WORLD JOURNAL OF PHARMACEUTICAL RESEARCH
SJIF Impact Factor 8.453
Volume 13, Issue 23, 61-72. Research Article ISSN 2277–7105

SAFETY ASSESSMENT AND HEALTH RISK ASSOCIATED WITH THE USE OF HAIR DYES: CHEMICAL COMPOSITIONS, TOXICITIES, AND SAFER ALTERNATIVES

Abirame S.[1]*, Kalyani P.[2] and Kamal Serasinghe S.V.[3]

[1,2]University of Peradeniya, Sri Lanka.

[3]Osethma Health (Pvt) Ltd, Sri Lanka.

Article Received on
14 Oct. 2024,

Revised on 03 Nov. 2024,
Accepted on 24 Nov. 2024

DOI: 10.20959/wjpr202423-34722

***Corresponding Author**
Abirame S.
University of Peradeniya,
Sri Lanka.

ABSTRACT

Since ancient Egypt, hair colouring has been a common technique. At first, people's usage of hair colour was limited to covering up their white and gray hair. The most often used type of dyes are permanent ones, which include ingredients such as hydrogen peroxide, p-phenylenediamine (PPD), and ammonia. Although these chemicals have been connected to a number of unfavorable health effects, they can penetrate the hair shaft to produce colour that lasts longer. Hair dye allergies, especially those involving PPD, have a well-established history and can manifest as anything from minor skin irritation to life-threatening. The objective of this study is to assess the safety concerns associated with hair dyes and their potential health risks. The review specifically aims to identify the chemical composition of commonly used hair dyes, evaluate their toxicological effects, and suggest safer alternatives. A systematic search of databases including PubMed, Scopus, and Google Scholar was conducted, focusing on peer-reviewed articles. Studies were selected based on their relevance to hair dye safety, toxicology, and regulatory issues. Data on adverse effects, toxicity levels, and safety profiles were extracted and compared. The results indicate significant health risks associated with certain heavy metals in hair dyes, particularly in darker shades, with some products exceeding safe limits. The findings highlight the need for safer formulations and best practices for hair dye application. Limitations include a lack of comprehensive geographical coverage and a need for long-term studies to fully understand chronic exposure risks.

KEYWORDS: Adverse reactions, Contact dermatitis, Hair colourants, Hair dye, Para-phenylenediamine, Patch test.

1. INTRODUCTION AND RESEARCH PROBLEM/ISSUE

1.1. History of Hair Colouring

Hair colouring was practiced by the Egyptians as early as 5000 BC.[1] In ancient Greece, hair was bleached with a potassium solution rinse and then massaged with a yellow flower petal and pollen ointment.[2] Greek ladies used to wash their hair with a special ointment made in Athens in the fourteenth century, and then they would sit in the sun to turn their hair golden. Ladies in the sixteenth century used the sun to bleach their hair. A mixture of elderberries and wine was used to produce black hair colour in 1694. Using a mixture of ceruse, lime, saffron, or turmeric for blond hair, and radish extract for red hair. Lead combs placed lead particles on each strand of gray hair, darkening it.[3] In a lab, the first synthetic dye was created in 1856. William Henry Perkin created the first synthetic dye, known as Mauveine, in 1863. Soon after, German chemist professor August Hoffman isolated a pigment called paraphenylenediamine, or PPD, from mauveine. Most permanent hair colours on the market today still start with this hue. In 1907, Eugene Schueller created the first artificial hair colour. Permanent hair colouring was created in the 1920s using an oxidizing and an alkalizing chemical.[4] Boonnevie suggested incorporating para-phenylenediamine exposure into the first standard series of patch test series allergy screening panel in 1939 after realizing the consequences of such exposure.[5] Hair dyes are currently going through a significant developmental stage, and since the second world war, significant advancements have been made in the discovery and use of new synthetic dyes. Due to significant levels of miscegenation, Brazil is home to nearly every form of hair. Furthermore, Brazil is currently the world leader in hair dye goods due to the emphasis that women place on their hair treatments.[6]

1.2. Epidemiology of hair dye use and contact sensitivity

The general population's para-phenylenediamine sensitivity has been estimated by population-based epidemiological research to be between 0.1 and 1%.[7] Globally, dermatitis patients have varying rates of positive patch test results for para-phenylenediamine: 11.5% in India, 6% in North America, 4.4% in Asia, and 4.1% in Europe. In Asia, men are more likely than women to be sensitized to para-phenylenediamine, whereas in Europe, the opposite is true.[8,9]

1.3. Justification

Numerous chemical ingredients used in hair colourants have the potential to trigger allergic reactions and life threading. Therefore, this review evaluates the health risks associated with hair dyes, focusing on toxic ingredients, allergic reactions, and the need for safer alternatives and stricter regulations to protect consumers.

1.4. OBJECTIVES

1.4.1. General objective

To assess the safety issues associated with the use of hair dyes and their potential health risks

1.4.2. Specific objectives

1.4.2.1. To identify the chemical composition of common hair dyes

1.4.2.2. To evaluate hair dye-induced toxicities and adverse health effects

1.4.2.3. To suggest safer substitutes and best methods for applying hair colour.

2. MATERIALS AND METHODS

2.1. Search protocol

An organized search procedure was used to carry out an extensive analysis of hair colourants' safety. In order to find pertinent peer-reviewed papers, case studies, and toxicological assessments, the search entailed accessing a number of electronic databases, including Google Scholar, PubMed, and Scopus. The relevant studies were found by using keywords like "hair colourant safety," "hair dye toxicity," "adverse effects of hair colourants," and "regulatory aspects of hair dyes." The studies were selected based on their focus on the safety profile, chemical composition, side effects, and regulation of hair colourants, excluding those that did not meet these criteria.

2.2. Study selection

A systematic approach was employed for study selection. The titles and abstracts of all the studies identified through the database search were screened for relevance. Full-text articles were retrieved for studies that appeared to meet the inclusion criteria or where there was uncertainty based on the title and abstract alone. A two-step process was used. First, preliminary screening to eliminate clearly irrelevant studies, followed by a more detailed assessment to ensure only high-quality, pertinent research was included.

2.3. Inclusion criteria

Published in peer-reviewed journals.

Focus on the safety, toxicology, or side effects of hair colourants.

Written in English (or any other relevant language).

2.4. Exclusion criteria

Studies focusing on non-human subjects without direct relevance to human safety.

Articles that lack sufficient data on hair colourants (E.g: Studies on hair care products in general without specific focus on hair dyes).

Duplicates and irrelevant studies from the initial search results.

2.5. Data extraction

Data extraction was performed using a standardized form. Key data points such as safety outcomes, side effects reported, and regulatory implications were collected. This information was tabulated for systematic comparison across studies to assess patterns, trends, and gaps in the research.

3. RESULTS AND DISCUSSION

This review explores the health risks associated with the use of hair dyes, especially focusing on their chemical composition, toxicity, and adverse effects.

Table 3: Health Risks of Hair Dyes: Chemical Composition, Toxicity, and Adverse Effects.

Author/Year	Type of study	Sample size	Findings
Wedad H. Al-Dahhan (2019)	Experimental Study	3 hair dye samples (K303/66, K303/4, K307/1)	The study found a large proportion of sulfur in the hair dyes, but none of the toxic heavy metals. Atomic absorption analysis showed acid digestion was not fully effective.
Puntaric D., Miskulin M., Bosnir J. (2012)	Health Ecology Study	N/A	Heavy metals at high concentrations cause health problems. Hair analysis can indicate an organism's status and reveal accumulated toxins.
Chojnacka K., Gorecka H., Chojnacki A. (2005)	Toxicology Study	N/A	Human hair can be used for toxicological and nutritional assessment. Inter-element interactions in hair provide insight into exposure to toxic substances.
Altaf W., Akanle O., Adams L. (2004)	Database Analysis	N/A	University of Surrey's database includes elemental composition of human hair, used for toxicology and environmental studies.
Bencko V. (1995)	Occupational	N/A	Human hair serves as a biomarker for

	and Environmental Toxicology		environmental and occupational exposure to pollutants, making it useful in toxicological assessments.
Wei L., Rui K., Shen L. (2008)	Effects of Hair Dyeing on Heavy Metals	N/A	Hair dyeing affects the content of heavy metals in hair. Dyed hair has higher Mn, Fe, Ni, Cu, Cd, and Sb, but lower As, Cr, Zn, Ag, Pb, and Hg levels.
Bhargava P., Matthew P. (2007)	Case Report (Hair Dye Poisoning)	N/A	The use of hair dyes, particularly those containing paraphenylenediamine (PPD), may result in poisoning and health issues, including risks of non-Hodgkin's lymphoma.
Ahmed H., Maaboud R., Latif F. (2013)	Analytical Study on Hair Dyes	N/A	Analytical methods were applied to evaluate the presence of toxic elements in hair dyes, highlighting the need for safe formulations.
Amhimmid et al. (2022)	Experimental research	5 hair dye brands	Detected heavy metals (Pb, Ba, Cd, Cr, Cu, As, Zn) in all samples; levels of Pb and Cd exceeded acceptable cosmetic limits. Hair dyes with darker shades had higher levels of heavy metals.
Baboli & Velayatzadeh (2013)	Heavy metal analysis in shrimp	N/A	Determined levels of heavy metals and trace elements in marine shrimp from the Persian Gulf.
Pehlić et al. (2019)	Analytical study	N/A	Measured heavy metals in hair dyes using Atomic Absorption Spectrophotometry
Arora et al. (2011)	Comparative review	N/A	Compared synthetic and herbal shampoo ingredients, highlighting the presence of harmful chemicals and heavy metals in synthetic products.
Arshad et al. (2020)	Analytical research	N/A	Evaluated heavy metals in cosmetics and conducted health risk assessments.
Wei et al. (2008)	Analytical study	N/A	Investigated the effects of hair dyeing on heavy metal content in human hair.
Bhargava & Matthew (2007)	Case study	N/A	Explored the toxicological effects of hair dye poisoning.
Al-Dahhan (2019)	Experimental research	N/A	Examined heavy metals in hair dye samples from Iraqi markets and reported toxic metal levels
Gago-Dominguez (2001)	Case-Control Study	897/897	2.1-fold increased risk of bladder cancer (P = 0.04)
Kogevinas (2006)	Case-Control Study	152/166	No significant association with bladder cancer (OR, 0.80; 95% CI: 0.50–1.50)
Thun (1994)	Epidemiologic	N/A	Reduced risk of bladder cancer (RR,

	Study		0.56; 95% CI: 0.32–0.99)
Hartge (1982)	Case-Control Study	2982/5782	No significant association with bladder cancer (RR, 1.00; 95% CI: 0.90–1.20)
Ros (2012)	Case-Control Study	1385/4754	No significant association with bladder cancer (OR, 0.87; 95% CI: 0.65–1.18)
Koutros (2011)	Case-Control Study	61/102	3.30-fold increased risk of bladder cancer (OR, 3.30; 95% CI: 1.20–8.90)
Gago-Dominguez (2003)	Case-Control Study	33/12a; 37/17a	2.90-fold and 2.50-fold increased risk of bladder cancer (OR, 2.90; 2.50)
Turati (2014)	Meta-Analysis	3657/5962	No significant association with bladder cancer (RR, 0.92; 95% CI: 0.77–1.09)
Boice (1995)	Case-Control Study	528/2628	No significant association with breast cancer (OR, 1.08; 95% CI: 0.87–1.30)
Koenig (1991)	Case-Control Study	398/790	No significant association with breast cancer (OR, 0.80; 95% CI: 0.60–1.10)
Cook (1999)	Case-Control Study	315/393b; 204/138b	RR, 1.10 for breast cancer; RR, 1.90 with two or more methods
Zheng (2002)	Case-Control Study	608/609	No significant association with breast cancer (OR, 0.90; 95% CI: 0.70–1.20)
Nasca (1992)	Case-Control Study	1617/1617	No significant association with breast cancer (OR, 1.04; 95% CI: 0.90–1.21)
Heikkinen (2015)	Case-Control Study	6567/21598	Increased risk of breast cancer (OR, 1.23; 95% CI: 1.11–1.36)
Petro-Nustas (2002)	Case-Control Study	100/100	Strong association with breast cancer (OR, 8.62; 95% CI: 3.33–22.28)
Eberle (2019)	Prospective Study	N/A	Increased risk of breast cancer (HR, 1.45; 95% CI: 1.10–1.90)
Nasca (1980)	Case-Control Study	118/233	4.50-fold increased risk of breast cancer (OR, 4.50; 95% CI: 1.20–15.78)
Gera (2018)	Meta-Analysis	N/A	Slightly increased risk of breast cancer (RR, 1.19; 95% CI: 1.03–1.37)
Xu (2021)	Meta-Analysis	N/A	Slightly increased risk of breast cancer (OR, 1.07; 95% CI: 1.01–1.13)
Gera et al., (2018)	Meta-analysis	12 studies	No increased risk of breast cancer found.
Llanos et al., (2017)	Case-Control Study	N/A	Endocrine distrupting chemicals containing hair dyes correlated with increased risk of estrogen receptor-positive breast cancer
Gao et al., (2018)	Case-Control Study	N/A	Risk of childhood acute lymphoblastic leukemia increased with maternal hair dye use; reduced by breastfeeding.
Chen et al., (2006)	Case-Control Study	N/A	Maternal hair dyeing linked to increased risk of malignant germ cell tumors in sons.

Ammar Abdulrahman Jairoun, Sabaa Saleh Al-Hemyari, Moyad Shahwan, Obaida Jairoun, Sa'ed H Zyoud (2023)	Quantitative Analytical Study	290 hair dye samples	The study quantified p-phenylenediamine (PPD) in hair dyes using RP-HPLC-DAD. It found that 7.2% of the tested hair dyes exceeded the recommended PPD concentration. Dyes from India and China had higher PPD levels, and products from India and the UAE often lacked proper labeling.
Vijayasankar Palaniappan et al.(2023)	Narrative review	N/A	Hair dyes can cause allergic reactions and contact dermatitis.
Pranjali Chahande et al.(2022)	Review of the history and chemistry of hair coloring	N/A	The use of natural and synthetic dyes, evolving methods, and the safety concerns associated with hair coloring.

3.1. Historical and chemical evolution of hair dyes

The evolution of hair dyes has seen a shift from natural ingredients to synthetic compounds. **Pranjali Chahande et al. (2022)** discussed the history of hair dyeing, which has transitioned from the use of plant-based materials such as henna to the development of synthetic dyes like PPD. The shift to synthetic dyes has allowed for more permanent and diverse hair coloring options, but it has also introduced new safety concerns, particularly related to the toxicity of chemical ingredients. The review of historical trends provides context for the modern challenges in ensuring the safety of hair dye products.

3.2. Toxic elements and heavy metals in hair dyes

Several studies have reported the presence of heavy metals in hair dyes. For instance, **Al-Dahhan (2019)** conducted an experimental study on hair dye samples from Iraqi markets and detected significant levels of sulfur, although heavy metals such as lead (Pb) and cadmium (Cd) were absent. However, **Amhimmid et al. (2022)** found that Pb and Cd exceeded acceptable cosmetic limits in their analysis of five hair dye brands, with darker shades containing higher concentrations of these metals. This finding aligns with **Wei et al. (2008)**, who reported that dyed hair has higher concentrations of Mn, Fe, Ni, and Cu. Heavy metal exposure from hair dyes can have profound health implications. **Puntaric et al. (2012)** emphasized the ability of hair analysis to reveal accumulated toxins in the body. Meanwhile, **Chojnacka et al. (2005)** noted that hair can serve as a biomarker for both toxicological and nutritional assessments. The presence of toxic elements such as lead and cadmium, as reported in these studies, suggests a need for stricter regulation and testing of hair dye

products to ensure they are safe for consumers.

3.3. Allergic reactions and dermatological effects

The dermatological impact of hair dye use is well-documented in the literature. According to **Vijayasankar Palaniappan et al. (2023)**, hair dyes can cause allergic reactions such as contact dermatitis. This is particularly concerning for products containing p-phenylenediamine (PPD), a common ingredient in permanent hair dyes. **Bhargava & Matthew (2007)** described a case of hair dye poisoning linked to PPD, underscoring the health risks posed by certain chemical components in these products.

The need for proper labeling and regulation is a recurring theme in the literature. **Ammar Abdulrahman Jairoun et al. (2023)** highlighted the fact that hair dyes from countries like India and the UAE often lack proper labeling, which could result in consumer misuse and increased health risks. This finding emphasizes the importance of regulatory oversight to ensure that products contain adequate warnings and usage instructions.

3.4. Carcinogenicity of hair dyes

The carcinogenic potential of hair dyes has been a significant area of study. Several case-control studies have investigated the association between hair dye use and the risk of cancer, particularly bladder and breast cancer. **Gago-Dominguez et al. (2001)** found a 2.1-fold increased risk of bladder cancer among hair dye users, while **Koutros et al. (2011)** reported a 3.3-fold increased risk. However, other studies, such as those by **Hartge (1982)** and **Ros (2012)**, found no significant association between hair dye use and bladder cancer risk. Similarly, for breast cancer, the results have been mixed. **Heikkinen et al. (2015)** reported a slightly increased risk of breast cancer with an odds ratio (OR) of 1.23, while **Boice (1995)** and **Koenig (1991)** found no significant association. The conflicting results in these studies highlight the complexity of determining causality and suggest that further research is needed, particularly with larger sample sizes and more controlled variables.

3.5. Specific health issues and their potential health risks

Heavy Metal Toxicity: Hair dyes, especially darker shades, often contain heavy metals like lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), and zinc (Zn). High levels of these metals pose toxicological risks when absorbed by the body.

Carcinogenic Risks: **Bladder Cancer:** Research links hair dye use to increased bladder cancer risk, with specific studies showing risk factors ranging from a 2.1-fold increase up to a

3.3-fold increase.

Breast Cancer: Some studies show a slight increase in breast cancer risk associated with hair dye use, with odds ratios (OR) ranging from 1.23 to 8.62 in certain populations.

Allergic Reactions: Ingredients such as p-phenylenediamine (PPD) commonly used in hair dyes can lead to allergic reactions, including contact dermatitis, skin irritation, and in severe cases, systemic reactions like non-Hodgkin's lymphoma. Rates of sensitization to PPD vary globally, with up to 11.5% in India and around 4-6% in North America and Europe.

Occupational Health Risks: Hairdressers and salon workers are at higher risk due to chronic exposure, which can lead to accumulated toxic elements in the body.

3.6. Safer Alternatives

Natural Dyes: Alternatives such as henna, indigo, and walnut are used as natural coloring agents. They pose fewer health risks but may have limited color options and less longevity than synthetic dyes.

Low-PPD and PPD-Free Formulations: Some manufacturers are creating hair dyes with reduced PPD content or using alternative chemicals that lower allergic potential.

Herbal and Non-Synthetic Formulations: There is an increasing shift towards herbal-based hair dyes. Although not as long-lasting as synthetic options, these are safer and suitable for sensitive users.

3.7. Regulatory concerns and labeling issues

The need for proper labeling and regulation is a recurring theme in the literature. **Ammar Abdulrahman Jairoun et al. (2023)** highlighted the fact that hair dyes from countries like India and the UAE often lack proper labeling, which could result in consumer misuse and increased health risks. This finding emphasizes the importance of regulatory oversight to ensure that products contain adequate warnings and usage instructions.

4. CONCLUSIONS

The findings from this review underscore the health risks associated with hair dye use, particularly concerning the presence of toxic metals, the potential carcinogenicity of certain ingredients, and the dermatological effects of PPD. The variability in study results, especially regarding the link between hair dye use and cancer, indicates the need for further research, with a focus on long-term exposure and the cumulative effects of multiple dyeing sessions.

Suggestions and Recommendations

1. Stricter regulatory oversight

There is a pressing need for enhanced regulation of hair dye products, especially regarding the levels of toxic substances such as heavy metals (e.g., Pb, Cd, Mn) found in some commercial brands. Regulatory bodies should establish stricter thresholds for permissible levels of these toxic elements in hair dyes, ensuring they align with cosmetic safety standards.

2. Mandatory and comprehensive labelling

Many hair dyes lack proper labeling, especially in terms of the presence of toxic substances such as p-phenylenediamine (PPD) and heavy metals. It is recommended that all hair dye products include comprehensive labeling that details:

3. Encouraging natural dye alternatives

Given the potential health risks associated with synthetic hair dyes, it is suggested that consumers be encouraged to option for natural alternatives where possible. Natural dyes like henna, indigo, and walnut have historically been used with fewer health concerns. Further research should be conducted to optimize the safety and effectiveness of these natural dyes while improving their commercial availability.

4. Regular testing and reporting

Manufacturers should be required to regularly test their products for heavy metal contamination and other toxic elements. These test results should be published and made accessible to the public. This transparency will build consumer trust and provide an additional layer of safety.

5. Public awareness campaigns

Governments, health agencies, and consumer protection organizations should launch public awareness campaigns to educate consumers about the potential risks associated with hair dye use, particularly repeated exposure.

6. Further research on long-term exposure

The conflicting results on the association between hair dye use and cancer (particularly bladder and breast cancer) highlight the need for more comprehensive, long-term studies.

7. Promoting safer formulations

The cosmetic industry should invest in developing safer, non-toxic hair dye formulations. Manufacturers should focus on reducing the use of known allergens like PPD and heavy

metals while finding alternative chemicals that provide effective results with minimal health risks. Promoting innovation in this area will help mitigate the negative health impacts associated with hair dye use.

8. REFERENCES (SELECTED)

1. Naser Zaid¸ A.¸ et al¸ Int J Pharm Pharm Sci., 2013; 5, 2, 485-488.
2. Da França SA, Dario MF, Esteves VB, Baby AR, Velasco MVR. Types of hair dye and their mechanisms of action. *Cosmetics,* 2015; 2: 110-26.
3. [Google Scholar]
4. Chua, S.L. and Levell, N., The art of hair coloring – A History, Journal of the American Academy of Dermatology, 2005; 35.
5. Wecker J. Secrets in beautifying the head and face. In: Wecker J, Read R, eds. Eighteen books of the secrets of art and nature. London: St Paul Church-yard, 1661: 83.
6. [Google Scholar]
7. Handa S, Mahajan R, De D. Contact dermatitis to hair dye: An update. *Indian J Dermatol Venereol Leprol,* 2012; 78: 583-90.
8. [CrossRef] [PubMed] [Google Scholar]
9. ABIHPEC—Associação Brasileira das Indústrias de Higiene, Perfumaria e Cosméticos. Anuário 2012. Available online: http://www.abihpec.org.br (accessed on 20 December 2014). (In Portuguese)
10. Schäfer T, Böhler E, Ruhdorfer S, Weigl L, Wessner D, Filipiak B, et al. Epidemiology of contact allergy in adults. *Allergy,* 2001; 56: 1192-6.
11. [CrossRef] [PubMed] [Google Scholar]
12. Thyssen JP, White JM, European Society of Contact Dermatitis Thyssen JP, White JM. Epidemiological data on consumer allergy to p-phenylenediamine. *Contact Dermatitis,* 2008; 59: 327-43.
13. [CrossRef] [PubMed] [Google Scholar]
14. Sharma VK, Chakrabarti A. Common contact sensitizers in Chandigarh, India. A study of 200 patients with the European standard series. *Contact Dermatitis,* 1998; 38: 127-31.
15. [CrossRef] [PubMed] [Google Scholar]
16. *Wedad H. Al-Dahhan, Department of Chemistry, College of Science, Al Nahrain University, Baghdad, Iraq, 2019.*
17. Puntarić D., Miškulin M., Bošnir J., Health ecology, Medicinskanaklada Zagreb, 2012.

18. Chojnacka K., Gorecka H., Chojnacki A., Gorecki H., Inter– Element interactions in humanhair. Environmental Toxicology and Pharmacology, 2005; *20:* 368–374.
19. Altaf W., Akanle O., Adams L., Beasley D., Butler C., Spyrou N., The University of Surrey database of elemental composition of human hair, Journal of Radioanalytical and Nuclear Chemistry, 2004; 259: 493-498.
20. Bencko V., Use of human hair as a biomarker in the assessment of exposure to pollutantsin occupational and environmental settings. Toxicology, 1995; 101: 29-39.
21. Wei L., Rui K., Shen L., Effects of hair dyeing on the heavy metals content in hair, Guang Pu Xue Yu Guang Pu Fen Xi. Sep, 2008; 28(9): 2187-8.
22. Bhargava P., Matthew P., Hair dye poisoning, J Assoc Physicians India, 2007; 55: 871–2.
23. Ahmed H., Maaboud R. , Latif F., El-Dean A., El-Shaieb K , Different analytical methods of paraphenylenediamine based hair dye, Journal of Cosmetics, Dermatological Sciences and Applications, 2013; 3(03): 17.