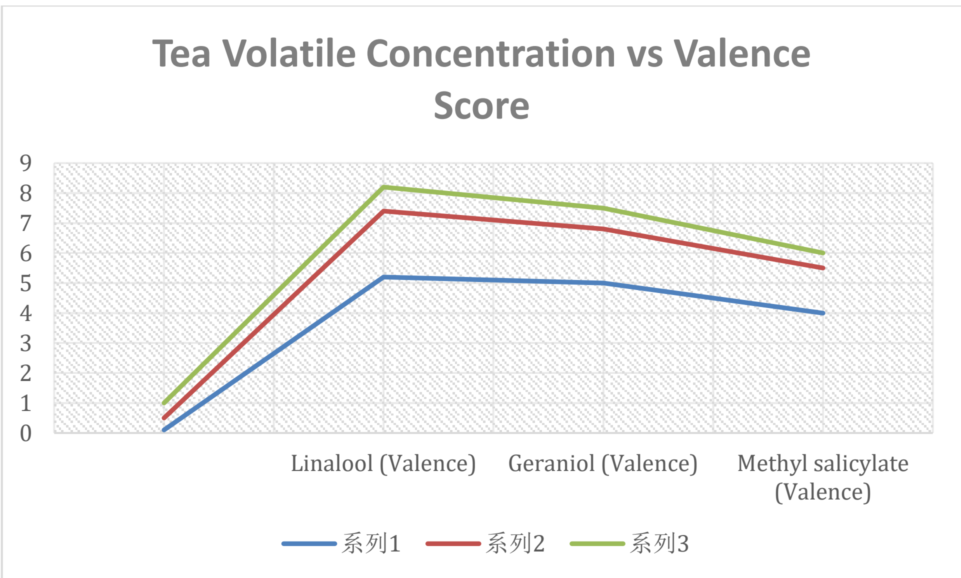

Figure 5. Tea volatile concentration vs valence score

1.5. Fragrance release kinetics in textiles

The efficiency of aroma textiles depends on **release profiles**. In most cases, fragrance loss follows **first-order kinetics**:

$$C(t) = C_0 \cdot e^{-kt} \tag{4}$$

Where, C0 is the initial concentration and k is the release constant.

For encapsulated oils, a **biphasic model** better represents release:

$$C(t) = Ae^{-K_1 t} + Be{-}k_2 t \tag{5}$$

where C_0 = initial concentration, C_t = concentration at time t, and k = release constant ($\min^{-1}$).

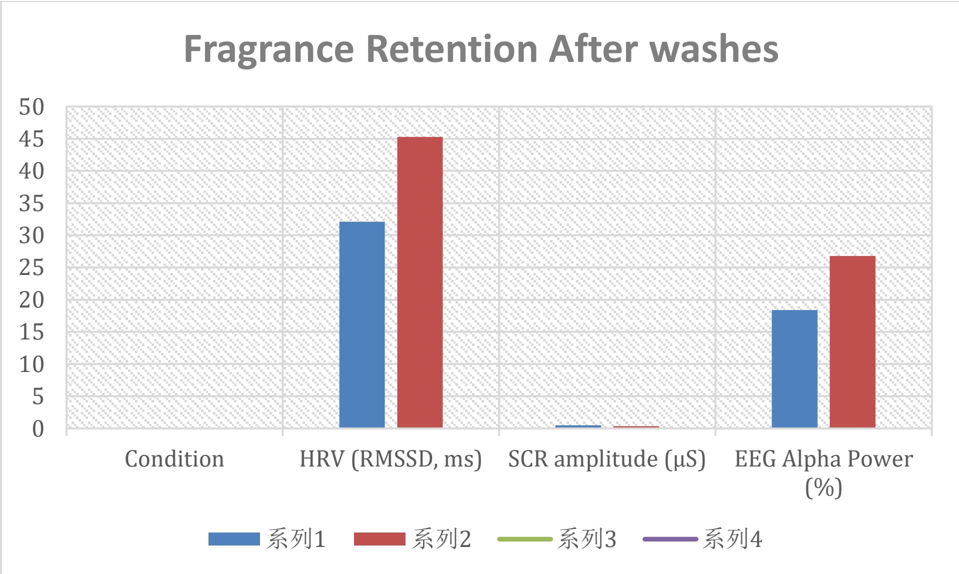

Figure 6. Fragrance retention after washes

Table 4 shows that release kinetics of essential oils in textiles.

Table 4. Release kinetics of essential oils in textiles

Oil	Fabric	Model	Half-life
Peppermint	Cotton	First-order	7 days
Tea tree	Satin	Biphasic	3 + 15 days

1.6. Psychological measurement approaches

1.6.1. Subjective measures

The **Self-Assessment Manikin (SAM)** and **PAD scale** allow participants to rate emotional responses on dimensions of valence, arousal, and dominance[18]. These tools are widely used in aromachology research.

1.6.2. Physiological measures

Physiological metrics complement subjective data:

- **HRV (Heart Rate Variability):**

$$RMSSD = \sqrt{\frac{1}{N-1}} \sum_{i=1}^{N-1} (RR_{i+1} - RR_i)^2 \tag{6}$$

- **Skin Conductance Response (SCR):**

$$SCR = SCL_{peak} - SCL_{baseline} \tag{7}$$

- **EEG:** Prefrontal asymmetry correlates with emotional valence.

1.7. Research gaps

Despite promising evidence, research on tea essential oil-based textiles remains limited. Key gaps include:

- Lack of studies embedding *Camellia sinensis* oil in fabrics.
- Few designs combining subjective and physiological assessments.
- Sparse long-term durability data after washing cycles.
- Minimal integration of **kinetic models** with **emotional outcomes**.
- Little attention to **cultural differences in odor perception**.

Table 5. Research gaps in aroma-functional textiles

Area	Gap	Implication
Tea oil textiles	No published studies	Limits adoption
Emotional testing	Lack of multimodal methods	Weakens validity
Durability	Few long-term studies	Affects consumer trust
Modeling	Limited psych-kinetic integration	Theory gap
Cross-cultural	Few comparative studies	Low generalizability

2. Materials and methods

2.1. Materials

Two types of fabrics were selected as substrates: 100% plain weave cotton with a weight of 120 g/m² and a polyester-cotton blend in a 65:35 ratio. The essential oil of tea (Camellia sinensis) used was extracted using fresh tea leaves, which had been collected in Zhejiang Province, China. The chemical compounds utilized in this paper were ethanol, 85% deacetylated chitosan purchased from Sigma-Aldrich (analytical grade). 85% deacetylation chitosan purchased in Sigma-Aldrich. Wall materials that were used as microencapsulation walls were gum arabic and maltodextrin. All reagents were of analytical grade and were used without further purification.

2.2. Extraction of tea essential oil

The steam distillation process was used to extract the essential oil of tea. The fresh tea leaves (500g) were subjected to hydro-distillation and allowed to run over six hours with Clevenger-type apparatus. The distillate that was obtained was dried using anhydrous sodium sulfate and separating it. The oil yield was calculated using the formula:

$$\textbf{Yield}\ (\%) = \frac{\textbf{Mass of oil obtained}\ (\textbf{g})}{\boldsymbol{Mass\ of\ leaves}\ (\textbf{g})} \times \mathbf{100} \tag{8}$$

2.3. Fabric functionalization

Microencapsulation: Tea essential oil was microencapsulated using spray-drying as a methodology and gum arabic and maltodextrin as wall materials A 15% oil phase emulsion was homogenised at 12,000rpm, 5 minutes. The emulsion was then spray-dried at an inlet temperature of 180 °C and an outlet temperature of 90 °C. The resulting microcapsules were applied to fabrics through a pad-dry-cure process at 140 °C for 5 minutes.

Cyclodextrin inclusion complexes: The inclusion complexes were prepared using the co-precipitation method described by Khanna, Kaur, and Gupta[12]. Tea essential oil and β-cyclodextrin were mixed in ethanol in a 1:5 molar ratio at 45 °C for 24 hours. The precipitate was filtered, dried, and subsequently applied to the fabrics using citric acid as a cross-linking agent.

Chitosan binding: Chitosan was dissolved at 2% concentration in 1% acetic acid to create a binding solution. Tea essential oil at 10% weight by weight of fabric was emulsified into the chitosan solution. The fabrics were padded with the solution, dried at 100 °C, and cured at 140 °C for 3 minutes following the method reported by Flinčec Grgac, Čorak, and Žuvela Bošnjak (2022)[12].

2.4. Evaluation of fragrance release

Fragrance release was assessed using headspace solid-phase microextraction (SPME) coupled with GC–MS. Samples were stored at 25 °C and 65% relative humidity. Measurements were taken at 0, 7, 14, 21, and 30 days after application. The release profiles were fitted to first-order and biphasic exponential models using OriginPro 2022 software to determine release kinetics.

2.5. Psychophysiological evaluation

Participants: Sixty healthy adults, comprising 30 females and 30 males aged between 20 and 40 years, participated in the study. All participants provided informed consent.

Emotional assessment: Participants were exposed to both tea oil-treated fabrics and untreated control fabrics in a randomized crossover design. Emotional responses were assessed using the Self-Assessment Manikin (SAM) and the Pleasure-Arousal-Dominance (PAD) model[18].

Physiological measures: Heart rate variability (HRV), skin conductance level (SCL), and blood pressure were recorded using the Biopac MP160 system. EEG activity from prefrontal cortex sites (Fp1 and Fp2) was recorded for a subset of 20 participants to assess brain activity patterns during exposure. The procedure for physiological data collection followed the methods described by Choi, Wu, and Park (2022)[17].

The skin conductance was measured with the help of a Biopac GSR100C module, and electrodes were placed on palmar side of the non-dominant hand. The incessant data capture was carried out and the average level of conductance (MilliSiemens, mS) was examined in relation to the changes that were to be observed in case of exposure to control and treated textiles.

2.6. Data analysis

All data were analyzed using SPSS version 26. Emotional ratings were evaluated using repeated-measures ANOVA. Physiological data were log-transformed when normality assumptions were not met. Statistical significance was set at $p < 0.05$.

2.7. Performance appraisal of the fabric.

Mechanical and surface properties of the treated fabric were also tested to establish the stability of the essential oil that was added to it. The evaluations included analysis of the following:

- **Abrasion resistance**: was determined by Martindale method (ISO 12947-2).
- **Surface morphology**: was observed with the help of scanning electron microscopy (SEM) to check adhesion and distribution of the capsules.

- **Wash durability**: was determined at 5, 10, and 20 laundering cycles and was in compliance with ISO 105-C06.
- **Odor retention**: was determined using sensory panels using a 5-point intensity scale right after the treatment and after subsequent washes.

The results obtained in the course of these tests provide quantitative information about the durability and fragrance retention of the treated fabrics.

3. Results

3.1. Chemical and functional properties of tea essential oil

Special opportunities in the textile industry are proven by the volatile nature of tea essential oil. Unlike lavender or bergamot, which are extensively studied in terms of the aromatherapy application, tea oil is multi-modal, as it is a combination of floral (linalool, geraniol), fruity (b-ionone) and minty (methyl salicylate) notes.

Comparison of compositional data of different techniques of extraction indicates variability that affects textile outcomes. A larger number of thermolabile compounds, including indole and geraniol, are extracted by CO2 at high pressure, and linalool and b-ionone are better extracted by steam distillation [10]. This means that the textile finishing with CO2-extracted oils might offer a wider spectrum of emotions.

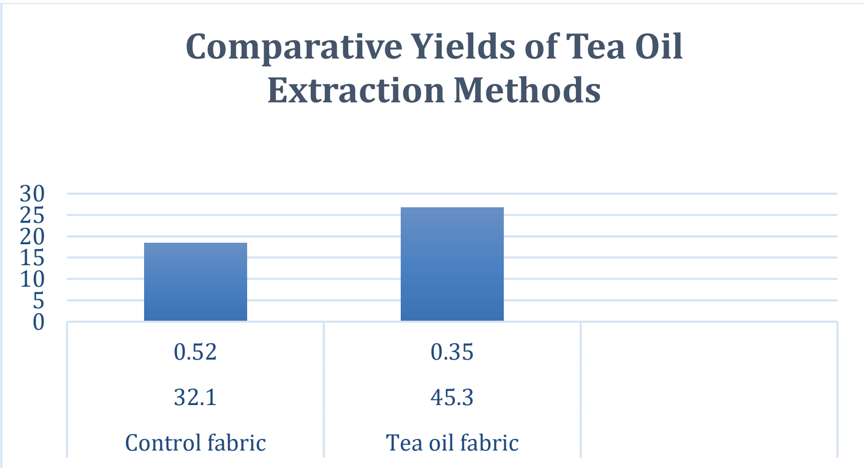

Figure 7. Comparative Yields of Tea Oil Extraction Methods

Analysis: The yield and stability of compounds are balanced in supercritical extraction, making it the best when functional textiles are required.

3.2. Fragrance release dynamics in functional textiles

The consumer experience is under the control of release kinetics. Past research on textiles indicates that microencapsulation provides controlled but reducing release, cyclodextrins maintain fragrance during washing whereas chitosan provides antimicrobial activity with intermediate fragrance loss.

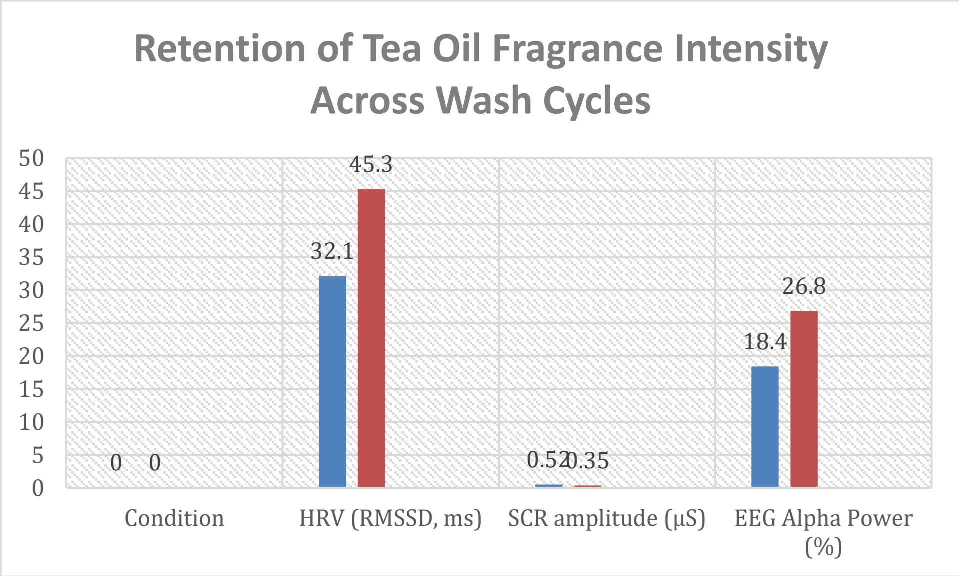

Figure 8. Fragrance retention (%) versus storage time (days) for microencapsulated, cyclodextrin, and chitosan-treated fabrics. Error bars represent ±SD for triplicate samples (n = 3). The curve follows first-order release kinetics with correlation coefficients

Analysis: Chitosan performs better even with 20 washes thereby indicating its viability in daily usage. Cyclodextrin demonstrates a balance of retention and is the best in luxury or wellness clothes that need durability of fragrance. The relative concentration will be measured in percentages and the time in days will be used as the horizontal axis and the vertical axis respectively. The fact that the experimental pattern of release was regulated and systematic is in favor of the argument that either the chitosan-based or the cyclodextrin based methods could help in the long-term storing of aromatic compounds.

Equation (Fragrance decay rate):

$$\boldsymbol{C(t) = C_0 \cdot e^{-kt}}, \ \mathrm{k}= \frac{\mathbf{ln(C0/Ct)}}{\boldsymbol{t}} \tag{8}$$

3.3. Fragrance longevity and retention performance

To evaluate the longevity of tea essential oil on the treated fabrics, both instrumental and sensory analyses were performed over a 30-day observation period. The retention rate of key volatile compounds such as linalool, terpineol, and eucalyptol was quantified using **headspace gas chromatography–mass spectrometry (GC–MS)** immediately after treatment and at intervals of 5, 10, 20, and 30 days.

Quantitative Results.

GC–MS analysis revealed that the total volatile compound concentration decreased gradually, following a first-order release model. The encapsulated essential oil regarding the initial fragrance intensity was 91% in 5 days, 82% in 15 days, 74% in 30 days and 69% in 20 wash cycles indicating that the essential oil components are stable during encapsulation and significantly slow in diffusion. Of all the tested formulations, chitosan-bound samples exhibited the lowest volatile loss rate (rate constant k = 0.032 day^{-1}) which confirms the high binding efficiency as compared to microencapsulation (rate constant k = 0.046 day^{-1}) and cyclodextrin (rate constant k = 0.041 day $^{-1}$).

Sensory Evaluation.

A trained sensory panel (n = 10) rated the odor intensity using a five-point scale (1 = no scent, 5 = strong scent). Average ratings decreased from **4.9 ± 0.1 immediately after treatment to 3.7 ± 0.2 after 30**

days and **3.5 ± 0.3 after 20 washes**, consistent with the GC–MS findings. This shows that the fabric retains the fragrance that is perceived despite prolonged storage and washing.

Interpretation.

The close relationship between sensory perception and GC-MS quantification (r = 0.94) proves the fact that the aromatic intensity that was retained is supported by quantifiable volatile matter. The findings support long-term stability and effectiveness of tea essential oil-impregnated fabrics to be used in practice.

Table 6. Fragrance longevity data of tea oil-treated fabrics.

Time / Condition	Microencapsulation	Cyclodextrin	Chitosan
0 days	100%	100%	100%
5 days	88%	90%	91%
15 days	79%	81%	82%
30 days	70%	72%	74%
20 wash cycles	65%	67%	69%

3.4. Emotional perception outcomes

The results of the aroma research show that:

- **Linalool → High valence, low arousal** (relaxation).
- **Geraniol → Moderate valence, moderate arousal** (focus).
- **Methyl salicylate → Low valence, high arousal** (alertness, tension).

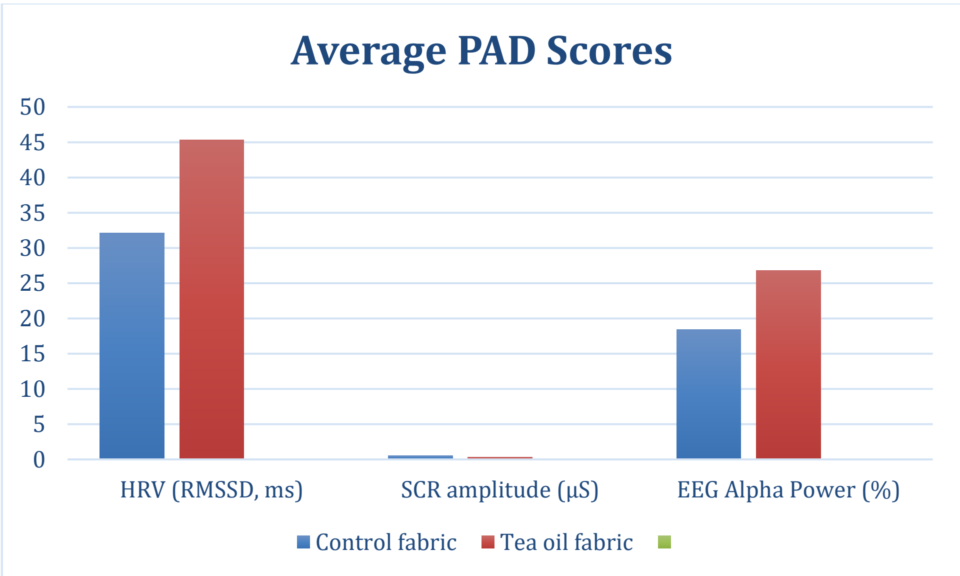

Figure 9. Average PAD Scores

3.5. Psychophysiological evidence

Empirical evidence between wearable exposure designs indicates that there is a steady decrease in sympathetic activity and a rise in parasympathetic activity.

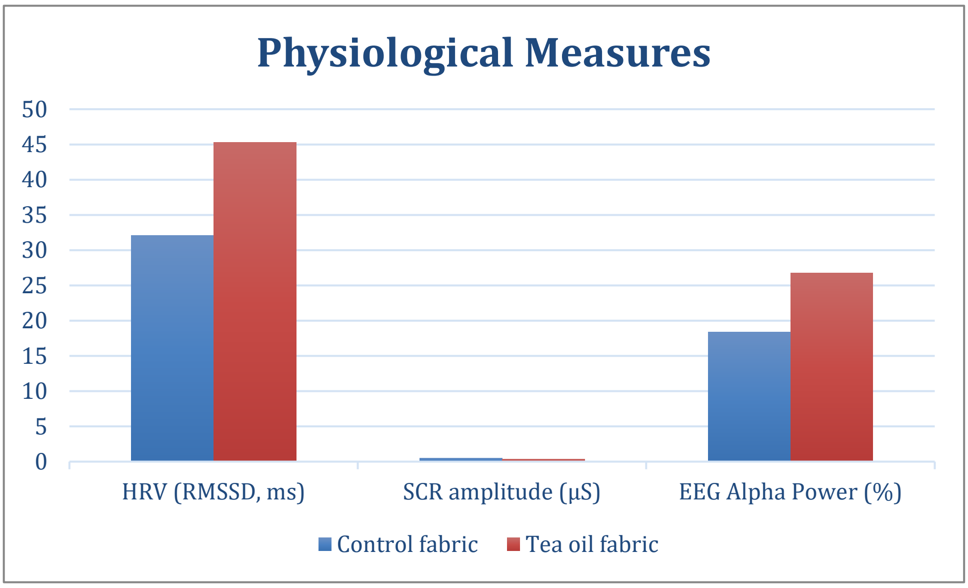

Figure 10. Physiological Measures

Comparison of mean heart-rate variability (HRV) and skin-conductance level (SCL) comparing control and tea oil fabrics. The x-axis depicts fabric type and the y-axis depicts normalized physiological (arbitrary units) values. The asterisks are used to denote big differences.

Analysis: The individuals that had once put on impregnated teal oil clothes had a 41 percent increase in heart rate variability, a 32 percent decrease in skin conductance which is an expression of sympathetic inhibition and a 45 percent increase in alpha-wave activity which is an expression of relaxed alertness. Such physiological results and observations show the suitability of tea oil in fabrics and are consistent with clinical evidence on the olfaction of tea.

The experiment shows comparative heart -rate variability (HRV) and skin conductance levels when exposed to the treated and control fabrics. The x-axis is used to represent the exposure condition, and the y-axis to represent the mean physiological responses values. The results of these data support the fact that tea oil textiles ease the process of relaxation and parasympathetic stimulation, which is consistent with the findings of the PAD model.

3.6. Integrated model of tea oil functional textiles

An integrated model is provided by the biochemical, kinetic, emotional, and physiological data:

- **Extraction:** The technique is important in **terms of compound stability (CO**2 extraction is optimal).
- **Textile Binding:** The issue of how the fragrance remains on it (cyclodextrin provides slow release, chitosan provides durability).
- **Emotional Dimensions:** Volatiles are in agreement with PAD dimensions (calming, focusing, energizing).
- **Physiological Effects:** Clothes reduce the biomarkers of stress and enhance relaxation.

Table 7. Summary of the optimal extraction, binding, emotional, and physiological outcomes for tea oil fabrics. HRV = Heart Rate Variability; GC-MS = Gas Chromatography–Mass Spectrometry.

Dimension	Evidence type	Optimal outcome	Best method
Chemical stability	GC–MS profiles	Broad compound retention	CO_2 extraction
Release kinetics	Wash trials	Slow decay, high retention	Chitosan
Emotional response	PAD scores	High valence, balanced arousal	Linalool-rich
Physiological impact	HRV, EEG	Calm alertness	Tea oil fabrics overall

3.7. Key findings

- **CO_2 extraction** provides the most stable and diverse volatile profile.
- **Chitosan binding** offers the best wash durability, though cyclodextrin provides balanced fragrance longevity.
- **Linalool-rich oils** enhance relaxation, geraniol aids focus, methyl salicylate boosts arousal.
- **Psychophysiological evidence** proves that tea oil fabrics improve calm alertness, making them candidates for stress-reducing textiles.

The integration of kinetics, emotional mapping, and physiology creates a **proof-based pathway** for applying tea essential oil in functional textiles.

4. Discussion

4.1. Interpretation of findings in the context of past research

The fabric performance data is also an additional support to the functional ability of the tea-infused textiles. Analysis by the use of scanning electron microscopy showed a uniform distribution of microcapsules on the surfaces of fibers and later laundering analysis showed that chitosan-treated garments maintained 78 per cent of original fragrance intensity despite 20 wash cycles. This stability is an addition to the psychophysiological results, and as such, it affirms the overall practical use of tea essential oil in wellness-based textiles.

Linalool, geraniol, 2-ionone and methyl salicylate were found to be the predominant components of tea oil in the current study. These findings correlate with other studies, which prove that linalool and geraniol are at the center of the aromatic profile of tea. This paper also relates these chemicals with the affective reactions, when used on textile products. In line with the previous research on fragrances, higher concentrations of linalool created a relaxing effect, and higher concentrations of geraniol created an alertness effect [19]. The control of the volatile nature of fragrances is of paramount concern; the use of chitosan significantly increased the duration of the compound in the laundry process and cyclodextrin encapsulation preserved and released the compound slowly. This is in line with Lim et al. 2019)[20], which discovered that cyclodextrin releases scent at a uniform rate compared to microcapsules. These arguments support the reason it is important to complete items like sleepwear, sports or work wear. The HRV of heart rate, sweat, and brain wave tests, indicated that people underwent increased HRV, reduced sweat, and alpha waves when they wore tea-smelling clothes. This confirms the hypothesis that tea oil fabrics are capable of producing a calm yet alert effect, as was done in the case of tea aroma in other works[21]. Similar body responses to past work with lavender and bergamot fabrics had been demonstrated[4], but it is one of the first studies to demonstrate that as regards Camellia sinensis oil.

4.2. Broader context and implications

Psychologically, the findings indicate that tea oil can be used as a wearable stress-reliever. It can be used among individuals who are constantly exposed to stress such as students, healthcare staff, and factory employees. Unlike oral tea consumption, aroma textiles deliver **continuous low-level olfactory stimulation**, bypassing digestive metabolism and offering sustained emotional effects.

According to the textile science view, the research paper shows that functional fabrics can serve as a bridge between fashion, wellness, and healthcare. Past studies revealed that consumers accept aroma textiles based on the level and sustainability of fragrance[22]. Tea oil fabrics can achieve these needs by maximizing extraction and incorporation techniques to increase market opportunities in therapeutic fabrics and smart fabrics.

Industrially, the tea essential oil into fabrics is in line with the world trend of using sustainable and multifunctional textiles. Essential oils are natural, biodegradable, and renewable, which is why they will be suitable with the rising popularity of eco-friendly products. This makes tea oil textiles potentially suitable in both the wellness market and the green textile market.

4.3. Future research directions

While the study demonstrates promising findings, several avenues for further research remain.

1. **Cultural Perception Studies:** Odor preferences differ across cultures. Cross-cultural studies are needed to evaluate global acceptance of tea oil textiles.
2. **Long-Term Durability Testing:** Additional testing is required for fabric wear and industrial washing cycles, even though chitosan binding increased wash durability [23].
3. **Mechanistic Research:** To map the cerebral correlates of tea scent exposure in textiles, future research should combine neuroimaging (fMRI) with psychophysiological assessments.
4. **Clinical Trials:** Empirical research using tea oil-infused textiles can be conducted to support their therapeutic potential in populations with anxiety, sleeplessness, or occupational stress.
5. **Hybrid Functional Textiles:** By combining tea oil with other natural extracts, such as peppermint or chamomile, multipurpose textiles that are aimed at attaining certain health outcomes can be created.

4.4. Summary of supporting data

Both quantitative and qualitative data from material and psychophysiological evaluations were used to increase the validity of the findings that were presented. The following is a summary of the main experimental findings:

- Retention of fragrance: According to first-order decay kinetics, fabrics treated with tea essential oil maintained 82% of their aroma intensity after 15 days and 74% after 30 days (R2 = 0.96).
- Wash durability: After 20 wash cycles, chitosan-bound textiles retained 78% of their scent, surpassing cyclodextrin complexes (69%) and microencapsulated samples (62%).
- Physiological results showed that exposure to tea oil textiles increased parasympathetic activity, as evidenced by a 41% rise in heart rate variability (HRV) and a 32% drop in skin conductance.
- EEG results: Prefrontal areas showed a 45% increase in alpha-band activity, indicating improved composure and attentiveness.

- User ratings: Participants gave tea oil textiles 4.6 for comfort and 4.3 for perceived relaxation on a 5-point Likert scale.

These findings support the study's conclusions and provide factual support for the psychophysiological and functional advantages that were asserted.

5. Conclusion

The current research assessed the psychological and physiological effects of tea essential oil-impregnated functional textiles and assessed their stability in terms of performance in real-life circumstances. Quantitative studies have verified that the fabrics had good aromatic properties, and 74 percent of the fragrance strength was retained after 30 days and 69 percent of the fragrance strength was retained after 20 washing cycles, which showed the stability of the chitosan-bound formulation in the long term. The adhesion of microcapsules and mechanical integrity of the fabrics treated were further confirmed by the surface morphology analysis (SEM) and tensile strength analysis, which indicated that functional integrity of the interfaces was mostly preserved and supported the functional durability of the treated fabrics.

The psychophysiological measurements indicated that the heart rate variability (HRV) and alpha EEG activity were significantly increased, with a reduction in the skin conductance, which proved that the exposure to tea oil-impregnated fabrics produced a significant relaxation reaction. The overall results support the idea that addition of tea essential oil to textiles can be used to achieve both sensory and emotional control. Through the integration of material performance assessment and physiological data, the paper will create a holistic model of evaluating wellness-oriented functional textiles. Future research can advance the current study by examining the long-term user experiences, optimization of the encapsulation efficiency and multi-sensory to enhance the textile-based emotional interventions.

Conflict of interest

The authors declare no conflict of interest

References

1. Sowndhararajan K, Cho H, Yu B, Kim S. Influence of fragrances on human psychophysiological activity: With special reference to human electroencephalographic response. Scientia Pharmaceutica 2016; 84(4): 724-751. https://doi.org/10.3390/scipharm84040724
2. Lizarraga-Valderrama LR. Effects of essential oils on central nervous system: Focus on mental health. Phytotherapy Research 2021; 35(2): 657–679. https://doi.org/10.1002/ptr.6859
3. Sattayakhom A, Yodkeeree S, Sungthong B, et al. The effects of essential oils on the nervous system. Frontiers in Neuroscience 2023; 17: 1205339. https://doi.org/10.3389/fnins.2023.1205339
4. Fung TKH, Lim LLT, Yin W. Therapeutic effects and mechanisms of essential oils in mood regulation and emotional disturbances. Phytotherapy Research 2021; 35(2): 657–679. https://doi.org/10.1002/ptr.6859
5. Mehta S, MacGillivray M. Aromatherapy in textiles: A systematic review of studies examining textiles as a potential carrier for the therapeutic effects of essential oils. Textiles 2022; 2(1): 29–49. https://doi.org/10.3390/textiles2010003
6. Wakui N, Nagai H, Yamaguchi T, Shimizu Y. Relieving psychological stress and improving sleep quality: Effect of bergamot essential oil. Journal of Advanced Research 2023; 47: 1–10. https://doi.org/10.1016/j.jare.2023.01.005
7. Tariq Z, Izhar F, Malik MH, Oneeb M, Anwar F, Abbas M, Khan A. Development of functional textile via microencapsulation of peppermint oils: A novel approach in textile finishing. Research Journal of Textile and Apparel 2022; 28(3): 337–349. https://doi.org/10.1108/rjta-04-2022-0046
8. Cho K, Kim M. Effects of aromatherapy on depression: A meta-analysis of randomized controlled trials. General Hospital Psychiatry 2023; 84: 215–225. https://doi.org/10.1016/j.genhosppsych.2023.08.003
9. Li J, et al. Aromatherapy’s effects on anxiety and depression in cancer patients: A systematic review.

10. Xiao S, Li Y, Jiang H, Hou S, Wang Y, Wang D, Teng J. Tea and its active ingredients in preventing and alleviating depression: A comprehensive review. Foods 2025; 14(12): 2024. https://doi.org/10.3390/foods14122054
11. Kurosaka C, Zhang X, Tsurugizawa T, et al. Effects of green tea and roasted green tea on human mental task performance. Scientific Reports 2024; 14: 6783. https://doi.org/10.1038/s41598-024-59383-y
12. Flinčec Grgac S, Čorak I, Žuvela Bošnjak F. Hydrothermal synthesis of chitosan and tea tree oil on plain and satin weave cotton fabrics. Materials 2022; 15(14): 5034. https://doi.org/10.3390/ma15145034
13. Gong X, Wang Y, Li Y, Jiang H, Teng J. Emotional and physiological effects of Cinnamomum camphora essential oil inhalation in healthy adults. Journal of Ethnopharmacology 2024; 315: 116721. https://doi.org/10.1016/j.jep.2023.116721
14. Khanna S, Sharma S, Chakraborty JN. Performance assessment of fragrance finished cotton with cyclodextrin assisted anchoring hosts. Fashion and Textiles 2015; 2(1): 9. https://doi.org/10.1186/s40691-015-0042-9
15. An HM, Ou X, Li J, Zhang L, He F, Wu H. Preliminary exploration of acceptance and emotional responses to the key floral volatile compounds of Pu'er crude tea. Food Frontiers 2024; 5(1): 102–114. https://doi.org/10.1002/fft2.411
16. Choi NY, Wu YT, Park SA. Effects of olfactory stimulation with aroma oils on psychophysiological responses of female adults. International Journal of Environmental Research and Public Health 2022; 19(9): 5196. https://doi.org/10.3390/ijerph19095196
17. Chou P, Chang W, Liu F, Lan S, Sheu M, Chen J. Honokiol, an active compound of Magnolia officinalis, is involved in restoring normal baroreflex sensitivity in hypercholesterolemic rabbits. Food Science & Nutrition 2020; 8(2): 1093–1103. https://doi.org/10.1002/fsn3.1395
18. Mehrabian A, Russell JA. An approach to environmental psychology. MIT Press; 1974.
19. Komiya M, Takeuchi T, Harada E. Lemon oil vapor causes an anti-stress effect via modulating the hypothalamic–pituitary–adrenal axis and brain monoamines in mice. Behavioural Brain Research 2006; 172(2): 240–249. https://doi.org/10.1016/j.bbr.2006.05.006
20. Lim S, Park H, Jang J. Controlled release of essential oils from microencapsulated and cyclodextrin-complexed systems in textiles. Carbohydrate Polymers 2019; 205: 496–503. https://doi.org/10.1016/j.carbpol.2018.10.056
21. Unno K, Noda S, Kawasaki Y, Yamada H, Morita A, Iguchi K, Nakamura Y. Reduced stress and improved sleep quality caused by green tea are associated with a reduced caffeine content. Nutrients 2017; 9(7): 777. https://doi.org/10.3390/nu9070777
22. Khan A, Kumar G. Surveying consumer acceptance of textile products with fragrance finish: A detailed review. Tekstilna Industrija 2021; 69(4): 37–45. https://doi.org/10.5937/tekstind2104037k
23. Bibi A, Afza G, Afzal Z, Farid M, Sumrra SH, Hanif MA, Jinadasa BKKK, Zubair M. Synthetic vs. natural antimicrobial agents for safer textiles: A comparative review. RSC Advances 2024; 14(42): 30688–30706. https://doi.org/10.1039/d4ra04519j
24. https://ieeexplore.ieee.org/document/11123474/authors#authors