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Quantitative determination of 2-Phenoxyethanol in commercial wet wipes by a validated GC-MS method

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Abstract

Quantitative determination of 2-Phenoxyethanol in commercial wet wipes by a validated GC-MS method

Objective: The extensive use of wet wipes for personal hygiene, household cleaning, and food service applications results in frequent dermal exposure to chemical preservatives such as 2-phenoxyethanol (PhE). Although PhE is permitted for use within established regulatory limits, data on its occurrence and concentration levels in consumer products remain limited, and recent systematic data are scarce. This study aimed to quantify PhE levels in commercially available wet wipes across different usage categories using a validated gas chromatography–mass spectrometry (GC-MS) method.
Methods: Due to substantial differences in wipe dimensions among products, a standardized subsampling approach (2×2 cm) was applied to enable comparable quantification and to characterize variability in preservative content. A total of 30 wet wipe products representing six usage categories were analyzed. The method demonstrated a linear range of 5–30 µg/mL (R^2 = 0.99), with a limit of detection (LOD) of 1.49 µg/mL and a limit of quantification (LOQ) of 5 µg/mL.
Results: In the study, PhE was detected in 17 of the 30 samples (56%), with concentrations ranging from 5.00 to 23.80 µg/mL in 2×2 cm wipe extracts and calculated full-size wipe concentrations ranging from 916.3 to 6246.4 µg/mL. The highest PhE levels were observed in products intended for sensitive use, such as baby wipes and feminine hygiene wipes, as well as in sachet wipes from small-scale food service venues.
Conclusion: The findings indicate considerable variability in PhE content among commercially available wet wipes, underscoring the importance of systematic analytical monitoring of preservative levels in frequently used skin-contact products.
Keywords: Biocidal product, cleaning products, hygiene, health, GC-MS

Öz

Ticari ıslak mendillerde 2-fenoksietanolün doğrulanmış GC-MS yöntemi ile kantitatif tayini

Amaç: Islak mendillerin kişisel hijyen, ev içi temizlik ve gıda hizmeti uygulamalarında yaygın olarak kullanılması, 2-fenoksietanol (PhE) gibi kimyasal koruyucularla cildin sık sık maruz kalmasına neden olmaktadır. PhE, mevcut düzenleyici sınırlar dâhilinde kullanımına izin verilen bir madde olmakla birlikte, tüketici ürünlerindeki varlığına ve konsantrasyon düzeylerine ilişkin veriler sınırlıdır ve güncel, sistematik çalışmalar az sayıdadır. Bu çalışmanın amacı, valide edilmiş bir gaz kromatografisi–kütle spektrometrisi (GC-MS) yöntemi kullanarak farklı kullanım kategorilerindeki ticari ıslak mendillerdeki PhE düzeylerini belirlemektir.
Yöntem: Ürünler arasında mendil boyutlarında önemli farklılıklar bulunması nedeniyle, karşılaştırılabilir kantifikasyon sağlamak amacıyla standartlaştırılmış bir alt örnekleme yaklaşımı (2 × 2 cm) uygulanmıştır ve ürünler arasındaki koruyucu madde içeriği değişkenliği değerlendirilmiştir. Altı farklı kullanım kategorisini temsil eden toplam 30 ıslak mendil ürünü analiz edilmiştir. Yöntem, 5–30 µg/mL doğrusal çalışma aralığı (R^2 = 0,99), 1,49 µg/mL tespit limiti (LOD) ve 5 µg/mL tayin limiti (LOQ) göstermiştir.
Bulgular: PhE, örneklerin 17'sinde (%56) tespit edilmiş olup, 2 × 2 cm'lik mendil ekstraktlarında konsantrasyonlar 5,00–23,80 µg/mL aralığında; tam boy mendil için hesaplanan değerler ise 916,3–6246,4 µg/mL aralığında bulunmuştur. En yüksek PhE seviyeleri, bebek mendilleri, kadın hijyen mendilleri ve küçük ölçekli yiyecek hizmeti veren işletmelerden temin edilen ıslak mendillerde gözlenmiştir.
Sonuç: Elde edilen veriler, ticari ıslak mendiller arasında PhE içeriği bakımından belirgin bir değişkenlik olduğunu ortaya koymakta ve sık kullanılan cilt temaslı ürünlerde koruyucu madde düzeylerinin sistematik olarak analitik olarak izlenmesinin önemini vurgulamaktadır.
Anahtar Kelimeler: Biyosidal ürün, temizlik ürünleri, hijyen, sağlık, GC-MS

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1. INTRODUCTION

Wet wipes, categorized as biocidal products, are widely used for hygiene across a broad spectrum of settings, from households to institutional environments. The global market share of these products has expanded rapidly, particularly under the influence of the COVID-19 pandemic (1). However, their widespread and largely uncontrolled consumption has raised concerns not only regarding potential human health effects but also environmental impacts. Wet wipes contribute significantly to environmental pollution due to their predominantly synthetic and non-biodegradable structure. Accumulation in wastewater systems and aquatic environments has rendered them one of the major contributors to microplastic pollution in marine ecosystems (1-5). This growing environmental burden reflects the scale of wet wipe usage and underscores the need for closer scrutiny of these products beyond their immediate hygienic function.

Wet wipes, sold commercially in single-use or multipacks, are designed to eliminate or control microbial contamination. Yet, their moist structure also promotes microbial growth if not properly preserved (6,7). To ensure microbiological stability, manufacturers commonly use preservatives such as alkyl parabens, benzoic acid, and 2-phenoxyethanol (PhE) (8-13). However, repeated and prolonged exposure to these chemicals may lead to dermatological effects, such as irritation, allergic contact dermatitis, or striae, particularly in sensitive populations, including infants and women. Various studies have investigated the presence and exposure risks of these compounds (7,14,15). PhE is extensively used not only in wet wipes but also in a wide range of consumer and household products, including cosmetic formulations, dishwashing detergents, and topical pharmaceutical gels (7,16-19). Notably, the expanding market for intimate hygiene products and eye make-up removers suggests that additional routes of exposure, particularly through mucosal membranes and periocular areas, are becoming increasingly relevant. The frequent use of these products in baby care, as well as on delicate skin regions, underscores the need for further toxicological evaluation regarding repeated low-dose exposure in vulnerable populations.

PhE, a member of the glycol ether family, is characterized by its high miscibility with both aqueous and organic solvents. This physicochemical property enables its widespread use in a variety of industrial and consumer products, including wet wipes, cosmetic formulations, and pharmaceutical preparations (20,21). Under routine use conditions, dermal contact is considered the primary route of exposure to PhE; however, exposure levels may vary depending on product formulation, frequency of use, and duration of skin contact. Most toxicological assessments to date have primarily focused on dermal exposure scenarios (22-25). Nevertheless, PhE has been reported to undergo degradation under certain conditions, such as elevated temperatures or low pH, potentially leading to the formation of byproducts that may affect product stability or skin tolerability (6,10,11,20). Clinical observations have associated repeated dermal exposure to PhE-containing products with adverse cutaneous reactions, including erythema, pruritus, edema, and contact urticaria, particularly in sensitive individuals (12,26,27). Additionally, prenatal exposure has been correlated with reduced neurocognitive performance in children (21). Another notable study emphasised the need for adequate ventilation during the use of products containing PhE; it was reported that exposure to PhE under inadequate ventilation conditions can lead to symptoms such as weakness, fatigue, skin and eye irritation (28). These findings highlight the importance of accurately and reliably characterizing preservative content in products intended for direct and frequent skin contact.

Regulatory bodies, including the Scientific Committee on Consumer Safety (SCCS), have established health-based guidance values and maximum allowable concentration limits for phenoxyethanol to ensure consumer safety under defined use conditions (29-31). In the European Union, PhE is permitted as a preservative in cosmetic products at concentrations up to 1% according to the Cosmetics Regulation (EC No. 1223/2009). These regulatory limits are derived from standardized exposure scenarios and are intended to provide a general margin of safety for consumers (7,30,31). However, in practice, wet wipe products exhibit substantial variability in formulation, size, liquid content, and intended use, which may influence the total preservative load delivered per application and the frequency of dermal exposure. Consequently, analytical data describing the actual PhE content of commercially available wet wipes remain essential for contextualizing regulatory limits and understanding product-to-product variability under real-world usage conditions.

Analytical methods have been developed to determine the main toxic groups contained in wet wipes, or general screening methods have been used to investigate the suitability of the components and amounts stated on the label (17,32,33). On the other hand, the detection of organic compounds in wet wipes requires a specific sample preparation technique. In this process, one of the most critical points for the detection of target analytes is the amount of liquid retained by each fibrous product and the extraction efficiency of toxic components in the obtained liquid content. In this context, gas chromatography-mass spectrometry (GC-MS) remains one of the most commonly used and reliable techniques for identifying volatile organic compounds in consumer products

(34). However, method validation and standardization are necessary to improve the precision and reproducibility of such measurements.

Therefore, this study aimed to develop and validate a robust, sensitive, and reproducible GC-MS method for the quantification of PhE in commercially available wet wipes. Due to substantial differences in wipe dimensions among products, a standardized subsampling approach (2×2 cm) was applied to enable comparable quantification across different product types. This method was applied to a selected set of products spanning six distinct usage categories, and the resulting data were evaluated for analytical screening purposes to characterize variability in preservative content among products.

2. METHOD

2.1. Chemicals and reagents

Reference standard of PhE (5mg, ≥98% purity) was purchased from Sigma-Aldrich (Taufkirchen, Germany). Methanol (MeOH), ethyl acetate (EA), hexane, and a pH meter were purchased from Merck (Darmstadt, Germany). A Direct-Q UV 3 ultrapure water (UPW) system (18.2 MΩ cm) was acquired from Millipore (Molsheim, France). Evaporation under nitrogen flow during sample preparation was conducted with a HyperVap HV-300 from Gyrozen (Daejeon, Republic of Korea). Nitrogen gas used in the evaporation of liquid eluents and helium gas at >99.99% purity used in the analytical system was supplied by Okser (Türkiye).

2.2. Sample collection

In this study, a total of 30 commercially available wet wipe products were selected from the Turkish market between 2022 and 2023. The samples were categorized into six distinct usage groups to represent a range of skin-contact and multi-purpose cleaning applications, including both household and industrial contexts.

- **Category 1** included market-leading wet wipes commonly used for household cleaning.
- **Category 2** comprised products intended for diapering, including those used in baby care and for individuals who are bed-bound.
- **Category 3** consisted of single-use sachet wipes obtained from full-service or dine-in restaurants.
- **Category 4** included similar sachet wipes provided in small-scale or take-away street food venues.
- **Category 5** represented single-use wipes distributed by transport companies in ground and air transport services.
- **Category 6** involved wipes specifically marketed for feminine hygiene.

2.3. Sample preparation and optimization

A stock solution of PhE was prepared in MeOH at a concentration of 100 µg/mL, and a working solution of 10 µg/mL was obtained by dilution. Calibration standards were prepared at six concentration points (5, 10, 15, 20, 25, and 30 µg/mL) using both EA and a PhE-free wet wipe matrix spiked with known concentrations of PhE. The blank matrix was obtained by purifying commercial wipes through repeated solvent washing and incubation. The recovery rates for spiked samples were examined using the extraction results.

Given the considerable variability in size, weight, and moisture content across different commercially available wet wipe products, a standardized sampling protocol was established to ensure analytical consistency and inter-sample comparability. Accordingly, a standardized 2×2 cm subsampling strategy was adopted to account for the substantial variation in wipe dimensions and fluid content across commercial products. This approach provided a consistent analytical unit, improving reproducibility and enabling accurate estimation of the total preservative load per wipe.

Prior to extraction, a series of preliminary tests was conducted to characterize each sample's liquid retention capacity and native pH level. For this purpose, the standardized 2 × 2 cm subsamples were first weighed in their original (wet) state. They were then washed with 5 mL of MeOH to extract the loosely held aqueous phase and centrifuged at 3000 rpm for 3 minutes to separate the liquid fraction. The supernatant was carefully transferred into a calibrated flask by pipetting. Subsequently, the residual wipe material was incubated at 50°C until complete dryness was achieved, and reweighed to determine the dry mass. The difference between the wet and dry weights provided a reliable estimation of the volume of liquid retained per unit surface area. This metric was later used to extrapolate the total amount of PhE in full-size wipes and to normalize concentration data across differently composed products.

To extract PhE, 2×2 cm wipe samples were transferred into 15 mL glass tubes and mixed with 10 mL of UPW. The obtained lotion (oil/water emulsion) was mechanically homogenized for 10 minutes at room temperature using a shaker. Two organic solvents (EA and hexane) were evaluated for their suitability in LLE. EA was found to yield higher compatibility with GC-MS conditions and better recovery, and was thus selected for all subsequent procedures. Following

homogenization, the MeOH washing solution of each sample was extracted with 2 mL of EA, then centrifuged at 5000 rpm for 3 minutes. The supernatant was transferred into a vial and evaporated with nitrogen at 40ºC, and reconstituted in 1 mL of EA prior to GC-MS analysis.

2.4. Instrumental analysis

Experiments were conducted using an Agilent 7820A GC system with a 5977E MS detector from Agilent Technologies (Palo Alto, CA, USA). Separation was conducted using HP-5MS (% 5-phenyl methyl siloxane, 30 m x 0.25 mm x 0.25 µm) column from Agilent Technologies at a constant flow rate of helium (> 99.995%) of 1.0 mL/min. The oven temperature was programmed from 55ºC (2 min hold) to 250ºC (10ºC/min). Injection was carried out with an inlet temperature of 250°C and a split ratio of 10:1. The solvent delay was set to 2 min, and the runtime was 31.50 min. The SCAN mode (*m/z* 50-500) was used for detection to verify the analytes' retention times (RT). ChemStation Data Analysis software (version G1701FA) was used to evaluate all analyses that were conducted.

2.5. Method validation

Validation of a method involves all the steps required to demonstrate that it is reliable for the intended analytical purpose, particularly in the quantitative determination of a target compound in a complex matrix. In this study, the method was validated according to the Scientific Working Group for Forensic Toxicology (SWGTOX) guidelines (35) by evaluating selectivity, linearity, limit of detection (LOD), limit of quantification (LOQ), accuracy (recovery), and precision.

The selectivity was evaluated by analysis of six different PhE-free samples with and without spiking of PhE to demonstrate the absence of any interference at the RT of the analyte. Linearity was assessed using calibration curves prepared in both EA and PhE-free wet wipe matrices spiked with known concentrations of PhE at six points (5, 10, 15, 20, 25, and 30 µg/mL). Each level was analyzed in triplicate. The slopes of the matrix-matched and solvent-based calibration curves were compared using Student's t-test. Linearity was further evaluated using analysis of variance, and calibration curves with correlation coefficients (R^2) greater than 0.99 were considered acceptable. The LOD and LOQ values were calculated based on the signal-to-noise (S/N) ratio (LOD = 3 x S/N, LOQ = 10 x S/N). The accuracy of the method was tested at three different concentration points (10, 20, and 30 µg/mL) in 6 replicates. The accuracy was calculated as the % recovery of the calculated concentration relative to the nominal concentration of each quality control (QC) sample. The procedure used to prepare the calibration samples was also employed to prepare the QC samples. Furthermore, the evaluation criteria were set at 80-120% for recovery according to SWGTOX guidelines. The precision of the method was evaluated intra- and inter-day, with six replicates for each of the three concentration points (10, 20, and 30 µg/mL). Relative standard deviation (RSD %) was used as the precision metric, and RSD values below 20% were considered acceptable.

3. RESULTS

3.1. Method optimization

To determine the most appropriate extraction solvent, EA and hexane were systematically evaluated in terms of compatibility with downstream GC-MS analysis. EA demonstrated superior analytical performance by producing cleaner chromatograms, significantly reducing baseline noise, and yielding higher recovery rates of the target analyte, PhE. As such, EA was selected as the solvent of choice for all subsequent extraction steps. The optimized EA-based LLE method proved to be both efficient and analytically robust, offering strong recovery performance and a well-defined linear calibration range suitable for quantitative analysis.

Various oven temperature programs were tested with this column to improve chromatographic resolution, selectivity, and peak sharpness for PhE. The initial temperature program, which resulted in a total analysis time of 18.33 minutes, produced broad and partially overlapping peaks, especially toward the end of the chromatogram. This indicated insufficient separation and poor peak resolution under rapid temperature ramping conditions. To address these limitations, the oven temperature program was re-optimized to extend the run time to 31.50 minutes. The adjusted temperature gradient provided improved separation, reduced baseline noise, and produced a well-shaped, symmetrical, and highly selective PhE peak.

3.2. Method validation

The developed method demonstrated high selectivity for PhE in both methanol and wet wipe matrices, as shown in **Figure 1**. The RT for PhE was 9.86 ± 0.05 minutes, and no interfering peaks were observed at this retention window, confirming the method's selectivity. **Figure 2** shows the mass spectrum and molecular structure of PhE.

Linearity was assessed by comparing calibration curves prepared in both solvent-based and matrix-matched conditions. Student's t-test ($p > 0.05$) showed no statistically significant difference between the slopes, indicating a negligible matrix effect. Therefore, matrix-matched calibration was used in all subsequent quantification steps. The method exhibited good linearity over the 5–30 µg/mL concentration range, with an R^2 of 0.9937. The LOD and LOQ for PhE were calculated using the formulas provided in Section 2.5. Based on ten replicate measurements, the LOD and LOQ were determined to be 1.49 µg/mL and 5 µg/mL, respectively. Accuracy and precision were evaluated using

six replicates at three concentration levels: low (10 µg/mL), medium (20 µg/mL), and high (30 µg/mL). The mean recovery values were 101.25%, 103.09%, and 100.31%, respectively. The overall mean extraction recovery was calculated as 101.55%, which showed that this study has excellent accuracy. **Table 1** presents the intra-day and inter-day precision results. The intra-day RSD values varied from 0.68% to 1.25%, while the inter-day RSD values varied from 0.40% to 1.22%. All values were within the acceptable limit of ≤20% as recommended by SWGTOX, confirming the precision of the method. Following SWGTOX guidelines, all validation parameters, including selectivity, linearity, accuracy, and precision, were found to be within acceptable limits. These results confirm that the developed method is reliable for the detection and quantification of PhE in wet wipe matrices.

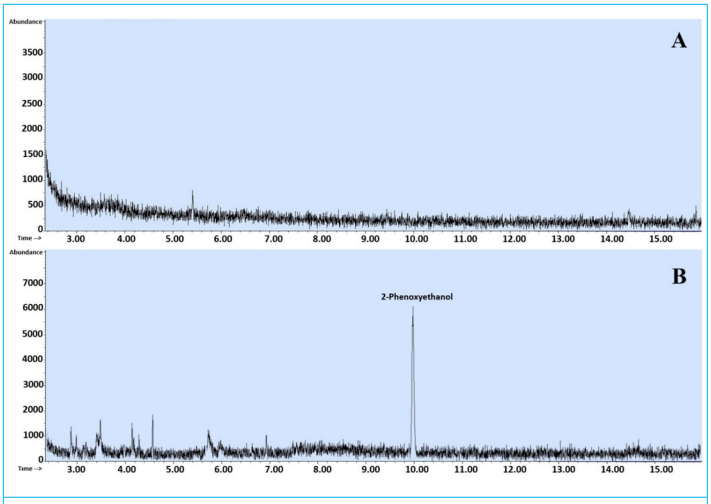

Figure 1. Zoomed GC chromatograms of blank (A) and PhE-spiked (B) wet wipe samples.

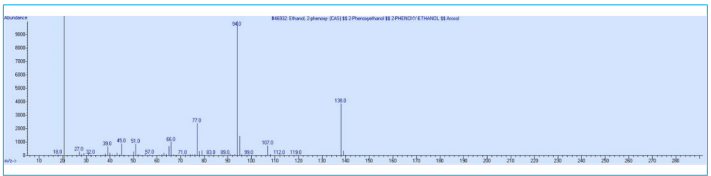

Figure 2. The mass spectrum of PhE

3.3. Analysis of the collected samples

The physical characteristics of the wet wipe samples were also evaluated. The average dimensions of the wet wipe samples were measured as 14 × 20 cm in their unstretched form. The pH values of the liquid content varied between 3.5 and 7.3 (**Table 2**). Notably, the majority of samples (70%, n = 21) fell within the range of 5.5–7.0, which aligns with the optimal pH of healthy human skin (33). However, four samples (13.3%) exhibited pH values below this range, while five samples (16.6%) exceeded 7.0.

Using the validated GC-MS method, all 30 collected samples were analyzed for PhE content. The results of both pH and PhE concentrations across six predefined product categories are summarized in **Table 2** and visualized in **Figure 3.** In 2×2 cm wipe subsections, PhE concentrations ranged from 5.0 µg/mL to 23.8 µg/mL. Thirteen samples (43.3%) were found to be below the LOQ, indicating either the absence or negligible presence of PhE in those products.

Table 1. Precision parameter results of PhE

Concentration Levels	Intra-day (n=6)			Inter-day (n=6)		
	Mean (µg/mL)	±SD	RSD %	Mean (µg/mL)	±SD	RSD %
10 µg/mL	10.12	0.06	0.68	10.11	0.05	0.56
20 µg/mL	20.61	0.25	1.25	20.56	0.25	1.22
30 µg/mL	30.09	0.28	0.95	30.16	0.12	0.40

RSD: relative standard deviation, SD: standard deviation.

The amount of PhE detected in 2×2 cm wipe subsamples ranged between 5.00 µg/mL and 23.80 µg/mL, while PhE was not detected in 13 out of 30 samples (43.3%) (Table II). Based on back-calculations incorporating the original dimensions and liquid retention capacity of each product, the estimated full-size PhE content ranged from 916.3 µg/mL to 6246.4 µg/mL.

To estimate real-world exposure, back-calculations were performed using each product's total surface area and fluid retention. Based on these extrapolations, total PhE concentrations per full-size wipe ranged from 916.3 µg/mL to 6246.4 µg/mL (**Figure 4**). Each category included five samples. Notably, Category 4 (sachet wipes from small-scale or street food venues) and Category 6 (feminine hygiene wipes) showed high detection frequencies, with PhE present in 4 out of 5 samples (80%) in both categories. This finding underscores the need for stricter regulation of preservative content in products targeting sensitive or less-controlled environments. Among all categories, the highest extrapolated concentrations were observed in general-purpose (up to 6246.4 µg/mL) and restaurant-sector wipes (up to 4973.7 µg/mL). Feminine hygiene wipes exhibited consistently elevated levels, ranging from 1950.0 µg/mL to 4175.4 µg/mL. While general-purpose, restaurant, and transportation products also contained quantifiable amounts of PhE, concentrations varied considerably between samples.

These results reveal substantial variability in both pH and preservative content across commercially available wet wipes. Such inconsistency may have implications for dermal safety, particularly for individuals with sensitive skin or those using these products frequently and over large surface areas. Although none of the samples exceeded the EU regulatory limit for PhE (%1 or 10.000 µg/mL; Regulation EC No 1223/2009), several approached critical levels, especially those designed for intimate or repeated use.

Table 2. pH and PhE concentration results in categorized wet wipe samples

Categories	Sample No	pH of liquid	PhE concentration in 2x2 cm sample (µg/mL)	Estimated PhE concentration in one wet wipe (µg/mL)
1	1	6.8	<LOQ	NC
	2	7.2	<LOQ	NC
	3	6.5	17.49	6246.4
	4	6.2	6.42	1211.3
	5	7.0	<LOQ	NC
2	6	7.2	5.04	916.3
	7	7.1	5.00	1041.6
	8	6.6	<LOQ	NC
	9	5.8	<LOQ	NC
	10	6.4	21.57	3719.0
3	11	5.9	<LOQ	NC
	12	7.1	<LOQ	NC
	13	6.2	<LOQ	NC
	14	7.0	8.94	1824.5
	15	6.7	<LOQ	NC
4	16	7.3	7.89	2391.0
	17	4.8	6.88	1859.5
	18	3.5	9.45	4973.7
	19	4.8	<LOQ	NC
	20	4.2	7.52	2211.8
5	21	5.5	12.56	2791.1
	22	6.2	8.57	1785.4
	23	6.8	<LOQ	NC
	24	6.9	<LOQ	NC
	25	5.9	5.60	1120.0
6	26	6.8	11.70	1950.0
	27	6.3	23.80	4175.4
	28	6.5	16.37	3410.4
	29	6.8	<LOQ	NC
	30	6.9	14.14	2356.7

PhE: 2-phenoxyethanol, <LOQ: The result is below the limit of quantification. "NC: could not calculated

4. DISCUSSION

Wet wipes are complex consumer products that exhibit substantial variability in formulation, size, liquid content, and intended use. This heterogeneity makes the accurate quantification and comparison of preservative content across products analytically challenging. The reliable determination of target analytes in complex consumer product matrices is highly dependent on effective sample preparation. Wet wipes typically contain a heterogeneous mixture of water, alcohols, binders, softeners, surfactants, pH buffering agents, emulsifiers, silicone oils, musks, and other additives (36), all of which can interfere with chromatographic analysis. For this reason, the pre-treatment stage plays a critical role in ensuring analytical selectivity and reproducibility. Given the complex and emulsified nature of wet wipe matrices, LLE represents a suitable sample preparation approach, as it enables efficient separation of target analytes while minimizing co-extraction of interfering substances. In this study, EA–based LLE provided favorable chromatographic performance and consistent analyte recovery, supporting its applicability for PhE determination in wet wipe formulations. In parallel, optimization of GC oven temperature conditions was essential to achieve adequate peak resolution and symmetry. Extension of the temperature program improved chromatographic separation and reduced baseline interference, facilitating reliable detection and quantification of PhE.

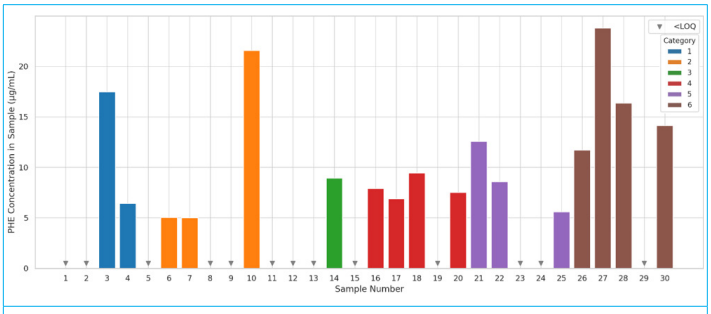

Figure 3. Detected PhE concentrations in 2x2 cm wet wipe samples (n = 30); LOQ-marked values indicate samples below quantification limit.

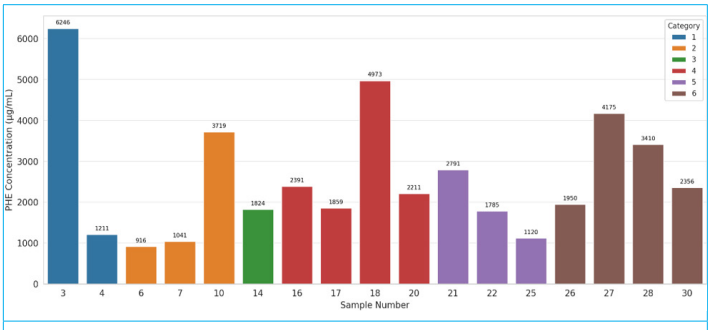

Figure 4. Estimated PhE Concentration (µg/mL) in 17 Wet Wipe Samples

Previous studies have employed alternative extraction strategies for wet wipe analysis, including Soxhlet extraction and pressurized liquid extraction (PLE) (12,37). Although these techniques can achieve broad analyte recovery, they are often associated with high solvent consumption, extended processing times, and labor-intensive workflows, which limit their suitability for routine screening. In contrast, the present study focused on a streamlined and solvent-efficient LLE protocol designed to operate with standardized small sample units (2×2 cm), allowing consistent quantification across products with highly variable dimensions and liquid content. The optimized GC-MS method was implemented using an HP-5MS capillary column, which is widely applied in forensic and

environmental analyses of semi-volatile organic compounds (38). The optimized temperature program demonstrated sufficient selectivity and resolution to support both the quantification of PhE and the potential screening of other polar toxic compounds present in wet wipe matrices.

Beyond methodological considerations, the analytical findings should be interpreted in the context of the complex composition and widespread use of commercial wet wipes (27,36). Despite their extensive daily use, toxicological studies specifically addressing individual preservative compounds such as PhE in wet wipes remain limited. Existing investigations have primarily focused on broad screening of chemical groups or label compliance rather than quantitative assessment supported by full analytical validation (17,32,33).

Numerous studies have utilized GC-MS and related analytical techniques to determine PhE levels in various consumer products, including dishwashing detergents, cosmetic formulations, and topical pharmaceutical gels. In contrast, studies specifically focusing on the quantitative determination of PhE in wet wipe matrices remain limited. To date, only three relevant studies have systematically evaluated PhE in commercial wet wipes (17,37,39). In 2019, Kenfack et al. reported tentative PhE detection in 3 out of 7 baby wipe samples using UV spectrophotometry; however, the findings could not be confirmed analytically due to method limitations (39). In a more robust effort, Lee et al. (2014) employed static headspace GC-MS with a DB-WAX capillary column to quantify 14 alkoxyalcohol compounds, including PhE, across three product categories (baby, general-purpose, and cleaning wipes). Their method demonstrated a LOQ of 1 µg/mL and a linear working range of 0.4–40 µg/mL. PhE concentrations in their study ranged from 1.18 to 7991.64 µg/mL, with the highest levels found in products intended for general or infant use (17). Celeiro et al. (2015) analyzed twenty baby wipe samples using PLE combined with GC-MS and an SLB™-5MS capillary column. Their method, with a working range of 5–1000 ng/mL, revealed PhE concentrations between 2.68 and 8368 µg/g across all samples. Despite detecting elevated levels, their study did not report recovery values, limiting its utility for quantitative risk assessment (37).

In this context, the present study complements existing literature by providing analytically validated PhE data across a broader range of usage categories. Using a liquid–liquid extraction approach coupled with GC-MS, the study establishes a consistent analytical framework for the quantification of PhE in commercial wet wipe matrices. Unlike prior investigations, the HP-5MS capillary column, commonly employed in forensic and environmental analyses, was applied for PhE determination in wet wipes. Under the optimized conditions, this column provided adequate chromatographic selectivity, well-defined peak shapes, and low baseline interference. When compared with previous studies, the analytical performance of the proposed method, particularly in terms of recovery and precision values, was comparable, despite operating within a narrower linear working range (5–30 µg/mL). The consistent performance characteristics observed indicate that the method is suitable for routine analytical applications aimed at monitoring preservative content in wet wipe formulations.

The analysis of collected samples also revealed notable variability in pH values across product categories. All samples with pH values below the skin-compatible range were classified within category 4, consisting of wipes obtained from low-quality food service establishments. Deviations from physiological skin pH may influence barrier function and irritation potential, as both acidic and alkaline conditions have been associated with increased skin permeability and sensitivity (32). These observations highlight the importance of considering formulation variability alongside preservative content when evaluating wet wipe safety.

Although the acute toxicological profile of PhE has been extensively characterized, data regarding chronic dermal exposure under real-world usage conditions remain limited. In addition, factors such as storage temperature, shelf life, and formulation pH may influence PhE stability and promote the formation of degradation products with uncertain toxicological relevance. The standardized subsampling approach applied in this study enables more consistent estimation of total preservative load across products of differing size and composition, thereby improving the analytical relevance of exposure-related assessments.

As Paracelsus stated, "All substances are poisons; the dose alone makes it so that a thing is not a poison". This principle remains particularly applicable to biocidal ingredients in frequently used consumer products. While the present study does not perform quantitative risk modeling, it provides analytically robust data that may inform future exposure assessments and regulatory evaluations. Further research should focus on expanded product sampling, investigation of degradation products, and integration of toxicokinetic considerations to better characterize long-term dermal exposure associated with wet wipe use.

5. CONCLUSION

Despite their widespread and routine use, wet wipes remain under-investigated in terms of preservative content and associated health risks, particularly for products intended for sensitive skin and frequent application. This study provides the first analytically validated data on PhE concentrations in commercially available wet wipes marketed in Türkiye, using a GC-MS method. PhE was detected in 56% of the

samples, with notably high levels in products intended for sensitive use, such as baby wipes, feminine hygiene products, and low-quality restaurant wipes. Considerable variability was observed across product categories, including among those specifically marketed for sensitive skin. Although all measured concentrations were below current regulatory limits, the observed variability underscores the importance of systematic analytical monitoring of preservative content in widely used skin-contact products. The validated analytical method demonstrated high selectivity and precision, making it suitable for ongoing monitoring of preservative content in wet wipe formulations. Future studies should expand the sample diversity, include additional preservatives, and explore usage-based exposure scenarios to further inform safety evaluation efforts.

Limitations

This study has several limitations that should be considered when interpreting the findings. First, the number of analyzed products was limited to 30 commercially available wet wipes obtained from the Turkish market. Although the sampling was intentionally structured to cover six distinct real-world usage categories and commonly encountered products, the dataset is not designed for statistically representative national prevalence estimates or for high-power inferential comparisons between categories. Therefore, the results should be interpreted as descriptive screening data that characterize product-to-product variability within the sampled categories.

Second, this study did not perform quantitative dermal exposure modeling (e.g., dose estimation or hazard quotient calculation). Regulatory limits are mentioned only to provide contextual background, whereas the primary contribution of the work is the development and application of a validated GC–MS method and the generation of quantitative PhE data across diverse product types. Future studies may integrate analytical findings with usage-pattern data to support exposure-based risk assessment where needed.

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Conflict of Interest

The authors declare that they have no conflict of interests regarding content of this article.

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Ethical Declaration

Helsinki Declaration rules were followed to conduct this study and no ethical approval is need for this study.

Previous Presentation

Some part of this study was presented as oral presentation at "5th Regional Symposium of Toxicology", in 2024, held in Eskişehir, entitled as "Çeşitli Islak Mendillerdeki 2-Fenoksietanol Konsantrasyonunun Karşılaştırılması".

Is derived from a thesis?

This study was prepared by rearrangement of the master's thesis by Fakhri Musayev, dated 2024, entitled as "Biyosidal bir ürün olarak ıslak mendilin toksikolojik açıdan değerlendirilmesi".

Authorship Contributions

Concept: ZT, FM Design: ZT, DSİ Supervising: SNK, ZA Financing and equipment: ZT, DSİ Data collection and entry: FM, SNK, ZA Analysis and interpretation: ZT, ZA, FM Literature search: FM, ZT, SNK Writing: FM, ZT, ZA, SNK, Critical review: ZT, ZA.

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