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DEVELOPMENT OF A RAPID COLORIMETRIC PAPER-BASED TEST KIT FOR ON-SITE SCREENING OF PARABENS IN COSMETIC AND HEALTHCARE PRODUCTS

DESENVOLVIMENTO DE UM KIT DE TESTE COLORIMÉTRICO RÁPIDO EM PAPEL PARA TRIAGEM DE PARABENOS EM PRODUTOS COSMÉTICOS E DE SAÚDE

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Abstract

Parabens, a class of synthetic esters of p-hydroxybenzoic acid, are extensively used as preservatives in cosmetics, pharmaceuticals, and personal care products, raising growing concerns about their potential endocrine-disrupting effects and cumulative exposure risks. This study aimed to develop a rapid, low-cost, and user-friendly paper-based colorimetric kit for the on-site detection of parabens. Two chromogenic systems—Fast Blue RR diazonium coupling and ferric ion (Fe^{3+}) complexation—were compared; the $FeCl_3$ system was selected for its superior color intensity and stability. Reaction conditions were optimized for solvent composition, reagent ratio, concentration, and pH, yielding the best performance at 10% $FeCl_3$ in 20% ethanol, pH 8.0, and a 1:10 reagent-to-analyte ratio. The optimized dipstick produced a visible purple color within 1 minute, with a detection limit of 0.2% and color stability for approximately 16 minutes. The kit demonstrated high selectivity with minimal matrix interference and was successfully applied to 25 commercial samples,

Resumo

Os parabenos, uma classe de ésteres sintéticos do ácido p-hidroxibenzóico, são amplamente utilizados como conservantes em cosméticos, produtos farmacêuticos e de higiene pessoal, levantando preocupações crescentes sobre seus potenciais efeitos desreguladores endócrinos e riscos de exposição cumulativa. Este estudo teve como objetivo desenvolver um kit colorimétrico em papel, rápido, de baixo custo e fácil de usar, para a detecção in loco de parabenos. Dois sistemas cromogênicos — o acoplamento diazônio Fast Blue RR e a complexação com íons férricos (Fe^{3+}) — foram comparados; o sistema $FeCl_3$ foi selecionado por apresentar maior intensidade e estabilidade de cor. As condições de reação foram otimizadas quanto à composição do solvente, razão reagente-analito, concentração e pH, apresentando melhor desempenho com 10% de $FeCl_3$ em etanol a 20%, pH 8,0 e razão 1:10. A fita otimizada produziu uma coloração roxa visível em 1 minuto, com limite de detecção de 0,2% e estabilidade da cor por aproximadamente 16 minutos. O kit demonstrou alta seletividade, com interferência mínima da matriz, e foi detecting parabens in 16% of products, primarily cosmetics. Although less sensitive than advanced chromatographic or electrochemical methods, the proposed $FeCl_3$-based paper strip offers a practical, rapid screening tool for preliminary quality control and field surveillance, particularly in resource-limited settings.

Keywords: Parabens. Colorimetric Detection. Paper-based Sensor. Ferric Chloride. Rapid Screening.

aplicado com sucesso em 25 amostras comerciais, detectando parabenos em 16% dos produtos, principalmente cosméticos. Embora menos sensível que métodos cromatográficos ou eletroquímicos avançados, a fita em papel baseada em $FeCl_3$ oferece uma ferramenta prática e rápida para triagem preliminar, controle de qualidade e vigilância em campo, especialmente em contextos com recursos limitados.

Palavras-chave: *Parabenos. Detecção Colorimétrica. Sensor em Papel. Cloreto Férrico. Triagem Rápida.*

1 INTRODUCTION

Parabens are synthetic esters of *p*-hydroxybenzoic acid widely used as preservatives in cosmetics, pharmaceuticals, and personal care products due to their antimicrobial efficacy and stability. Their extensive application has led to near-universal human exposure, with methylparaben and ethylparaben most frequently detected in biological samples worldwide [1-3]. Although average exposure levels are generally below regulatory limits, certain subgroups—such as women, children, and frequent users of personal care products—may experience cumulative exposures approaching safety thresholds [4-6].

Evidence from experimental and epidemiological studies suggests potential endocrine-disrupting and systemic effects of parabens, including alterations in thyroid function, reproductive outcomes, and risks of metabolic and immune disorders [7-9]. However, findings remain inconsistent, and regulatory assessments differ across regions. Longer-chain parabens such as propyl- and butylparaben have faced increasing scrutiny, leading some countries to impose restrictions, while others maintain existing safety standards [9, 10].

Conventional analytical methods for paraben detection, such as HPLC and LC–MS, are highly sensitive but require costly instrumentation and trained personnel, limiting their use for large-scale or field testing. Emerging platforms, including β-cyclodextrin-based supramolecular sensors [11], offer improved analytical performance but remain laboratory-bound. There is a clear need for a rapid, inexpensive, and user-friendly on-site screening tool. This study therefore aimed to develop and validate a simple paper-based colorimetric test kit for quick paraben detection, enabling preliminary quality control and public health surveillance in resource-limited settings.

2 MATERIALS AND METHODS

2.1 Chemicals and reagents

Methylparaben (analytical grade) was selected as the representative analyte because it is the most commonly used paraben in cosmetic and healthcare formulations. Ferric chloride ($FeCl_3$), Fast Blue RR, sodium carbonate, ethanol, sodium hydroxide, and boric acid were purchased from Merck (Germany). Cellulose filter paper (Whatman No. 1) was used as the substrate for reagent immobilization. All solutions were prepared with deionized water, and ethanol concentrations were adjusted as specified.

2.2 Design of the test kit

The colorimetric test kit was constructed as a paper-based dipstick consisting of three fixed zones on a transparent mica support: a positive control (A), negative control (B), and sample test area (C). Paper strips (20 × 0.4 mm) were affixed to the support using pressure-sensitive adhesive (PSA). The $FeCl_3$ reagent was impregnated onto the paper surface and air-dried to form the active detection layer. Finished strips were stored in sealed aluminum pouches with desiccant to maintain stability until use.

2.3 Optimization of detection conditions

Optimization experiments were performed to identify the most effective color-developing system for paraben detection. Two colorimetric chemistries were compared: (1) the diazonium coupling reaction with Fast Blue RR, producing an orange–red color, and (2) ferric ion complexation with the phenolic hydroxyl group of parabens, producing a purple color.

The $FeCl_3$ system was selected based on superior color intensity, reagent stability, and visual clarity. Parameters optimized included (i) ethanol concentration (10–100%), (ii) $FeCl_3$ concentration (2.5–15%), (iii) reaction ratio between reagent and paraben solution (1:6–1:15), (iv) pH range (6–10), and (v) reagent loading on paper (30–150 μg/mm²). Color intensity was quantified spectrophotometrically at 528 nm to determine optimal conditions.

2.4 Analytical procedure

For each test, 50 µL of the sample solution was applied to the sample zone. The strip was kept at room temperature, and color development was observed within 1–2 minutes. The presence of parabens was indicated by a visible purple coloration compared with the negative control. The optimal reaction was achieved at pH 8 using $FeCl_3$ (10%) in 20% ethanol with a reagent loading of 60 µg/mm².

2.5 Performance evaluation

Sensitivity (limit of detection, LOD): Serial dilutions of methylparaben (0.1–0.8%) were tested to determine the lowest concentration that produced a discernible color change by visual observation. Response time: The time required to reach maximum color intensity and the duration before fading were recorded in six replicates. Selectivity: The kit's response was evaluated using real cosmetic and healthcare matrices, both with and without added paraben (0.4%), to assess interference from sample components. Repeatability: Measurements were performed in triplicate under the same conditions to confirm reproducibility.

2.6 Application to commercial products

The validated kit was applied to 25 commercial samples, including pharmaceuticals, functional foods, cosmetics, and herbal preparations purchased from local markets. Samples were prepared by simple extraction in 20% ethanol, and 50 µL of extract was tested directly on the strip. Results were interpreted visually as positive (distinct purple coloration) or negative (no color change) relative to the controls.

2.7 Data analysis

Quantitative measurements were expressed as mean ± standard deviation (SD) from at least three replicates. Data were analyzed using Microsoft Excel and presented in tabular or graphical form where applicable. Visual color results were cross-referenced with absorbance readings to confirm consistency.

3 RESULTS

3.1 Optimization of reagent system and detection conditions

Two color-developing systems were evaluated for the detection of parabens: the Fast Blue RR diazonium coupling and Fe^{3+} complexation reactions. The Fast Blue system produced a weak orange–red color with poor visual contrast and limited stability in humid conditions. In contrast, the $FeCl_3$ system generated a distinct purple complex with the phenolic hydroxyl group of methylparaben, providing higher color intensity and stability under ambient conditions (Figure 1 and Figure 2). Therefore, ferric chloride was selected as the optimal reagent for further experiments.

Figure 1

Reaction between methylparaben and Fast Blue RR reagent (Negative control (A), reagent only (B), positive control (C))

A B C

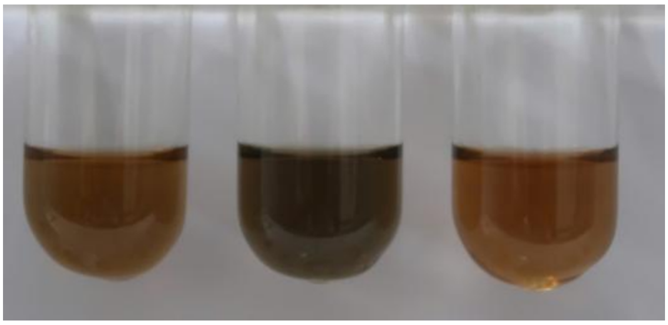
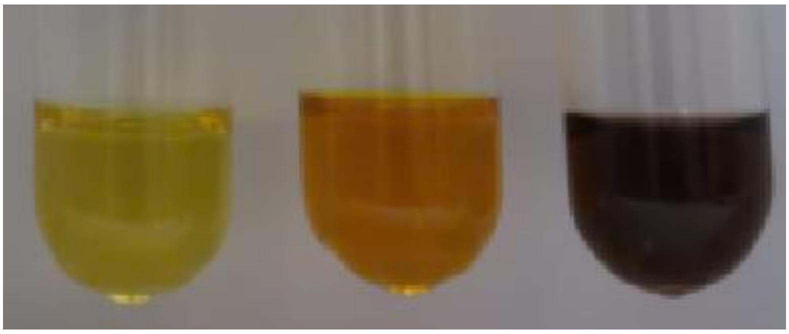


Figure 2

Reaction between methylparaben and ferric chloride (Fe^{3+}) reagent (Negative control (A), reagent only (B), positive control (C))

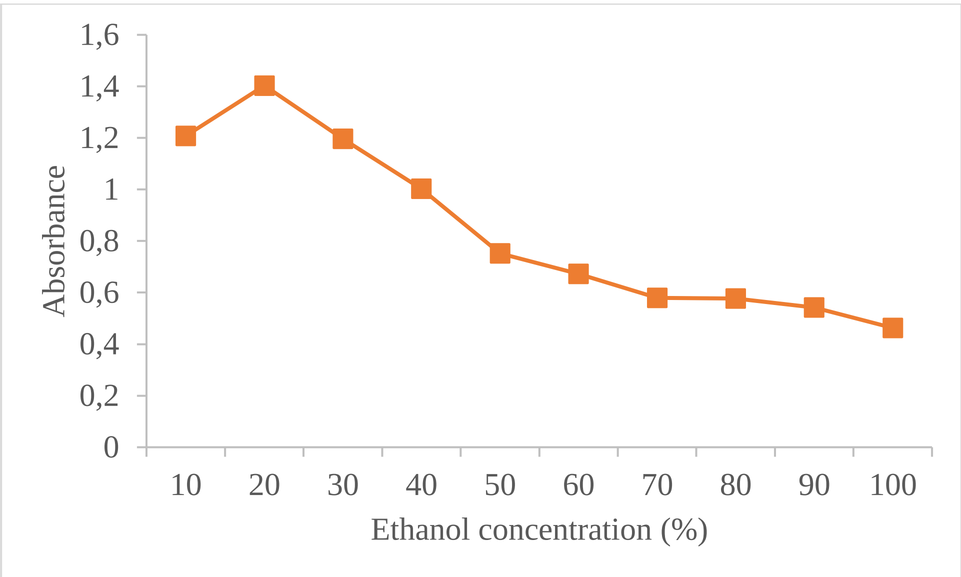


3.2 Effect of solvent composition

The intensity of the Fe^{3+}–paraben complex was strongly influenced by ethanol concentration. Absorbance at 528 nm increased with ethanol content up to 20%, after which it declined. Thus, 20% ethanol was identified as the optimal solvent system, yielding the highest color intensity (Figure 3).

Figure 3

(A) Absorbance of the complex between paraben and ferric ion (Fe^{3+}) in different solvent environments; (B) Effect of ethanol concentration (10–100%) on color development — Negative control (A) and reaction conditions (B–L).



A)

B

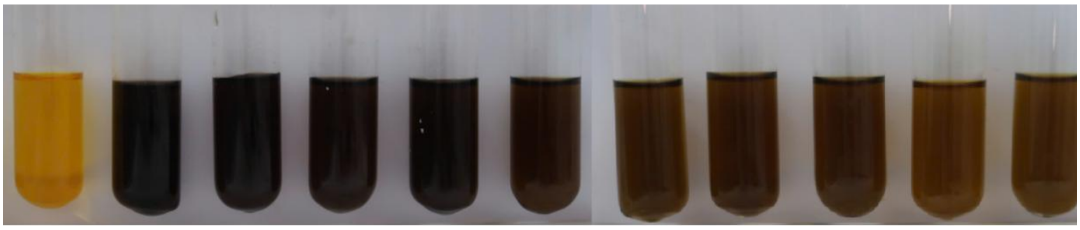


Table 1 summarizes the optimization of analytical conditions for the colorimetric detection of parabens using the Fe^{3+} complexation system. Each parameter was varied systematically to identify the combination that produced the highest absorbance at 528 nm. The results show that color intensity increased with reagent concentration, ratio, and pH up to optimal points, after which further increases provided no significant improvement. The best response was achieved using a 1:10 reagent-to-analyte ratio, 10% $FeCl_3$ concentration, and pH 8.0, with a reagent loading of 60 µg/mm² on the paper substrate. These optimized conditions ensured maximum color development, stability, and reproducibility for the rapid paper-based test kit.

Table 1

Optimization of conditions for colorimetric detection of parabens (n = 6).

Parameter	Experimental condition	Mean absorbance	SD	Optimal value
Reagent/Test solution ratio	1/6	1.316	0.004	
	1/8	1.316	0.003	
	1/10	1.333	0.003	1/10
	1/12	1.317	0.005	
	1/15	1.283	0.006	
$FeCl_3$ concentration (%)	2.5	0.921	0.003	
	5.0	1.098	0.003	
	7.5	1.103	0.002	
	10.0	1.339	0.002	10%
	12.5	1.252	0.003	
pH	6	1.303	0.002	
	7	1.332	0.003	
	8	1.498	0.006	8.0
	9	1.501	0.011	
	10	1.515	0.008	

3.3 Performance evaluation of the test kit

Serial dilutions of methylparaben (0.1–0.8%) showed that 0.2% was the lowest concentration producing a clearly visible purple color (Figure 3), establishing the kit’s limit of detection (LOD) = 0.2%. The mean response time was approximately 58.5 ± 0.8 s, and the color remained stable for about 16 ± 0.3 minutes before fading (Table 2).

Table 2

Response characteristics of the paper-based test kit (n = 6).

Parameter	Mean ± SD
Time to maximum color (s)	58.45 ± 0.76
Color fading time (min)	16.01 ± 0.29

3.4 Selectivity

A spiked-sample experiment confirmed the kit's specificity: the native sample produced no visible color change, whereas the same matrix fortified with 0.4% methylparaben yielded a distinct purple coloration. This demonstrated negligible interference from cosmetic or herbal excipients under test conditions.

3.5 Application to commercial samples

The optimized kit was applied to 25 market-available products, including pharmaceuticals, functional foods, cosmetics, and food supplements. As shown in Table 3, 16% of samples yielded positive results, most frequently in cosmetic formulations. Two pharmaceutical samples containing paracetamol also tested positive, possibly due to phenolic interference rather than actual paraben presence.

Table 3

Screening of parabens in commercial samples.

Product category	No. of samples	Positive results (%)
Pharmaceuticals	3	2 (66.7%)
Functional foods	**12**	**0 (0%)**
Foods	8	1 (12.5%)
Cosmetics	**2**	**1 (50%)**
Total	25	4 (16%)

In summary, the developed $FeCl_3$-based colorimetric paper kit demonstrated high visual sensitivity (LOD = 0.2%), rapid response (<1 min), good selectivity, and practical applicability for field screening of parabens in diverse product matrices.

4 DISCUSSION

he study successfully developed a rapid, low-cost colorimetric test kit for on-site paraben detection based on the Fe^{3+} complexation mechanism. Compared with the Fast Blue diazonium system, ferric chloride provided higher color stability, stronger visual contrast, and greater environmental robustness, making it more suitable for field applications. The optimized reaction conditions—10% $FeCl_3$ in 20% ethanol, 1:10 reagent-to-analyte ratio, and pH 8.0—enabled fast color formation within one minute and maintained stability for up to 16 minutes, ensuring sufficient time for visual interpretation. These findings demonstrate the feasibility of simplifying paraben detection chemistry into a portable paper-based format that requires no specialized equipment or technical expertise.

Although the kit's visual detection limit (LOD = 0.2%) is considerably higher than laboratory-based analytical techniques, it fulfills a distinct operational niche. Advanced methods such as β-cyclodextrin-based supramolecular imprinted fiber arrays[11], polyaniline–ZnO nanocomposite electrodes [12], and microextraction coupled with chromatographic analysis [13, 14] achieve detection limits in the microgram or micromolar range. However, these methods rely on complex instrumentation and trained personnel, limiting their practicality for rapid field screening. By contrast, the paper-based kit provides a qualitative yet actionable result in less than two minutes, making it appropriate for preliminary quality control, point-of-sale screening, and regulatory inspection in resource-limited settings.

Selectivity experiments confirmed that the Fe^{3+} colorimetric reaction was highly specific for phenolic hydroxyl groups, showing negligible interference from most cosmetic and herbal matrices. This observation is consistent with prior findings that selective chemical recognition—such as molecular imprinting or nanocomposite sensing—enhances paraben discrimination even in complex samples [11, 12]. While two pharmaceutical products produced false-positive signals, likely due to paracetamol's phenolic structure, these cases underscore the importance of interpreting positive results as preliminary indicators requiring confirmatory laboratory analysis rather than definitive evidence of paraben contamination.

Field application further demonstrated the practicality of the kit, with 16% of 25 tested commercial products showing detectable paraben levels. Most positive samples were cosmetics, reflecting common preservative use in that sector. This simple test enables rapid identification of potentially non-compliant or mislabeled products, supporting consumer safety and regulatory enforcement. In addition, the method's ease of fabrication and low production cost suggest potential scalability for community-level surveillance, particularly in countries lacking extensive laboratory infrastructure.

5 CONCLUSION

The $FeCl_3$-based paper strip developed in this study provides a fast, inexpensive, and user-friendly tool for screening parabens in cosmetics and healthcare products. Although less sensitive than laboratory-based analytical techniques, it offers sufficient specificity and response speed for preliminary field testing. The kit represents a promising step toward democratizing chemical safety assessment, enabling broader monitoring of preservative use in consumer products and contributing to improved public health protection.

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Authors' Contribution

Both authors contributed equally to the development of this article.

Data availability

All datasets relevant to this study's findings are fully available within the article.

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