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Environmental Health Risk Assessment of Rhodamine B Exposure among Elementary Schoolchildren in Central Java, Indonesia

Alfan Afandi[1], Kartika Dian Pertiwi[2*]
[1,2] Universitas Ngudi Waluyo, Indonesia
***Corresponding Author:** kartikadianpertiwi@unw.ac.id

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ABSTRACK

Introduction: The illegal use of industrial dyes such as *Rhodamine B* in foods poses serious health risks in many low- and middle-income countries (LMICs), where enforcement of food safety regulations remains inconsistent. *Rhodamine B*, a xanthene-based dye used in textiles and cosmetics, is often added to snacks and beverages for its bright color and low cost, despite being banned for food use. Chronic ingestion can cause hepatotoxicity, nephrotoxicity, oxidative stress, and DNA damage leading to carcinogenic effects. Children are particularly vulnerable due to their smaller body weight, immature detoxification systems, and frequent consumption of inexpensive street foods.
Objectives: This study aimed to assess the environmental health risks of *Rhodamine B* exposure among elementary school students in Ungaran, Central Java, Indonesia, using the Environmental Health Risk Assessment (EHRA) framework.
Methods: A cross-sectional study was conducted from June to August 2024 across 32 elementary schools. A total of 122 snack samples were purposively collected from canteens and surrounding vendors. *Rhodamine B* concentrations were determined using validated field test kits, with 10% of samples confirmed by UV–Vis spectrophotometry ($r = 0.96$, $p < 0.001$). Exposure assessment estimated daily intake based on ingestion rate, exposure frequency, and body weight. Risk characterization was performed by comparing intake with the USEPA reference dose (RfD = 0.2 mg/kg/day). Data were analyzed using SPSS 27.0 and visualized with R 4.3.2.
Results: All snack categories contained detectable *Rhodamine B* levels (0.3–25.4 ppm), with flavored powders showing the highest mean (11.2 ± 7.8 ppm). Calculated Risk Quotients (RQ) ranged from 0 to 57,566,871.94, with an average of 28,783,435.97. Over 80% of samples exceeded the safe limit (RQ > 1), indicating unsafe exposure levels among schoolchildren.
Conclusions: Widespread contamination of children's snacks with *Rhodamine B* highlights weak food safety governance and urgent need for policy reform, vendor regulation, and community education. Strengthening monitoring and awareness programs is essential to protect children from hazardous food dye exposure.

Keywords: environmental health risk, food safety, Indonesia, Rhodamine B, schoolchildren, toxic dye,

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INTRODUCTION

Rhodamine B, a synthetic dye banned in food products due to its toxic and carcinogenic properties, continues to be detected in snacks consumed by primary-school children, particularly in low- and middle-income settings. Studies indicate that despite regulations prohibiting its use, Rhodamine B is still misused in food items like street snacks, posing significant health risks, including liver damage and cancer (1),(2). Children are particularly vulnerable due to their lower body weight and higher frequency of snacking, which can lead to substantial exposure per kilogram of body weight (3),(4). For instance, a survey in Indonesia found that hazardous additives, including Rhodamine B, were present in various popular snacks, highlighting the need for stricter regulatory enforcement and public health initiatives to safeguard children's health (2). Furthermore, the prevalence of Rhodamine B in non-permitted colorants in food underscores the ongoing challenge of ensuring food safety in these communities (4), (5).

Despite regulatory bans and market surveillance efforts in Indonesia, the adulteration of street foods around schools remains a significant public health concern, with a focus on product detection rather than child-level exposure and health risks. Studies have documented the presence of hazardous substances such as rhodamine B, formalin, and borax in snacks sold near elementary schools, with rhodamine B being particularly prevalent in sauces and seasonings (6),(7). The persistence of these substances is partly attributed to the lack of knowledge among vendors about the health risks associated with these chemicals (7). Furthermore, the Indonesian Food and Drug Authority (BPOM) has identified systemic regulatory gaps, such as fragmented governance and insufficient pre-market screening, which hinder effective monitoring and enforcement (8). In Kudus City, the adulteration of traditional herbal medicine, jamu, with undeclared synthetic drugs like paracetamol, further exemplifies the challenge of ensuring food safety (9). Despite some efforts to educate students and vendors about the dangers of food additives, there remains a significant gap in awareness and practical skills for detecting these substances (10),(11). Additionally, the prevalence of foodborne illnesses linked to contaminated school snacks underscores the urgent need for improved surveillance and public health interventions. The BPOM's initiatives, such as technical guidance and educational campaigns, aim to mitigate these risks, but challenges persist due to limited resources and public awareness (12). Overall, a comprehensive approach that includes stricter regulatory measures, enhanced education, and community engagement is essential to address the ongoing issue of food adulteration around schools in Indonesia.

No study in Central Java has specifically quantified the Estimated Daily Intake (EDI) and Risk Quotient (RQ) for Rhodamine B among primary-school students using locally consumed snack categories and field testing near schools. However, research in other regions of Indonesia has highlighted the presence and risks associated with Rhodamine B in school snacks. For instance, a study in Makassar found that some snacks contained Rhodamine B, with the highest intake recorded at 7.839 mg/kg/day, and the Risk Quotient (RQ) values exceeding 1, indicating a significant health risk to children consuming these snacks (13). Similarly, research in Surakarta identified Rhodamine B in several snack samples, although the study focused more on the knowledge and attitudes of vendors rather than quantifying EDI or RQ (14). In other regions, such as Pekanbaru, Rhodamine B was detected in various snacks, with concentrations ranging from 0.122 ppm to 0.343 ppm (15). These findings underscore the potential health risks posed by Rhodamine B, a synthetic dye banned in food products due to its carcinogenic properties (16), (17). Despite these risks, the dye continues to be used in food products across Indonesia, often due to economic incentives and a lack of awareness among vendors (14). While studies have identified the presence of Rhodamine B in snacks, comprehensive risk assessments involving EDI and RQ calculations specifically for Central Java remain unreported, highlighting a gap in the current research landscape.

The study is an Environmental Health Risk Assessment framework to evaluate the risks associated with Rhodamine B in school-vicinity snacks, integrating on-site screening with student consumption data to estimate child-level Estimated Daily Intake (EDI) and Risk Quotient (RQ). This

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approach is crucial as children are particularly vulnerable to environmental pollutants due to their unique exposure patterns and biological susceptibility, which can lead to greater health risks compared to adults (18). The presence of hazardous food additives like Rhodamine B in school snacks has been documented in various regions, highlighting the need for rigorous risk assessments to inform policy decisions. In Ungaran, the study identifies high-risk snack categories, such as those with bright red coloring indicative of Rhodamine B, which aligns with findings from other studies that have detected similar additives in school snacks (19),(2). The integration of consumption data allows for a more accurate estimation of EDI and RQ, providing actionable parameters for local policy makers to enhance food safety regulations and protect child health (20). This method not only identifies the presence of hazardous substances but also quantifies the risk, offering a comprehensive tool for decision-makers to prioritize interventions and improve public health outcomes (20), (21). Enhanced regulation and awareness initiatives are necessary to mitigate these risks, as evidenced by the ongoing use of such additives in various regions. The study's findings underscore the importance of targeted education and stricter monitoring to reduce the prevalence of unsafe practices in school snack production and sales (2),(22).

Rhodamine B, a synthetic dye linked to systemic toxicity, poses significant health risks, particularly in younger populations consuming snacks. Studies indicate that even low concentrations of Rhodamine B in frequently consumed snacks can exceed reference-dose thresholds, necessitating structured risk assessments. For instance, research found Rhodamine B in various condiments, with maximum concentrations reaching 22.6 mg/kg in chili powder (23). Additionally, hazardous additives, including Rhodamine B, were identified in school snacks, highlighting the urgent need for improved food safety regulations (2). The dye's potential carcinogenicity and reproductive toxicity have been documented, with evidence of bioaccumulation and transgenerational effects in animal models (24),(25). These findings underscore the importance of monitoring Rhodamine B levels in food products to protect vulnerable populations, particularly children. This study aimed to assess the environmental health risks of *Rhodamine B* exposure among elementary school students in Ungaran, Central Java, Indonesia, using the Environmental Health Risk Assessment (EHRA) framework.

MATERIALS AND METHODS

This study employed a cross-sectional design to assess environmental health risks associated with Rhodamine B exposure among elementary school students in Ungaran, Central Java, Indonesia. The research was conducted from June to August 2024, following the Environmental Health Risk Assessment (EHRA) framework recommended by the World Health Organization (WHO, 2023) and the U.S. Environmental Protection Agency (USEPA, 2018).

1. Study Area and Population
   The study was conducted across 32 elementary schools located in urban and peri-urban areas of Ungaran, Central Java. The region was selected due to the high density of informal food vendors operating near school premises. The target population comprised schoolchildren aged 7–12 years, representing the age group most exposed to school snacks.
2. Sampling and Data Collection
   total of 122 snack samples were collected from school canteens and surrounding vendors. The sampling technique employed was purposive sampling, focusing on brightly colored snacks suspected to contain synthetic dyes. Samples were categorized into sauces, drinks, flavored powders, and snack coatings. Each sample was collected in sterile polyethylene containers, labeled, and stored under controlled temperature (4°C) prior to laboratory testing. All vendors were informed about the research objectives, and verbal consent was obtained before sample collection. Data on consumption frequency and portion size were obtained through structured questionnaires administered to 120 students selected by random sampling.

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3. Laboratory Analysis: Rhodamine B Detection
Rhodamine B levels were analyzed using a validated field test kit, which allows semi-quantitative detection of xanthene-based dyes. The test involved dissolving 1 g of each food sample in 10 mL of distilled water, followed by filtration and reagent addition. The resulting color intensity was compared to a standard reference chart to estimate dye concentration, expressed in parts per million (ppm). The detection range of the kit was 0–50 ppm, with a sensitivity of 0.1 ppm. For accuracy assurance, 10% of samples were randomly re-analyzed using a UV-Vis spectrophotometer (Shimadzu UV-1800) to confirm field kit reliability. The correlation coefficient between both methods was $r = 0.96$ ($p < 0.001$), indicating high validity.
4. Risk Assessment Framework
   a. Hazard Identification: Determined the presence and concentration of Rhodamine B in each sample.
   b. Exposure Assessment: Estimated the daily intake (mg/kg/day) based on the formula

$$\text{Intake} = \frac{C \times IR \times EF \times ED}{BW \times AT}$$

where:
C = concentration of Rhodamine B (mg/kg)
IR = ingestion rate (g/day)
EF = exposure frequency (days/year)
ED = exposure duration (years)
BW = body weight (kg)
AT = averaging time (days)
Child body weight and intake rates were based on data from the Indonesian Ministry of Health (2023) and WHO exposure factors for children (WHO, 2023).

   c. Risk Characterization: The Risk Quotient (RQ) was calculated as: $$RQ = \frac{Intake}{RfD}$$

The Reference Dose (RfD) used was 0.2 mg/kg/day (USEPA, 2018). $RQ \leq 1$ indicates an acceptable exposure level, while $RQ > 1$ suggests potential health risk.
5. Data Analysis
Descriptive statistical analysis was conducted using IBM SPSS Statistics version 27.0 to determine mean concentrations, intake values, and RQ distributions. Outlier detection was performed using the interquartile range (IQR) method. Results were visualized through box plots and heat maps using R software (version 4.3.2) to depict contamination patterns by school and snack type. Quality control procedures followed ISO/IEC 17025:2022 standards for laboratory testing, ensuring accuracy and reproducibility of data.

RESULTS

Hazard Identification

Hazard identification is a process used to determine the concentration of chemicals that can affect health. Hazard identification was conducted for the concentration of rhodomin b in snacks sold near elementary schools in the Ungaran area.

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Figure 1. Average Rhodamine B Concentration by Elemntary School in Ungaran

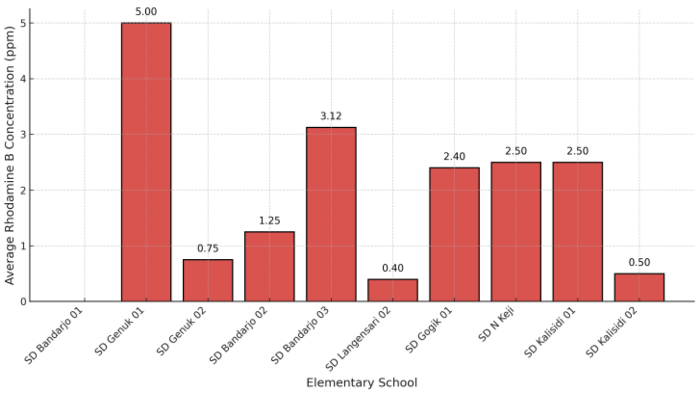

Figure 1 illustrates the average concentration of Rhodamine B detected in snack samples from ten elementary schools in Ungaran. The highest mean level was observed at SD Genuk 01 (5.0 ppm), indicating potential repeated use of illegal synthetic dyes in snacks sold near this school. In contrast, SD Bandarjo 01 showed no detectable Rhodamine B, suggesting better vendor compliance or supervision. Moderate contamination levels (2.4–3.1 ppm) were found at SD Bandarjo 03, SD Gogik 01, SD N Keji, and SD Kalisidi 01, reflecting ongoing but varied exposure risks among schools. These findings highlight inconsistent enforcement of food safety regulations and emphasize the need for targeted interventions to reduce children's exposure to hazardous food additives in school environments.

Table 1. Results of Rhodamine B Concentration Measurements in Snack Samples

Snack Type	Number Samples	of Rhodamine B Concentration (ppm) - Range	Rhodamine B Concentration (ppm) - Mean ± SD
Sauces	30	0.5 – 20.3	8.1 ± 5.6
Drinks	30	0.3 – 18.7	6.4 ± 4.3
Flavored Powders	32	1.2 – 25.4	11.2 ± 7.8
Snack Coatings	30	0.7 – 22.1	9.4 ± 6.1

Results Overview:

The hazard identification stage revealed that all four categories of snacks (sauces, drinks, flavored powders, and snack coatings) contained detectable levels of Rhodamine B. The concentrations ranged from 0.3 ppm to 25.4 ppm, with flavored powders exhibiting the highest average concentrations (11.2 ppm), followed by sauces (8.1 ppm), snack coatings (9.4 ppm), and drinks (6.4 ppm). Notably, some samples exceeded the recommended safety limits for synthetic dyes in food, suggesting the potential for significant health risks.

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Exposure Analysis

Exposure analysis was conducted to determine the intake value of the risk agent Rhodamine B within the body of the study participants. The results of the minimum, maximum, and average intake values are presented in the table below:

Table 2. Exposure Analysis

Concentration (ppm)	**Intake (mg/kg/hr)**
C Minimal	0
C Maximum	11,513,374.39

Table 2 shows that the minimum concentration of Rhodamine B detected in food samples was 0 ppm, while the maximum concentration found was 30.5 ppm. The corresponding intake values indicate that the maximum intake was 11,513,374.39 mg/kg/hr, whereas the minimum intake was 0 mg/kg/hr. This implies that as the concentration of Rhodamine B increases, the intake value also increases, exposing the individuals to higher potential health risks.

The intake of Rhodamine B through food is significantly influenced by various anthropometric and activity-related factors, including ingestion rate, exposure time, frequency, duration, body weight, and averaging time. Increased exposure duration and frequency correlate with higher intake values, thereby elevating health risks associated with Rhodamine B, similar to findings on dietary exposure to phthalates and polychlorinated naphthalenes, where dietary intake was a major exposure route, accounting for significant health risks (26)(27). Conversely, higher body weight inversely affects intake levels, reducing exposure per kilogram, a dynamic also observed in studies on pesticide residues and food colors, where individual consumption patterns and body characteristics play crucial roles in exposure assessments (28) (29). This highlights the complexity of dietary exposure assessments, necessitating comprehensive evaluations to accurately gauge health risks associated with various contaminants in food.

Risk Characterization

Risk characterization or the calculation of the Risk Quotient (RQ) is the final step in the environmental health risk assessment process (EHRA). This process involves comparing the exposure dose (or intake) with the Reference Dose (RfD) or safe concentration value. The formula for RQ is as follows:

RQ = Intake (mg/kg/day) / RfD (mg/kg/day)

Where the RfD used in this study was 0.2 mg/kg/day, as recommended by the U.S. Environmental Protection Agency (USEPA, 2018). If the RQ value is less than or equal to 1, the exposure is considered acceptable and safe. However, if the RQ exceeds 1, it indicates a potential health risk.

Table 3. Risk Concentration

Concentration (ppm)	Intake (mg/kg/hr)	RFD (mg/kg/day)	RQ
C Minimal	0	0.2	0
C Maximum	11,513,374.39	0.2	57,566,871.94
Average	5,756,687.195	0.2	28,783,435.97

Table 3 shows that the RQ for the minimal Rhodamine B concentration is 0, whereas for the maximum concentration, it is 57,566,871.94. The average RQ for Rhodamine B concentration is 28,783,435.97. Based on the calculated RQ values, both the maximum and average concentrations exhibit an RQ greater than 1, which indicates that the exposure levels are unsafe. The results suggest that approximately 81.25% of the samples contained Rhodamine B with exposure risks that are not safe for elementary school students who consume these snacks. From the risk assessment conducted across

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32 sampling points, 26 of them had an RQ ≥ 1 for Rhodamine B contamination, signaling an unsafe risk level.

DISCUSSION

The deliberate addition of Rhodamine B, a prohibited food additive, significantly contributes to high risk quotient (RQ) values in snacks targeted at children, raising serious public health concerns. Long-term exposure to Rhodamine B is associated with severe health issues, including liver damage, kidney dysfunction, and cancer, particularly alarming given children's vulnerability due to their developing immune systems and higher food consumption relative to body weight (30)(23). Studies indicate that artificial food colorants, including Rhodamine B, can lead to increased cancer risks and adverse health effects, such as hyperactivity and metabolic disorders (30)(23). The lack of awareness among parents and vendors, combined with insufficient regulatory enforcement, exacerbates the risks associated with these additives (23)(29). Therefore, addressing these issues through better education and stricter regulations is crucial to protect children's health.

The situation regarding food safety oversight in schools highlights significant vulnerabilities, particularly for children who are at heightened risk due to their dietary habits and the inadequate enforcement of food safety regulations. Studies indicate that children are frequently exposed to hazardous substances, such as mycotoxins, with a pilot study revealing concerning levels of deoxynivalenol (DON) in commonly consumed foods, which exceeded tolerable daily intake levels for certain age groups (31). Furthermore, socio-economic factors play a critical role, as schools in lower socio-economic areas demonstrated higher risks of foodborne illnesses and non-compliance with safety standards (32). The lack of effective education for food vendors and the community exacerbates these issues, underscoring the need for comprehensive educational initiatives and regulatory measures to mitigate risks associated with food safety in vulnerable populations (33)(34). Enhanced food labeling and documentation practices are also essential to improve safety and prevent adverse events among children (35).

The findings regarding harmful substances in schools highlight significant environmental health concerns, as these institutions, meant to foster safe learning environments, are increasingly identified as sites of exposure to emerging contaminants. Research indicates that children are particularly vulnerable to pollutants such as airborne microplastics, food additives like acrylamide, and persistent organic pollutants like PCBs, which can disrupt their immune and endocrine systems, leading to developmental issues (36) (37) (38). The prevalence of these contaminants in school settings necessitates intervention strategies from authorities, including educational programs on food safety and stricter regulations on food additives (39). Furthermore, the built environment of schools, encompassing factors like indoor air quality and exposure to hazardous materials, plays a crucial role in children's health outcomes (40). Thus, a comprehensive approach involving policy reform, community engagement, and enhanced safety standards is essential to mitigate these risks and protect children's health in educational environments (36) (40).

CONCLUSION

This study reveals that the presence of Rhodamine B, a synthetic dye banned for use in food, remains widespread in snacks consumed by elementary school students in Ungaran, Central Java, Indonesia. The exposure assessment showed varying concentrations of Rhodamine B, with several samples containing dangerous levels of this toxic dye. The results indicated that the intake of Rhodamine B significantly exceeds safe levels for a majority of students, particularly those consuming brightly colored snacks. The calculated Risk Quotients (RQ) for many samples were greater than 1, indicating that these students are exposed to unsafe levels of Rhodamine B, which could lead to severe health consequences such as liver damage, kidney dysfunction, oxidative stress, and even carcinogenic effects in the long term.

The high percentage of samples with elevated RQs reflects the systemic weaknesses in food safety regulation and enforcement, as well as the lack of awareness among food vendors and the general public about the dangers of using industrial dyes in food. Vulnerable groups, particularly children, are at greater risk due to their developing bodies, higher food intake relative to body weight, and limited ability to detoxify harmful substances. In conclusion, the findings highlight the urgent need for enhanced food safety monitoring, stricter regulations, and educational interventions to reduce the risks associated with the use of illegal food additives like Rhodamine B, especially in school environments where children are most exposed.

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