

Research Article

VOC Emissions from Natural Latex Pillows: HS-SPME-GC/MS Characterization and Health Implications

Roosanee Kulvijitra ^{a*}, Waraporn Ratsameephakai ^a and Ekwipoo Kalkornsurapranee ^b

^a Office of Scientific Instrument and Testing, Prince of Songkla University, Hat Yai, Songkhla 90110, Thailand.

^b Department of Material Science and Technology, Faculty of Sciences, Prince of Songkla University, Hat Yai, Songkhla 90110, Thailand.

ABSTRACT

Article history:

Received: 2025-08-25

Revised: 2026-04-10

Accepted: 2026-04-25

Keywords:

Natural latex pillow;

GC-MS;

VOCs

Natural rubber pillows are widely used household products; however, their production process may release volatile organic compounds (VOCs) that can affect indoor air quality and human health. This study aimed to identify and characterize VOCs in commercial rubber pillows and evaluate their potential health implications based on toxicological references. Ten pillow samples (P01–P10) were analyzed using headspace solid-phase microextraction coupled with gas chromatography–mass spectrometry (HS-SPME–GC–MS). VOC identification was performed by comparison with NIST 14 and Wiley 10 mass spectral libraries, using a match score acceptance criterion of $\geq 90\%$. Semi-quantification was conducted based on relative peak area normalization. A total of 44 VOCs were identified and classified into nine chemical categories. Frequently detected compounds in all samples included sulfur compounds (e.g., carbon disulfide and benzothiazole); aromatic hydrocarbons (e.g., toluene and styrene); alcohols (e.g., 2-ethyl-1-hexanol and linalool); aromatic compounds (e.g., benzenemethanol, α,α -dimethyl-, and diethyl phthalate); and cyclic alkenes (e.g., α -copaene and δ -cadinene). Benzothiazole and phenol, 2-(1,1-dimethylethyl)-6-methyl-, both considered toxicologically relevant compounds, were consistently detected in all samples. The presence of benzothiazole was attributed to its role in the vulcanization process, whereas amines were observed only in selected samples (P04, P06, P08). Several detected VOCs have been identified as causing potential health risks, including neurotoxicity (carbon disulfide), mucosal irritation (amines), and endocrine disruption (phthalates). These findings indicate that natural rubber pillows may act as sources of diverse VOC emissions, predominantly sulfur- and aromatic-derived compounds. Notably, this is the first study on finished pillows to provide comprehensive evaluations of VOC emissions from them rather than raw materials. Although absolute concentrations were not determined, the results highlight the need for further exposure and risk assessment studies. These findings indicate that natural rubber pillows may act as sources of diverse VOC emissions, predominantly sulfur- and aromatic-derived compounds, particularly under prolonged exposure conditions during sleep. From a practical perspective, these results suggest that manufacturers should consider emission-reduction strategies, including process optimization and the use of low-emission additives, and support the development of eco-labeled, low-VOC products in line with international indoor air quality guidelines in order to enhance consumer safety.

© 2026 Kulvijitra, R., Ratsameephakai, W. and Kalkornsurapranee, E. Recent Science and Technology published by Rajamangala University of Technology Srivijaya

1. Introduction

More people are increasingly concerned about environmental sensitivities arising from a wide range of consumer products, including cosmetics, household items, food, and pharmaceuticals (Ramírez *et al.*, 2010; Khalid and Abdollahi, 2021). In particular, indoor air quality has become a

significant public health issue, as highlighted by international organizations such as the World Health Organization (WHO, 2010) and the U.S. Environmental Protection Agency (U.S. EPA, 2023), which emphasize the impact of VOCs on indoor air quality and human health in indoor environments. Natural rubber-based products, such as latex pillows and mattresses,

* Corresponding author.

E-mail address: roosanee.i@psu.ac.th

Cite this article as:

Kulvijitra, R., Ratsameephakai, W. and Kalkornsurapranee, E. 2026. VOC Emissions from Natural Latex Pillows: HS-SPME-GC/MS Characterization and Health Implications.

Recent Science and Technology 18(3): e268926.

<https://doi.org/10.65411/rst.2026.268926>

are widely used personal and household items and are significant exports from Thailand. However, their manufacturing and processing stages can generate odorous compounds. VOCs in natural rubber are primarily formed through microbial degradation of non-rubber components, including carbohydrates and proteins, as well as through chemical additives used during production (Nor-Hidayaty *et al.*, 2012; Pajarito *et al.*, 2018). In particular, sulfur-containing compounds are commonly associated with vulcanization processes, where sulfur and accelerators are used to improve elasticity and durability. Additional VOCs may originate from antioxidants (e.g., butylated hydroxytoluene, BHT), plasticizers, foaming agents, and residual solvents. These compounds can contribute not only to unpleasant odors but also to potential health risks. VOCs are organic chemicals with high vapor pressure at ambient temperature, enabling their release into indoor air. Prolonged exposure to VOCs may cause irritation, respiratory effects, and other adverse health outcomes depending on their chemical properties (Capíková *et al.*, 2019). Consequently, reducing VOC emissions has become a priority for manufacturers, and regulatory frameworks such as the European Union (EU) Ecolabel for bed mattresses have established criteria to limit total VOC emissions in consumer products (European Commission, 2014).

Much research focused on the identification of the malodors of natural products in various stages reported in the main technique was gas chromatography coupled with mass spectrometry (GC-MS) and various sampling processes. The components of obnoxious odor derived from various solid rubbers by headspace sampling. Various components were found in them. Standard Thai Rubber (STR XL) were mainly comprised of hydrocarbons, and STR 5L was found to contain small amounts of volatile fatty acids. In the case of skim crumb rubber was detected the sulfur-containing compounds (Sakdapipanich and Insom, 2006). Kamarulzaman *et al.* (2012) studied the malodorous vapors from the natural rubber drying process with the thermal desorption-gas chromatography technique and found mainly consisted of volatile fatty acids (VFA), acetic acid, and propionic acid were present with the highest concentrations. The odorous compounds of cup lamp natural rubber were collected using solid-phase micro extraction (SPME) to analyze the odor on a day-to-day basis for six days. It was found that samples were analyzed at early incubation period were mainly hydrocarbons, and other volatile compounds produced throughout the incubation were low-molecular-weight compounds such as volatile fatty acids, sulfurous compounds, amino compounds, esters and alcohols (Nornanysya *et al.*, 2013). Kamarulzaman *et al.* (2019) studied four headspace sampling techniques of raw rubber materials such as Static headspace sampling (SHS), Dynamic headspace sampling (DHS), Headspace SPME (HS) and Micro-chamber/thermal Extractor (μ -CTE) and found that the highest extraction

efficiency corresponded to aromatics and acids, and the lowest compound extraction was aldehyde and hydrocarbon. The various VOCs signature based on the extraction procedures and the experimental conditions employed.

This study was conducted to evaluate the VOCs and the malodors of rubber mattresses by HS-SPME in combination with GC-MS. It is the most common technique for headspace analysis, although it is limited by fiber discrimination (Kamarulzaman *et al.*, 2019) and combines the advantages of both SHS and DHS (Jeleń, 2006). The advantages of this technique are highly sensitive, reliable and a beneficial alternative to classical methods for VOCs determination without sample preparation (Jeleń, 2006). An attractive alternative for the determination of VOCs in various samples (Caroprese *et al.*, 2009; Shinoda *et al.*, 2020; Chen *et al.*, 2022; Agatonovic-Kustrin *et al.*, 2023). Despite multiple studies on VOCs from rubber during processing, limited data is available on emissions from finished consumer products such as latex pillows. However, no studies have comprehensively reported the VOC emission profiles of finished natural latex pillows intended for indoor consumer use, despite their widespread market presence. This represents a critical gap in understanding the potential health implications of VOC emissions from final consumer products. Although several studies have investigated VOC emissions during rubber processing, there is limited scientific data regarding emissions from finished latex bedding products, which are directly relevant to public exposure.

Therefore, this study aimed to identify and semi-quantify volatile organic compounds (VOCs) emitted from commercially available natural rubber latex pillows using HS-SPME–GC–MS. The identified VOCs were further evaluated based on using Safety Data Sheets (SDS) to assess their potential health risks.

2. Materials and Methods

2.1 Chemicals and materials

A tripolar-phase divinylbenzene/carbozen/polydimethyl siloxane (DVB/CAR/PDMS) StableFlex autosampler fibre (1 cm, 50/30 μ m, 24 gauge; Agilent Technologies Inc., USA) was used for headspace solid-phase microextraction (HS-SPME). Twenty-millilitre headspace screw-top vials fitted with PTFE/silicone septa and magnetic screw caps (Agilent Technologies Inc., USA) were also used. No solvents or additional chemical reagents were employed in this work because HS-SPME is a solvent-free extraction technique.

2.2 Natural latex pillow samples

The natural latex pillow samples were supplied by Natural Rubber Innovation Research Institute, Prince of Songkla University. The natural latex pillow samples were cut into small cubes (approx. 0.5 cm $\times$ 0.5 cm $\times$ 0.5 cm). 4 g of each sample was weighed and placed in the 20 mL headspace vial with screw cap. The cap was tightened, and the vial placed in the PAL system sample rack for analysis. As the objective of this

study was qualitative VOC profiling, each sample was analyzed in a single run without replicate measurements.

2.3 Analytical instrumentations

2.3.1 Headspace-SPME

For the HS-SPME method, the natural latex pillow samples were pre-incubated at 60 °C for 60 min with the agitation speed of 250 rpm to release the volatile compounds prior to extraction, and then the fiber was exposed in the headspace of the vial at 60 °C for 60 min for extraction. After the extraction of volatiles from the natural latex pillow samples onto the fiber, the analytes were thermally desorbed from the fiber in the injector port of the GC-MS for 15 min and transferred to the GC-MS column where volatile compounds were separated. After extraction and desorption, the SPME fiber was conditioned at 270 °C for 30 min the SPME conditioning module (PAL3RTC Auto Sampler Systems).

2.3.2 GC-MS condition

The characterization and identification of VOCs were performed using a 7890B gas chromatograph coupled with a 7000D tandem mass spectrometer (Agilent Technologies Inc., USA), equipped with a VF-WAXms capillary column (J&W Scientific, Berkshire, USA; 30 m × 0.25 mm i.d., 0.25 µm film thickness). Helium (UHP grade) was used as the carrier gas at a constant flow rate of 1.0 mL/min. Samples were introduced via a splitless injector maintained at 270 °C. The oven temperature program was set at 35 °C for 1 min, ramped at 5 °C/min to 250 °C, and held at the final temperature for 1 min. Mass spectra were acquired over the range of m/z 29–500 at a scan rate of 2 scans/s. MassHunter version 7 was used for GC–MS control and data acquisition.

Each VOC was tentatively identified by comparison of its EI mass spectrum with the National Institute of Standards and Technology (NIST) Mass Spectral Library, version 14, and Wiley version 10, using an acceptance criterion of match score $\geq 90\%$. The relative abundance of each detected compound was expressed as % of total peak area, calculated by dividing

the peak area of an individual compound by the sum of all detected peak areas in the chromatogram and multiplying by 100. These values were used only to indicate the relative abundance of compounds within each sample and do not represent absolute concentrations.

As the present work was designed as a qualitative VOC screening study, no calibration curves, spiked standards, blank correction, or quantitative recovery experiments were performed. Likewise, repeatability parameters were not determined in this work.

3. Results and Discussion

A total of ten natural latex pillow samples were analysed for volatile organic compounds (VOCs) using headspace solid-phase microextraction coupled with gas chromatography–mass spectrometry (HS-SPME–GC/MS). This analytical technique enables solvent-free pre-concentration of VOCs directly from the sample headspace, followed by efficient chromatographic separation and mass spectral identification. Compound identification was performed by comparing the acquired mass spectra with the Wiley 10 and NIST 14 mass spectral libraries, with an acceptance criterion of match score $\geq 90\%$. The total ion chromatogram (TIC) obtained from sample P01 is presented in Figure 1 as a representative profile. The chromatogram shows a complex distribution of peaks with varying retention times and intensities, reflecting the diverse chemical nature and relative abundance of VOCs emitted from the sample. The major chemical classes identified included sulfur-containing compounds, aromatic compounds, aldehydes, ketones, terpenes, and hydrocarbons.

To better position the present work within the existing literature, a comparison with previous studies on VOC emissions from bedding, latex, and rubber-based materials is presented in Table 1. As shown, earlier studies have mainly focused on bedding products in general, raw rubber materials, or latex product development, whereas the present study specifically examines natural rubber latex pillows.

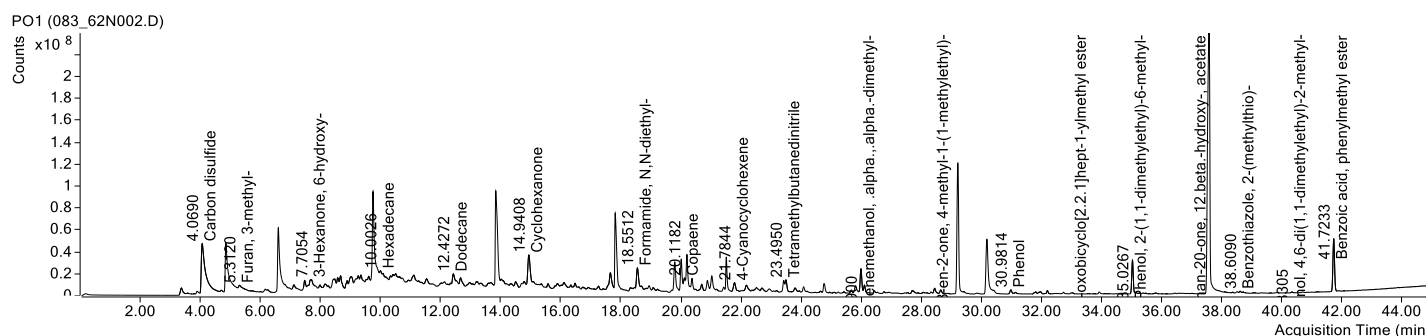


Figure 1 Representative total ion chromatogram (TIC) of volatile organic compounds (VOCs) from natural latex pillow sample P01 obtained using HS-SPME–GC/MS.

In addition to the within-sample VOC distribution, comparison with conventional pillow products reported in the

literature provides further context for interpreting the VOC profile observed in the present study. Polyethylene-based pillows have

been shown to emit higher levels of aliphatic hydrocarbons, including tetradecane, toluene, and xylene, whereas the natural rubber latex pillows analysed in this study exhibited a distinct VOC profile dominated by sulfur-containing compounds, phenolic derivatives, and alcohols. This difference may reflect variations in raw materials, additives, and manufacturing processes between natural rubber latex and conventional synthetic pillow products. However, this comparison should be interpreted cautiously because it is literature-based and the products were evaluated under different analytical conditions.

Following these comparisons, the VOC profiles obtained from all samples were compiled and summarised in Table 2 for comparative evaluation and toxicological assessment. Table 2 presents the volatile organic compounds (VOCs) detected in natural rubber latex pillow samples, categorised by chemical group. For each compound, the molecular structure and formula, Globally Harmonized System (GHS) hazard pictograms, sample codes (with relative abundances expressed as % of total peak area), and potential health risks are presented. A more comprehensive summary of the detected VOCs, including chemical grouping, occurrence across samples, and relative abundance, is therefore provided to facilitate comparative interpretation.

Nitrogen-containing compounds were identified in several samples. Diethylamine, detected in P04, P06, and P08 (0.17–8.77%), is associated with severe skin and eye irritation or burns and respiratory damage. Triethylamine, present in P06 and P08 at trace levels (0.01–0.02%), is known to cause irritation to the eyes, skin, and respiratory tract.

Sulfur-containing compounds such as carbon disulfide and benzothiazole derivatives were among the most abundant VOCs detected, with documented neurotoxic, reproductive, and skin-sensitisation risks. These compounds are also likely associated with vulcanization chemistry and the degradation of sulfur-based accelerators and additives commonly used in rubber processing. In addition, several ketones, namely α -isomethylionone, 1-(4-tert-butylphenyl)propan-2-one, and 2(3H)-furanone, 5-heptyldihydro-, were primarily detected in P02 ($\leq 1.81\%$ of total VOCs). Although present at lower relative abundances, these compounds are classified as irritants and may intensify skin and respiratory irritation when present alongside sulfur-containing compounds. Moreover, the aldehyde 2-(4-tert-butylbenzyl)propionaldehyde detected in P02 presents further concern because of its potential to cause skin irritation, allergy, and reproductive toxicity. The co-occurrence of these chemical groups in specific samples suggests the possibility of additive or synergistic effects, particularly in sensitive individuals. In this context, the detected sulfur-containing compounds may reflect not only manufacturing residues but also progressive chemical changes occurring during material ageing and degradation.

Acidic compounds were detected across multiple samples, encompassing both aliphatic and aromatic acids. The most

abundant, benzoic acid, phenylmethyl ester (P01, 2.54%), is a serious eye and respiratory irritant and poses long-term aquatic toxicity. Other acids, such as decanoic and dodecanoic acids, were linked to mild skin or respiratory irritation. Propanoic acid, 2-methyl-, 3-hydroxy-2,2,4-trimethylpentyl ester, while generally of low toxicity, may cause eye irritation. Acetic acid in P08 (1.12%) carries inhalation toxicity and can severely irritate the eyes, nose, and throat at higher concentrations, while nonanoic acid may also cause irritation at high exposure levels. Although each acid was detected at relatively low relative abundance, their combined presence could contribute to the cumulative sensory profile of the pillows and to overall inhalation risks.

Notably, the occurrence of acidic compounds, although generally less volatile than aromatic hydrocarbons, can significantly influence the toxicological profile of the samples. For example, acetic acid is a simple but corrosive carboxylic acid capable of irritating skin, eyes, and respiratory tract, with prolonged exposure causing discomfort and inflammation. Higher molecular weight acids such as hexanoic and octanoic acids, despite their natural occurrence, can produce strong odours and cause irritation upon contact. Some of these acids may also arise as degradation products, suggesting oxidative or hydrolytic processes within the material.

Alcohol compounds were also detected, adding to the complexity of the VOC profile. The predominant alcohol, 1-hexanol, 2-ethyl-, occurred in multiple samples at relatively high abundances. Although of low acute oral and dermal toxicity, it poses moderate inhalation risks. Linalool, a terpene alcohol found in fragrances, was also detected. While safe at low levels, linalool can act as a skin irritant and sensitiser, especially after oxidation. Polyfunctional alcohols such as 2-propanol, 1,1'-oxybis- and 2,2,4-trimethyl-1,3-pentanediol diisobutyrate were identified; both exhibit mild irritation potential, with the latter serving as a plasticiser in consumer products. The co-occurrence of alcohols with acidic and aromatic compounds suggests possible additive or synergistic irritant effects.

Alkanes were present at varying relative abundances. Heptane, while generally of low toxicity, can cause central nervous system (CNS) depression and mucous membrane irritation with repeated exposure. Higher molecular weight alkanes, such as tetradecane, showed low acute toxicity but mild irritation potential, and aspiration can lead to respiratory harm. Decane, although of low toxicity, may cause CNS depression at elevated levels. Halogenated alkanes such as methane, dichloro-, pose higher hazards, including respiratory irritation and cardiac effects. Branched-chain alkanes, such as octane, 3,6-dimethyl-, can cause skin and eye irritation and anaesthetic-like effects. Cyclic alkenes included both monocyclic and bicyclic structures. Furan, 3-methyl-, shares toxicological features with furan and is considered possibly carcinogenic to humans (IARC), as well as being an acute toxicant and irritant. 3-Cyclohexene-1-methanol, $\alpha,\alpha,4$ -trimethyl-, (S)- is a GHS Category 2 irritant to skin and eyes. Bicyclic sesquiterpenes such as α -copaene

Table 1 Comparison of the present study with previous studies on VOC emissions from bedding, latex, and rubber-based materials.

Study	Material/Product	Analytical method	Main objective	Key findings	Distinction from the present study
Oshima et al. (2021)	Bedding products (pillows and mattresses)	VOC analysis of commercial products	Survey VOCs from household bedding items	Showed that bedding products can emit VOCs relevant to indoor exposure	Did not focus specifically on natural rubber latex pillows or provide compound-level hazard profiling
Kamarulzaman et al. (2019)	Natural rubber materials	SHS, DHS, HS-SPME, and μ -CTE coupled with GC-MS	Compare headspace techniques for VOC detection from natural rubber	Demonstrated suitability of HS-based methods for VOC recovery from rubber materials	Focused on extraction techniques and raw rubber, not finished pillow products or health-risk interpretation (PubMed) DOI: 10.1016/j.talanta.2018.09.019
Ramli et al. (latex pillow development)	Latex foam pillows	Product testing / materials characterisation	Develop and evaluate latex foam pillow properties	Addressed product development and physical properties of latex foam pillows	Did not provide detailed VOC profiling with GHS and potential health risks (ResearchGate) https://doi.org/10.1007/s42464-021-00130-7
Liu et al. (2025)	Latex pillows	GC-Orbitrap HRMS	Nontargeted screening of chemicals in latex pillows	Identified a broad range of volatile/semi- volatile compounds in multiple latex pillows	Broader nontargeted screening; the present study provides HS-SPME-GC/MS-based qualitative profiling with grouped occurrence and hazard-focused discussion (ScienceDirect) https://doi.org/10.1016/j.microc.2025.115275
Present study	Natural rubber latex pillows	HS-SPME-GC/MS	Qualitative profiling of VOCs and hazard interpretation	Identified key VOC groups, occurrence frequency, relative abundance, GHS pictograms, and potential health risks	Provides pillow-specific VOC profiling with integrated chemical and toxicological interpretation

Table 2 Summary of volatile organic compound (VOC) groups detected in natural rubber latex pillow samples, including molecular structures, GHS hazard classifications, sample occurrence with relative abundance (% of total peak area), and associated potential health risks.

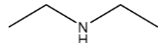
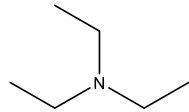
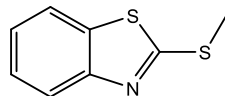
Compound group	Chemical structure and molecular formula	GHS pictograms	Sample codes (% of total peak area)	Potential Health Risks
1. Nitrogen-containing compounds				
Diethylamine	 C ₄ H ₁₁ N	 Flammable Corrosive Irritant	P04 (0.17%)	Severe skin and eye irritation/burns; respiratory damage
			P06 (0.50%)	
			P08 (8.77%)	
Triethylamine	 C ₆ H ₁₅ N	 Flammable Corrosive Acute Toxic	P06 (0.02%)	Eye, skin, and respiratory tract irritation
			P08 (0.01%)	
2. Sulfur-containing compounds				
Carbon disulfide	$S=C=S$ CS ₂	 Flammable Irritant Health Hazard	P01 (6.30%)	Neurotoxic; reproductive/skin sensitisation risks; high prevalence
			P02 (5.43%)	
			P03 (10.83%)	
			P04 (9.67%)	
			P05 (5.73%)	
			P06 (5.00%)	
			P07 (9.14%)	
			P08 (10.13%)	
			P09 (7.00%)	
			P10 (7.87%)	
2-(Methylmercapto)benzothiazole	 C ₈ H ₇ NS ₂	 Irritant	P08 (1.37%)	Skin/respiratory irritation; sensitisation; potential carcinogenicity/genotoxicity
			P10 (0.19%)	

Table 2 Summary of volatile organic compound (VOC) groups detected in natural rubber latex pillow samples, including molecular structures, GHS hazard classifications, sample occurrence with relative abundance (% of total peak area), and associated potential health risks (Continuous).

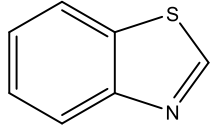
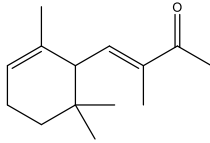
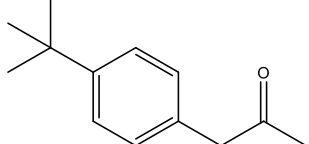
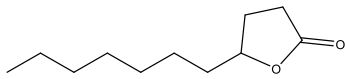
Compound group	Chemical structure and molecular formula	GHS pictograms	Sample codes (% of total peak area)	Potential Health Risks
Benzothiazole	 C_7H_5NS	 Acute Toxic  Irritant	P01 (3.81%) P02 (8.34%) P03 (5.60%) P04 (7.14%) P05 (6.32%) P06 (3.62%) P07 (5.09%) P08 (2.70%) P09 (7.54%) P10 (5.36%)	Respiratory and dermal irritation
3. Ketones				
alpha-isomethylionone	 $C_{14}H_{22}O$	 Irritant  Environmental Hazard	P02 (1.81%)	skin irritation and sensitization
1-(4-tert-Butylphenyl)propan-2-one	 $C_{13}H_{18}O$	 Irritant	P02 (0.14%)	Irritant; endocrine disruption potential; possible long-term effects
2(3H)-Furanone, 5-heptyldihydro-	 $C_{11}H_{20}O_2$	 Irritant	P02 (0.22%)	May cause mild skin and respiratory irritation

Table 2 Summary of volatile organic compound (VOC) groups detected in natural rubber latex pillow samples, including molecular structures, GHS hazard classifications, sample occurrence with relative abundance (% of total peak area), and associated potential health risks (Continuous).

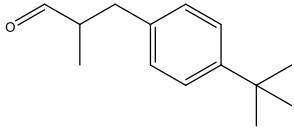
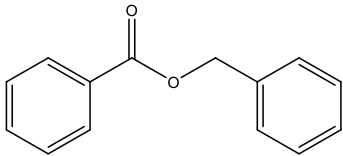
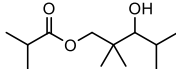
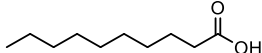
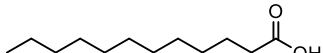
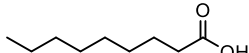
Compound group	Chemical structure and molecular formula	GHS pictograms	Sample codes (% of total peak area)	Potential Health Risks
4. Aldehydes compounds				
2-(4-tert-butylbenzyl)propionaldehyde (Lily aldehyde)	 $C_{14}H_{20}O$	 Health Hazard	P02 (1.29%)	Skin irritation; allergy; reproductive toxicity
5. Acids compounds				
Benzoic acid, phenylmethyl ester	 $C_{14}H_{12}O_2$	 Irritant Environmental Hazard	P01 (2.54%)	Serious eye irritation; respiratory irritation; toxic to aquatic life (long-term)
Propanoic acid, 2-methyl-, 3-hydroxy-2,2,4-trimethylpentyl ester	 $C_{12}H_{24}O_3$	Not classified under GHS	P03 (0.53%) P04 (0.35%) P09 (0.44%)	Low toxicity; possible eye irritation
Decanoic acid	 $C_{10}H_{20}O_2$	 Irritant	P04 (0.33%) P06 (0.44%)	May cause skin irritation
Dodecanoic acid	 $C_{12}H_{24}O_2$	 Corrosive Irritant	P04 (0.19%) P06 (0.13%)	Skin/respiratory irritation; may cause redness and discomfort
Nonanoic acid	 $C_9H_{18}O_2$	 Irritant	P07 (0.27%)	Low toxicity; possible irritant at high concentrations
Acetic acid	 $C_2H_4O_2$	 Flammable Corrosive	P08 (1.12%)	Slightly toxic by inhalation; 50 ppm causes severe eye/nose/throat irritation

Table 2 Summary of volatile organic compound (VOC) groups detected in natural rubber latex pillow samples, including molecular structures, GHS hazard classifications, sample occurrence with relative abundance (% of total peak area), and associated potential health risks (Continuous).

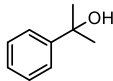
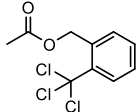
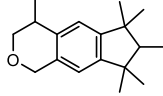
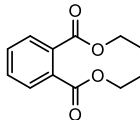
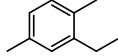
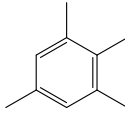
Compound group	Chemical structure and molecular formula	GHS pictograms	Sample codes (% of total peak area)	Potential Health Risks
6. Aromatics compounds				
Benzenemethanol, .alpha.,.alpha.-dimethyl-	 $C_9H_{12}O$	 Corrosive Irritant	P01 (1.20%) P02 (0.46%) P05 (0.74%) P07 (0.92%) P09 (0.69%) P10 (0.53%)	Harmful if swallowed; eye/respiratory/skin irritation; repeated contact may cause dryness/cracking
Benzenemethanol, .alpha.- (trichloromethyl)-, acetate	 $C_{10}H_9Cl_3O_2$	 Irritant	P02 (0.58%)	Skin/respiratory irritant; mild oral toxicity; may cause eye damage
Cyclopenta[g]-2-benzopyran, 1,3,4,6,7,8-hexahydro-4,6,6,7,8,8-hexamethyl (Galaxolide)	 $C_{18}H_{26}O$	 Environmental Hazard	P02 (0.09%)	Potential reproductive effects; environmentally persistent
Diethyl phthalate	 $C_{12}H_{14}O_4$	 Irritant	P01 (17.79%) P04 (0.12%) P06 (0.79%) P08 (0.35%)	Toxic if inhaled; may cause organ damage
Benzene, 2-ethyl-1,4-dimethyl-	 $C_{10}H_{14}$	 Flammable Corrosive Irritant	P10 (0.20%)	Low acute toxicity; irritant (eyes, skin, respiratory); chronic exposure risks
Benzene, 1,2,3,5-tetramethyl-	 $C_{10}H_{14}$	 Irritant	P10 (0.47%)	Irritant (skin, eyes, respiratory); prolonged exposure may cause dermatitis, nausea, dizziness, headaches; combustible

Table 2 Summary of volatile organic compound (VOC) groups detected in natural rubber latex pillow samples, including molecular structures, GHS hazard classifications, sample occurrence with relative abundance (% of total peak area), and associated potential health risks (Continuous).

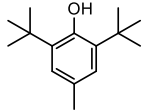
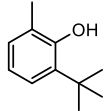
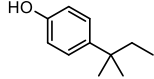
Compound group	Chemical structure and molecular formula	GHS pictograms	Sample codes (% of total peak area)	Potential Health Risks
2,6-bis (1,1-dimethylethyl)-4-methyl-phenol	 $C_{15}H_{24}O$	 Environmental Hazard	P01 (6.43%) P02 (4.87%) P03 (8.93%) P04 (4.78%) P05 (7.34%) P06 (5.44%) P07 (0.82%) P09 (2.60%) P10 (8.03%)	Low acute oral toxicity; skin/eye irritant; harmful if swallowed
Phenol, 2-(1,1-dimethylethyl)-6-methyl-	 $C_{11}H_{16}O$	 Corrosive Acute Toxic	P01 (1.50%) P02 (1.64%) P03 (3.00%) P04 (0.94%) P05 (2.12%) P06 (0.23%) P07 (0.61%) P08 (0.09%) P09 (0.51%) P10 (2.19 %)	Low general toxicity; corrosive/irritant (skin, eyes, respiratory); aquatic toxicity
Phenol, 4-(1,1-dimethylpropyl)-	 $C_{11}H_{16}O$	 Corrosive Irritant Environmental Hazard	P02 (0.22%) P04 (0.23%) P05 (0.31%) P06 (0.82%) P07 (1.20%) P08 (0.67%) P09 (0.12%) P10 (0.10%)	Low acute oral/dermal toxicity; causes severe skin burns and eye damage; toxic if inhaled

Table 2 Summary of volatile organic compound (VOC) groups detected in natural rubber latex pillow samples, including molecular structures, GHS hazard classifications, sample occurrence with relative abundance (% of total peak area), and associated potential health risks (Continuous).

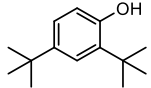
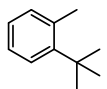
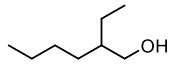
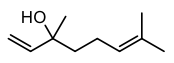
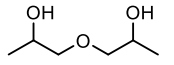
Compound group	Chemical structure and molecular formula	GHS pictograms	Sample codes (% of total peak area)	Potential Health Risks
Phenol, 2,4-bis(1,1-dimethylethyl)-	 <chem>C14H22O</chem>	 Irritant	P06 (0.10%) P07 (0.23%) P10 (0.29%)	Toxic natural secondary metabolite; also used as antioxidant
2-tert-Butyltoluene	 <chem>C11H16</chem>	 Flammable Irritant Environmental Hazard	P02 (0.40%) P03 (1.06%)	Harmful; skin/eye/respiratory irritant; harmful if swallowed or inhaled
7. Alcohols				
1-Hexanol, 2-ethyl-	 <chem>C8H18O</chem>	 Irritant	P01 (1.61 %) P02 (1.21%) P03 (1.99%) P04 (1.15%) P05 (1.74%) P06 (1.55%) P07 (1.58%) P08 (1.53%) P09 (1.95%) P10 (1.30%)	Low acute oral/dermal toxicity; moderate inhalation toxicity
Linalool	 <chem>C10H18O</chem>	 Irritant	P04 (0.92%)	Skin irritant; potential sensitisation upon oxidation
2-Propanol, 1,1'-oxybis-	 <chem>C6H14O3</chem>	 Irritant	P04 (1.01%)	Low toxicity; used in cosmetics/fragrances/solvent; mild skin/eye irritant

Table 2 Summary of volatile organic compound (VOC) groups detected in natural rubber latex pillow samples, including molecular structures, GHS hazard classifications, sample occurrence with relative abundance (% of total peak area), and associated potential health risks (Continuous).

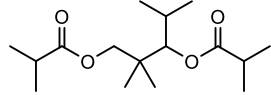
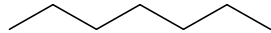
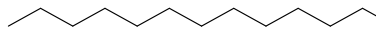
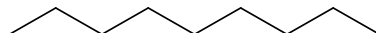
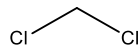
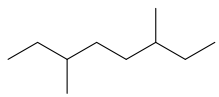
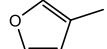
Compound group	Chemical structure and molecular formula	GHS pictograms	Sample codes (% of total peak area)	Potential Health Risks
2,2,4-Trimethyl-1,3-pentanediol diisobutyrate	 $C_{16}H_{30}O_4$	 Health Hazard	P08 (0.75%)	Low acute toxicity; not classified as acutely toxic
8. Alkanes				
Heptane	 C_7H_{16}	 Flammable Irritant Health Hazard Environmental Hazard	P03 (0.39%)	Low overall toxicity; acute/chronic exposure may cause CNS depression, mucous membrane irritation, neurobehavioral effects
Tetradecane	 $C_{14}H_{30}$	 Health Hazard	P04 (2.17%)	Low toxicity; skin/eye irritant; may be fatal if swallowed and aspirated
Decane	 $C_{10}H_{22}$	 Flammable Health Hazard	P05 (0.46%) P10 (0.91%)	Low toxicity; high levels may cause irritation, CNS depression, narcotic effects; harmful if aspirated
Methane, dichloro-	 CH_2Cl_2	 Health Hazard	P07 (0.57%)	Eye irritant; respiratory tract irritation; high levels may cause arrhythmia or cardiac arrest
Octane, 3,6-dimethyl-	 $C_{10}H_{22}$	 Flammable	P09 (0.08%)	Toxic; skin/eye irritant; may cause anaesthetic effects (drowsiness, dizziness)
9. Cyclic alkenes				
Furan, 3-methyl-	 C_5H_6O	 Acute Toxic Irritant	P01 (0.22%) P05 (0.35%)	Similar toxicity to furan (IARC: possibly carcinogenic to humans)

Table 2 Summary of volatile organic compound (VOC) groups detected in natural rubber latex pillow samples, including molecular structures, GHS hazard classifications, sample occurrence with relative abundance (% of total peak area), and associated potential health risks (Continuous).

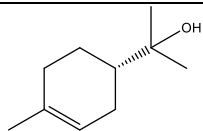
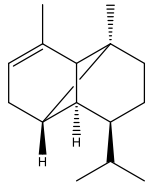
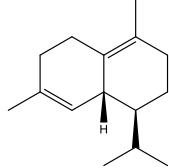
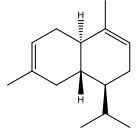
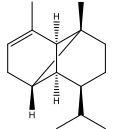
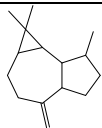
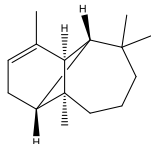
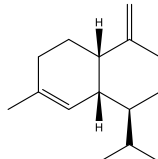
Compound group	Chemical structure and molecular formula	GHS pictograms	Sample codes (% of total peak area)	Potential Health Risks
3-Cyclohexene-1-methanol, .alpha.,.alpha.,4-trimethyl-, (S)-	 $C_{10}H_{18}O$	 Irritant	P02 (0.39%)	Causes skin irritation (GHS Category 2) and eye irritation (GHS Category 2)
.alfa.-Copaene	 $C_{15}H_{24}$	 Irritant	P02 (0.93%) P04 (0.36%) P05 (1.68%) P07 (0.81%) P10 (1.30%)	Mixed antioxidant/cytotoxic profile; inhibits cell proliferation at high concentrations
.delta.-Cadinene	 $C_{15}H_{24}$	 Irritant	P01 (0.34%) P03 (0.26%) P04 (0.39%) P05 (0.51%) P07 (0.33%) P09 (0.31%) P10 (0.54%)	Low toxicity; some derivatives cause liver toxicity; skin/eye irritant; potential anticancer, antimicrobial, insecticidal
.beta.-Cadinene	 $C_{15}H_{24}$	Not classified under GHS	P02 (0.63%)	Irritant; allergy risk; hepatotoxic at high doses; antimicrobial potential
Copaene	 $C_{15}H_{24}$	 Flammable	P03 (0.56%)	Potential cytotoxicity (high concentrations)

Table 2 Summary of volatile organic compound (VOC) groups detected in natural rubber latex pillow samples, including molecular structures, GHS hazard classifications, sample occurrence with relative abundance (% of total peak area), and associated potential health risks (Continuous).

Compound group	Chemical structure and molecular formula	GHS pictograms	Sample codes (% of total peak area)	Potential Health Risks
Aromadendrene	 $C_{15}H_{24}$	 Irritant Health Hazard	P08 (0.83%)	Generally safe at typical levels; concentrated forms may be irritant/toxic
Tricyclo[5.4.0.0(2,8)]undec-9-ene, 2,6,6,9-tetramethyl-, (1R,2S,7R,8R)-	 $C_{15}H_{24}$	Not classified under GHS	P08 (0.83%)	Possible skin/eye irritation; avoid contact
gamma.-Muurolene	 $C_{15}H_{24}$	Not classified under GHS	P10 (0.15%)	Potential risks remain unclear; further toxicological studies required.

and δ -cadinene were also detected. α -Copaene has both antioxidant and cytotoxic effects, potentially inhibiting cell proliferation at high concentrations. δ -cadinene is of low acute toxicity, though some derivatives are hepatotoxic; it is also a mild irritant with potential anticancer, antimicrobial, and insecticidal properties.

Overall, the coexistence of diverse VOC groups including nitrogen-, sulfur-, oxygen-, and hydrocarbon-based compounds indicated a chemically complex environment within natural rubber pillow products. Such mixtures may present additive or synergistic toxicological effects, underscoring the need for

comprehensive hazard assessments, particularly for products intended for prolonged human contact.

Building upon the compositional insights presented in Table 2, the frequency distribution of VOC occurrences across samples (Figure 2) further illustrates the chemical profile of natural rubber latex pillows. By integrating both concentration and occurrence data, it becomes evident that sulfur-containing compounds, phenolic derivatives, and alcohols are not only dominant in abundance but also highly prevalent across products, making them key chemical markers for VOC characterisation in these materials.

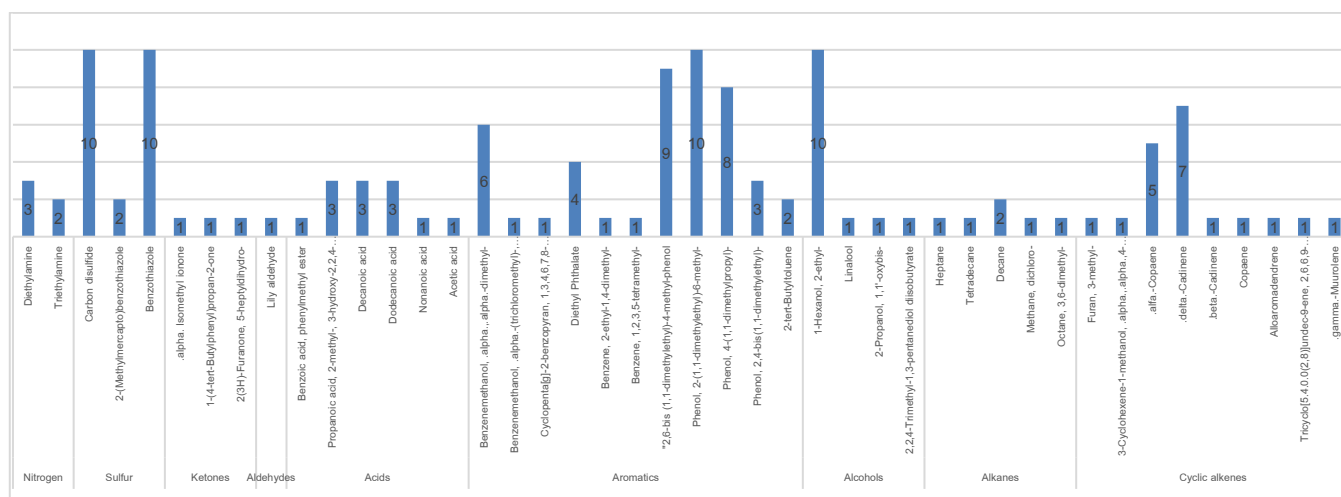


Figure 2 Distribution of volatile organic compounds (VOCs) detected in natural rubber latex pillow samples, classified by chemical groups.

The y-axis represents the number of samples in which each compound was detected, while the x-axis lists individual compounds grouped under their respective chemical classes.

From a health perspective, inhalation during sleep is likely to be the most relevant exposure pathway, since pillows are used for prolonged periods in close proximity to the breathing zone. Temperature and duration of use may also influence VOC emissions through enhanced volatilisation, off-gassing, and material ageing or degradation. However, these factors were not specifically evaluated in the present study and should be investigated in future work.

The present findings are also relevant in the context of product safety and regulatory assessment. Frameworks such as the EU Ecolabel criteria for bed mattresses and latex foam, together with ISO 16000-based emission testing approaches, provide useful benchmarks for future studies on VOC emissions from bedding materials. Under the EU Ecolabel criteria for latex foam, total VOC emissions are limited to 0.5 mg/m³, and carbon disulfide is specifically limited to 0.02 mg/m³ under standardised chamber-based testing conditions (European Commission, 2014). Since the present work was designed as a qualitative VOC profiling study using HS-SPME–GC/MS, the reported VOC data should be interpreted as preliminary qualitative to semi-quantitative information rather than chamber-based quantitative emission concentrations.

In addition to compound identification, the occurrence frequency of VOCs across the ten samples is illustrated in Figure 2, highlighting the most recurrent VOC markers and inter-sample variability. Sulfur-containing compounds, phenolic derivatives, and alcohols were among the most prevalent groups detected across the analysed products. This distribution pattern also helps distinguish compounds that were consistently detected from those that appeared only in selected samples, suggesting differences in raw materials, additives, or manufacturing conditions.

4. Conclusion

Multiple volatile organic compounds (VOCs) were detected in natural rubber pillow samples, including sulfur-containing compounds, phthalates, amines, alcohols, and aromatic antioxidants. Notably, substances such as carbon disulfide, diethyl phthalate, and butylated hydroxytoluene (BHT) are associated with potential health risks, including neurotoxicity, endocrine disruption, and respiratory irritation. In addition, naturally occurring terpenes may undergo indoor chemical reactions, leading to the formation of secondary pollutants.

Given that latex pillows are used in proximity to the human respiratory zone for extended periods during sleep, these VOC

emissions may contribute to continuous indoor exposure, particularly in poorly ventilated environments. The co-occurrence of multiple VOCs highlights the importance of comprehensive safety evaluations for latex-based consumer products intended for prolonged human contact.

From a manufacturing perspective, the findings suggest that VOC emissions could be reduced through process optimization, such as improving washing and post-curing steps to remove residual chemicals, selecting low-emission additives (e.g., alternative antioxidants and plasticizers), and optimizing vulcanization conditions to minimize sulfur-related byproducts. The adoption of eco-design principles and compliance with VOC emission standards, such as eco-label criteria, may further enhance product safety and environmental performance. This study provides essential baseline data for VOC profiles in commercially available natural latex pillows, which can be used to inform manufacturers, consumers, and policymakers.

This study provides essential baseline data on VOC profiles in commercially available natural latex pillows, which can support manufacturers, regulators, and consumers in decision-making. However, the study was limited to semi-quantitative analysis using a single sampling technique. Future research should focus on quantitative emission measurements, long-term exposure assessment under real indoor conditions, and the evaluation of alternative raw materials or green manufacturing technologies to reduce VOC emissions.

5. Acknowledgments

The authors gratefully acknowledge the Office of Scientific Instrument and Testing, Prince of Songkla University, for providing laboratory facilities and technical support. Appreciation was also extended to the Natural Rubber Innovation Research Institute, Prince of Songkla University, for supplying the rubber pillow samples used in this study.

6. References

Agatonovic-Kustrin, S., Gegechkori, V., Kobakhidze, T. and Morton, D. 2023. Solid-phase microextraction techniques and application in food and horticultural crops. **Molecules** 28(19): 1-14.

Capíková, A., Tesařová, D., Hlavaty, J., Ekielski, A. and Mishra, P.K. 2019. Estimation of volatile organic compounds (VOCs) and human health risk assessment of simulated indoor environment consisting of upholstered furniture made of commercially available foams. **Advances in Polymer Technology** 2019(1): 1-10.

Caroprese, A., Gabbanini, S., Beltramini, C., Lucchi, E. and Valgimigli, L. 2009. HS-SPME-GC-MS analysis of body odor to test the efficacy of foot deodorant formulations. **Skin Research and Technology** 15(4): 503-510.

Chen, X., Zhang, B., Wang, D., Chen, L., Du, Z. and Wu, Y. 2022. Traceability of VOCs in tire inner liner by chromatography-mass spectrometry. **Environmental Science and Pollution Research** 29(7): 9685-9692.

European Commission. 2014. **Commission Decision 2014/391/EU of 23 June 2014 establishing the ecological criteria for the award of the EU Ecolabel for bed mattresses**. Official Journal of the European Union. Available Source: <https://www.eur-lex.europa.eu/legalcontent/EN/TXT/?uri=CELEX:02014D0391-20220718>, August 24, 2025.

European Commission. 2014. **EU Ecolabel bed mattresses: User manual**. Official Journal of the European Union. Available Source: <https://api.eublomsten.dk/api/docs/CriteriaDocumentFiles/1008>, March 20, 2026.

Idris, N.F., Le-Minh, N., Hayes, J.E. and Stuetz, R.M. 2022. Performance of wet scrubbers to remove VOCs from rubber emissions. **Journal of Environmental Management** 305: 1-13.

Jeleń, H.H. 2006. Solid-phase microextraction in the analysis of food taints and off-flavors. **Journal of chromatographic science** 44(7): 399-415.

Kamarulzaman, N.H., Idris, N.F. and Nor, Z.M. 2012. Characteristics of odour concentration from rubber processing factories via olfactometry technique. **Chemical Engineering Transactions** 30: 121-126.

Kamarulzaman, N.H., Le-Minh, N. and Stuetz, R.M. 2019. Identification of VOCs from natural rubber by different headspace techniques coupled using GC-MS. **Talanta** 191: 535-544.

Khalid, M. and Abdollahi, M. 2021. Environmental distribution of personal care products and their effects on human health. **Iranian journal of pharmaceutical research** 20(1): 216-253.

Liu, J.-Q., Han, H.-L., Zhang, Q., Ding, S.-N., Wang, Z.-J. and Lv, Q. 2025. Nontargeted analysis of potential chemicals in latex pillows using gas chromatography–Orbitrap high resolution mass spectrometry. **Microchemical Journal** 218: 115275.

Nornanysya, F.K., Aminah, S.M. and Samsuri, A. 2013. Odourless natural rubber (ONR). **Journal of Rubber Research** 16(1): 15-35.

Oshima, N., Tahara, M., Sakai, S. and Ikarashi, Y. 2021. Analysis of volatile organic compounds emitted from bedding products. **BPB Reports** 4(6): 182-192.

Pajarito, B.B., Castañeda, K.C., Jeresano, S.D.M. and Repoquit, D.A.N. 2018. Reduction of offensive odor from natural rubber using zinc-modified bentonite. **Advances in Materials Science and Engineering** 2018(1): 1-8.

Ramírez, N., Marcé, R.M. and Borrull, F. 2010. Development of a thermal desorption-gas chromatography–mass spectrometry method for determining personal care products in air. **Journal of Chromatography A** 1217(26): 4430-4438.

- Ramli, R., Chai, A.B., Kamaruddin, S., Ho, J.H., Mohd. Rasdi, F.R. and De Focatiis, D.S.A. 2021. Development of latex foam pillows from deproteinized natural rubber latex. **Journal of Rubber Research** 24(4): 615-630.
- Sakdapipanich, J. and Insom, K. 2006. High-resolution gas chromatography-mass spectrometry - Characterization and mechanism to generate the obnoxious odor in natural rubber. **Kautschuk Gummi Kunststoffe rubberpoint** 59(7-8): 382-387.
- Shinoda, R., Takahashi, K., Ichikawa, S., Wakayama, M., Kobayashi, A., Miyagawa, S. and Uchimura, T. 2020. Using SPME-GC/REMPI-TOFMS to measure the volatile odor-active compounds in freshly cooked rice. **American Chemical Society Omega** 5(32): 20638-20642.
- Unites Stated. Environmental Protection Agency. 2023. **Volatile organic compounds' impact on indoor air quality**. Available Source: <https://www.epa.gov/indoor-air-quality-iaq/volatile-organic-compounds-impact-indoor-air-quality>, March 23, 2026.
- World Health Organization. 2010. **WHO guidelines for indoor air quality: Selected pollutants**. WHO Regional Office for Europe. Available Source: <https://www.who.int/publications/i/item/9789289002134>, March 23, 2026.