SUDAN II AND SUDAN III DYE ADULTERATION IN GARRI AND PALM OIL FROM THE NIGER DELTA: OCCURRENCE, RISKS, AND ANALYTICAL EVIDENCE

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Abstract

Garri and palm oil are widely consumed staple foods in the Niger Delta region of Nigeria. In recent years, concerns have emerged over the adulteration of these products with synthetic azo dyes, particularly Sudan II and Sudan III, which are banned for use in foods due to their toxic and carcinogenic potential. This review examines available scientific evidence on the contamination of garri and palm oil with Sudan II and Sudan III dyes. Emphasis is placed on reported occurrence levels, sources of contamination, analytical detection techniques, and associated health risks. Both conventional and modern analytical methods, including spectroscopic and chromatographic approaches, are reviewed. Existing studies indicate sporadic but concerning detection of Sudan dyes in market samples of palm oil and garri, often linked to intentional colour enhancement and poor regulatory enforcement. While analytical advances such Surface-Enhanced Raman Scattering (SERS) spectroscopy combined with chemometric analysis show promise for rapid screening. Analytical methods such as High-Performance Liquid Chromatography with Ultraviolet detection (HPLC- UV), Liquid Chromatography with mass spectrometry (LC- MS), and UV- visible spectrophotometry have proven effective for detection and quantification of these contaminants in food matrices. while chromatographic techniques remain critical for confirmatory analysis. Public awareness and regulatory monitoring remain limited. The continued presence of these dyes in staple foods poses significant food safety and public health challenges in the Niger Delta. Strengthened surveillance, adoption of rapid screening tools, and improved regulatory enforcement are essential to mitigate the risks associated with Sudan dye adulteration in garri and palm oil.

***Keywords**: Sudan dyes, Garri.*

1.0 INTRODUCTION

Food adulteration remains a pervasive public health and socio-economic challenge in many developing economies, where informal markets and limited regulatory oversight create fertile ground for economically motivated adulteration (EMA). At its core, food adulteration involves the intentional addition, substitution, or tampering of food substances with inferior or harmful agents to increase profit margins, often at the expense of consumer safety and nutritional quality. Such practices are propelled by weak enforcement of food safety standards, fragmented supply chains, and gaps in analytical monitoring capacities, particularly in low- and middle-income nations.[1]

As a result, adulterated food products can inflict both acute and chronic health effects, including carcinogenic, toxic, or metabolic disorders among vulnerable populations. Among the array of adulterants encountered in developing country food systems, industrial azo dyes such as Sudan II and Sudan III have attracted particular concern due to their misuse in staple and widely consumed products. Originally designed for industrial applications such as colouring textiles, plastics, and materials unrelated to human ingestion these dyes are banned for use in foods owing to their potential carcinogenicity and toxicological effects. [2]. Despite regulatory prohibitions, Sudan dyes have been repeatedly detected in edible oils and spice derivatives imported into developed economies and within local markets, indicating the global scope of this fraud tactic. [2.4].

In the context of West Africa, palm oil and garri (cassava flakes) represent cornerstone dietary fats and carbohydrate staples, respectively, forming the backbone of daily nutrition for millions. The natural deep red or orange hues of palm oil often serve as visual quality cues for consumers, creating incentives for unscrupulous actors to enhance or mimic desirable sensory attributes through the addition of banned dyes, including Sudan II and III. [4] Similarly, garri produced through the fermentation and roasting of cassava tubers can be subject to adulteration with extraneous materials (e.g., non-food fibrous matter) to boost weight and profitability, underscoring the broader vulnerability of staple foods to fraudulent practices. [1] This intersection of economic pressures, aesthetic preferences, and limited testing infrastructure typifies the complex drivers of food fraud in developing economies, where enforcement capacity often fails to keep pace with creative adulteration strategies.

The Niger Delta region, with its unique socio-economic profile and extensive networks of artisanal and commercial food distribution, provides a salient case for examining the occurrence, health risks, and analytical evidence of Sudan dye adulteration in food. Understanding not just the prevalence of such adulterants but also the analytical challenges and emerging detection techniques is critical for framing effective regulatory responses and protecting public health. This review synthesizes current evidence on Sudan II and Sudan III adulteration in garri and palm oil in the Niger Delta, situating these findings within the broader discourse on food adulteration in developing economies and the urgent need for robust analytical and policy interventions.

2. 0 IMPORTANCE OF GARRI AND PALM OIL IN THE NIGER DELTA DIET IN THE NIGER DELTA REGION OF NIGERIA.

Garri and palm oil are central to everyday nutrition, culture, and livelihoods. These staples are more than food items they are embedded in regional identity, economics, and social life. Their production, trade, and consumption reflect deep historical roots and ongoing socio-economic dynamics in one of Nigeria's most distinctive cultural landscapes.

2.1 Nutritional Significance

2.1.1 Garri

Garri is a major form of processed cassava consumed across the Niger Delta and Nigeria at large. It is a dehydrated, fermented granular food that can be rehydrated as a staple dish or served cold with accompaniments. Nutritionally, garri provides a significant source of carbohydrates and energy:

- Per 100 g, garri supplies around 350–400 kcal, with 85–90 g carbohydrates, modest fibre, negligible protein, and a trace of fat. Its energy value makes it an accessible carbohydrate staple in both rural and urban diets.
- Variations like yellow garri are fortified with palm oil or orange fleshed Sweet Potato, increasing their vitamin A and micronutrient content. [6]

Though low in protein, garri's high carbohydrate and caloric density make it a core caloric source in resource-limited settings.

2.1.2 Palm Oil

Palm oil, extracted from the fruit of the Elaeis guineensis palm, is rich in fats and fat-soluble vitamins:

- Unrefined (red) palm oil contains vitamin A precursors (beta-carotene) and vitamin E, which support vision, immunity, and antioxidant functions. [7]
- It also provides essential fats that enhance energy intake and facilitate the absorption of fat-soluble micronutrients.

While global health discussions note that palm oil is high in saturated fat, its traditional unrefined form remains a nutritionally valuable dietary fat in the context of many Niger Delta meals when consumed in moderation.

2.2 Cultural Significance

2.2.1 Staple Identity and Daily Life

Garri and palm oil are cultural pillars in Niger Delta cuisine. Garri is consumed daily in multiple forms soaked as a snack with water, sugar, or groundnuts, or transformed into eba, a dough eaten with soup. Palm oil defines many regional dishes and cultural foods such as:

- Oghwo Soup, a palm oil-based dish, is a traditional Urhobo preparation commonly served with garri and is integral to celebrations like weddings.

2.2.2 Symbolism in Social Rituals

Palm oil also features prominently in festivals, rites of passage, and communal sharing symbolizing hospitality, fertility, and wealth in many Niger Delta societies. It is often used in ceremonies and offered during family or communal rites, marking it as more than a culinary ingredient. [7]

2.3 Economic Significance

2.3.1 Livelihoods and Employment

Both garri and palm oil form the backbone of local agricultural economies:

- Cassava cultivation, garri processing, and palm oil extraction support numerous smallholder farmers, processors, and traders in rural and peri-urban areas throughout the Niger Delta.
- A large share of palm oil production and processing is carried out by women, making it a key source of income and economic participation for female household heads and rural families.

2.3.2 Market Dynamics

The market structure for garri and palm oil in the Niger Delta is typically characterized by:

- Numerous small producers and traders operating in a competitive market with many buyers and sellers.
- Assembly markets that aggregate garri from smallholder producers and distribute to urban centres and institutions like hotels and schools.
- Both items are traded in bulk (e.g., 50 kg sacks) and increasingly in smaller packaged units, reflecting diverse consumer accessibility.

These market functions sustain food availability, employment, and income generation, with potential for expansion if production and value-chain efficiency improve.

2.4 Consumption Patterns in the Niger Delta

2.4.1 Staple Frequency

Cassava derivatives (especially garri) feature in almost every household's diet in the region, consumed multiple times weekly in varying forms. In some states of the Niger Delta, over half of households consume cassava products more than four times a week, illustrating its dominance in dietary patterns. Garri's versatility as a quick meal solution or as part of elaborate meals with soups and its affordability make it indispensable in urban and rural diets alike.

2.4.2 Market Consumption Trends

Palm oil remains the preferred cooking fat and flavour base for many Niger Delta dishes, although price fluctuations influence consumption quantity and substitution choices. Traditional markets, roadside stalls, and retail environments facilitate widespread access to both garri and palm oil across socio-economic groups.

2.4.2 Challenges and Opportunities

While garri and palm oil are central to food security, their production and supply face challenges, including:

- Environmental degradation from oil industry pollution, which negatively affects agriculture and food availability in some communities.
- Declining yields in locally grown cassava and palm due to soil contamination and reduced farmland suitability in impacted zones. [8]

However, strengthened value-chain investments, improved processing technologies, and market access expansion could significantly enhance rural incomes, food security, and nutritional outcome. Garri and palm oil are foundational to the Niger Delta diet, offering nutritional sustenance, cultural identity, and economic empowerment. Their roles extend beyond sustenance to shape community rituals, local markets, and regional economies. Supporting their sustainable production and equitable market integration can promote food security, cultural continuity, and economic resilience in one of Nigeria's most dynamic regions.

3. 0 EMERGENCE OF SYNTHETIC DYE ADULTERATION IN FOODS

Food colorants substances added to food to alter or enhance appearance have a long history that spans many cultures and eras. While natural colorants were traditionally used, the industrial revolution and advances in organic chemistry led to the development of synthetic dyes. Over time, concerns about adulteration the addition of unauthorized or harmful substances, including synthetic dyes to food products have risen due to potential health risks and deceptive practices.

3.1 Early Practices and Natural Colorants

Before industrialization, food was coloured using natural sources such as plant extracts (e.g., beetroot, saffron) or mineral pigments. Ancient Egyptian bakers around 1500 B.C. added natural extracts and wine to improve the appearance of sweets, illustrating early use of colorants in foods. [9]

3.2 Industrial Revolution and First Synthetic Dyes

The first synthetic dye, mauveine, was discovered by Sir William Henry Perkin in 1856 during coal-tar research, marking a watershed in dye chemistry. These early dyes were widely adopted due to their bright colours, low cost, and ease of production, quickly spreading into the food industry by the late 19th century. [9] By 1900, artificial colouring agents often derived from coal tar chemicals were prevalent in numerous foods across Europe and the United States. Some of these colours were toxic; for instance, red lead and copper arsenate were used to colour cheese and tea leaves, respectively, leading to documented health issues including deaths. [10]

3.3 Regulation Begins

Concerns about harmful colorants led to government intervention:

- In 1906, the U.S. Food and Drugs Act prohibited the use of poisonous or deleterious colours in food that were used to mask inferior products. [11]
- In 1907, the USDA listed seven approved dyes for use in food.
- By 1938, additional regulatory frameworks required all food dyes to be clearly listed on labels and restricted unsafe additives. [10]

3.4 Synthetic Food Dyes and Adulteration

3.4.1 What Are Synthetic Food Dyes?

Synthetic food dyes are man-made chemicals, often originating from petroleum or coal-tar derivatives, engineered to provide vibrant and stable colour in processed foods. Unlike natural pigments, these dyes are designed for consistency, long shelf life, and cost-effective production.

Commonly used synthetic dyes include Red 40, Yellow 5, Blue 1, and others certified for food use by safety authorities in various jurisdictions. They can impart hues not achievable with natural colorants and are widely applied in candies, beverages, snacks, and baked goods. [12]

3.4.2 Adulteration Practices

Adulteration occurs when substances are added to foods in a way that deceives consumers or substitutes cheaper materials for higher-quality ingredients. In the context of colorants, adulteration takes several forms:

- Unauthorized synthetic dyes added to foods to mask spoilage or inferior quality.
- Excessive dye use beyond permitted levels to enhance appearance for market appeal.
- Use of industrial dyes not intended for food but co-opted due to lax regulation.

Historical records show that unmonitored synthetic dyes were used broadly in the early 1900s, often without knowledge of their toxicity. Some of these early products were actually textile or industrial pigments sold to food producers.

3.5 Case Studies and Modern Incidents

Instances of synthetic dye adulteration continue to surface. In 2024, Taiwan experienced a major contamination incident in which banned Sudan Red dyes industrial dyes with known carcinogenic potential were illegally mixed into chili powder and distributed to multiple food manufacturers, triggering public health responses and product recalls.[13]

This underscores that, despite regulation, food adulteration remains a global challenge and that vigilance in monitoring supply chains and enforcing safety standards remains critical.

Henry, E. Peters, et al [14] reported the effect of Sudan II Adulteration of Palm Oil on the Serum Enzyme, Bilirubin Concentration, and Renal Function Biomarkers of Albino Wistar Rats.

The study evaluates the health impacts of Sudan II-adulterated palm oil on albino Wistar rats, analysing its effects on liver enzymes, bilirubin levels, and renal biomarkers.

Nyorkeh, R., et al [2] provided insights into palm oil adulteration over 18 years using the European Union's (EU) rapid alert system for food and feed (RASFF),
and the methods for detecting this adulterant.

A report by Stiborova et al [14] classified various Sudan dyes (including Sudan II and Sudan III) as Group 3 carcinogens, highlighting their health risks in food products.

A review by Prabha et al [15] also discussed the adulteration of various granulated food products, including garri and spices, with chemical dyes, including the Sudan series.

3.6 Health Concerns and Regulatory Responses

3.6.1 Health Risks

Synthetic food dyes have no nutritional benefit and can pose health risks when consumed in large amounts or when unauthorized dyes are used. Scientific studies have linked certain azo dyes to:

- Carcinogenicity and DNA damage in animals.
- Allergic reactions such as hives and asthma in sensitive individuals.
- Behavioural issues (especially in children), including hyperactivity and attention problems.

These concerns have led regulators and advocacy groups to reevaluate the safety of routinely permitted dyes.

3.6.2 Regulatory Actions

Authorities in several countries are updating policies on synthetic dyes:

- The U.S. FDA banned Red No. 3 in foods starting in 2025 due to cancer concerns in animal studies, with full removal deadlines set for 2027 in foods and 2028 in medicines. [12]
- Some U.S. states have enacted broader bans on multiple synthetic dyes in school meals and statewide food supplies.

These regulatory shifts reflect growing awareness of potential risks and public pressure to substitute synthetic dyes with natural alternatives where possible.

The emergence of synthetic dye adulteration in foods is deeply rooted in technological change and economic incentives that favoured low-cost, vibrant colorants. While synthetic dyes revolutionized food aesthetics and processing efficiency, they also introduced risks associated with adulteration and human health. Over more than a century, regulatory frameworks have evolved to reduce harmful practices, but ongoing concerns and incidents reveal that food dye safety remains an active area of public health focus.

4.0 OVERVIEW OF SUDAN DYES

Sudan II and Sudan III are part of the Sudan dye family a group of synthetic lipophilic azo dyes characterized by one or more azo (-N=N-) functional groups linking aromatic systems. Azo dyes derive their characteristic chromophore (intense colour) from this extended conjugated system of alternating double bonds and aromatic rings, which absorbs visible light. Such dyes are widely used industrially to colour oils, waxes, plastics, and textiles but are illegal in foods because of health risks.

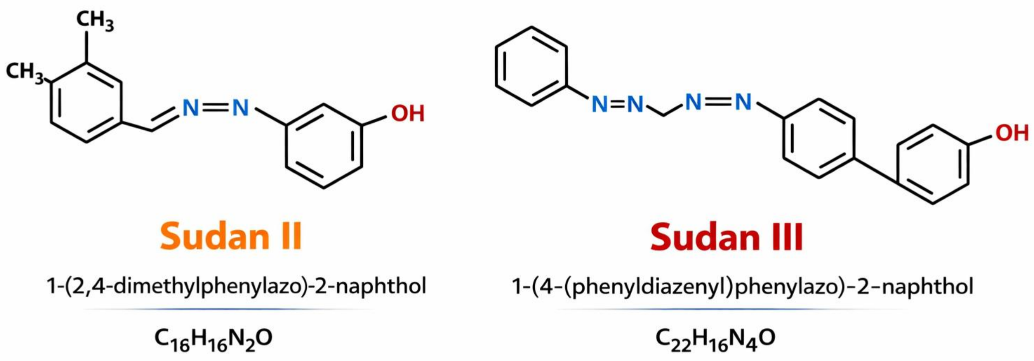

Fig. 1 Chemical structures of Sudan II and Sudan III dyes

4.1 Sudan II

- Chemical name: 1-(2,4-dimethylphenylazo)-2-naphthol.
- Molecular formula: $C_{18}H_{16}N_2O$; molar mass: 276.34 g/mol.
- Structure: A single azo linkage joins a methyl-substituted phenyl ring to a naphthol unit.
- Its extended conjugation and aromatic framework provide strong orange-red coloration and fat solubility. (see Fig. 1)

4.2 Sudan III

- Chemical name: 1-(4-(phenyldiazenyl) phenylazo)-2-naphthol.
- Molecular formula: $C_{22}H_{16}N_4O$; molar mass: 352.39 g/mol.
- Structure: Contains two azo groups linking three aromatic rings (a naphthol with a diazo benzene moiety), which enhances the intensity and stability of its reddish-orange hue relative to simpler Sudan dyes. (see Fig. 1)

These structural features place Sudan II and Sudan III in the oil-soluble class of azo dyes, often referred to as lysochromes dyes that preferentially partition into non-polar (lipid) phases rather than aqueous environments.

4.3 Azo Dye Chemistry

4.3.1 Azo Functional Group

The defining chemical feature of azo dyes is the azo linkage (-N=N-), which:

- Connects two aromatic moieties, creating an extended π-conjugated system that absorbs visible light and produces vivid colours.
- Is formed through diazotization and azo coupling reactions in synthetic dye chemistry.
- Contributes to chromophoric behaviour the spectrum of colours seen across azo dye families depends on the number of azo linkages and the nature of substituent groups on the aromatic rings.

4.3.2. Lipophilicity and Solubility

The aromatic, non-polar nature of Sudan dyes confers:

- High solubility in fats and oils (non-polar media).
- Low water solubility due to lack of strongly polar substituents.

- Their chemistry makes them especially suitable for colouring hydrophobic substances, such as edible oils or fatty food matrices the very property exploited in food adulteration.

4.3.3 Physicochemical Properties Relevant to Food Adulteration
Colour and Detection

- Sudan II and Sudan III exhibit strong orange-red hues when dissolved in non-polar solvents, making them visually attractive for adulterating products where a vibrant red or orange colour is desirable (e.g., chili powder, palm oil).
- Their UV-visible absorbance arises from extensive π-conjugation, with detectable peaks that support analytical detection methods like spectrophotometry and chromatography.

Solubility and Partitioning

- These dyes are oil-soluble and partition strongly into lipid-rich food stuffs such as palm oil, sauces, or spice pastes making them hard to remove once introduced.
- Their low polarity and high molecular weight also contribute to strong retention in non-polar matrices, complicating food authentication.

4.3.4 Health and Regulatory Context

- Sudan dyes are not approved for food use by global authorities (e.g., WHO , EFSA, FDA) and are banned due to genotoxic and carcinogenic potentials observed in laboratory studies.
- Their chemical stability and lipophilicity, while advantageous industrially, make them resistant to degradation under normal food processing, raising health exposure risks if consumed.

Table 1 Some Physicochemical Properties of Sudan II and Sudan III dyes

Feature	Sudan II	Sudan III
Azo Groups	One	Two
Molecular Formula	$C_{18}H_{16}N_2O$	$C_{22}H_{16}N_4O$
Solubility	Fat-soluble, water-insoluble	Fat-soluble, water-insoluble
Colour	Orange-red	Reddish-orange
Food Adulteration Risk	High	High

Table 1 illustrates that both Sudan II and Sudan III are synthetic azo dyes with extended conjugation and oil solubility, which underlie their chromatic properties, lipophilicity, and misuse in food adulteration despite international bans. Their structural features and physicochemical behaviour also support analytical detection in contaminated food products.

4.3.5 Regulatory prohibitions

The adulteration of palm oil and garri with Sudan dyes has prompted calls for stronger regulatory measures and public health interventions. Although Sudan dyes are banned for use in food products in Nigeria, enforcement remains weak, and adulteration continues to be widespread in local markets.
Onyeaka et al [16] stressed the need for improved regulation and enforcement of food safety standards in Nigeria. The study suggested that authorities such as the National Agency for Food and Drug Administration and Control (NAFDAC) should implement more rigorous testing and monitoring programs, the report also suggested that consumer education campaigns are crucial to raising awareness about the dangers of Sudan dye contamination. These campaigns should focus on informing both consumers and food producers about the health risks and the legal consequences of adulteration. In a bid to proffer sustainable solutions to this menace Abide et al. [6]proposed that the use of natural food colorants could reduce the reliance on harmful artificial dyes like Sudan I in both palm oil and garri production.

4.3.6 Toxicological and Carcinogenic Properties

Sudan dyes are a group of synthetic azo dyes that have been widely used in various industries, including food, textiles, and cosmetics. However, these dyes, particularly Sudan I, Sudan II, Sudan III, and Sudan IV, have raised significant concerns due to their toxicological and carcinogenic properties. Below is an overview of the toxicological and carcinogenic effects of these dyes, along with relevant scientific references.

Toxicological Properties of Sudan Dyes

Sudan dyes are known for their toxicity, especially when exposure is prolonged or occurs at high concentrations. The primary toxic effects of Sudan dyes are as follows:
Acute Toxicity: Sudan dyes, particularly Sudan I, are toxic when ingested or absorbed through the skin. They can cause nausea, vomiting, abdominal pain, and skin irritation upon acute exposure.[14] In animal studies, the ingestion of large doses has been linked to organ damage, particularly to the liver and kidneys.[17]
Skin and Eye Irritation: Direct contact with Sudan dyes can result in skin irritation, allergic reactions, and dermatitis. The dyes also cause significant irritation to the eyes, with possible long-term damage if not promptly treated. [18, 19]
Organ Toxicity: Chronic exposure to Sudan dyes can lead to damage to vital organs. Studies have shown that prolonged exposure can result in liver fibrosis, necrosis, and kidney damage.[19]

Carcinogenic Properties of Sudan Dyes

Sudan dyes, particularly Sudan I, are classified as potential human carcinogens based on extensive animal studies. The carcinogenic properties are highlighted by the following findings:

Carcinogenicity in Animals: Studies on rodents have shown that Sudan I, in particular, induces liver tumors, particularly when animals are exposed to high concentrations over long periods. These effects have led researchers to classify Sudan I as a probable carcinogen for humans. Sudan III and Sudan IV have also demonstrated mutagenic properties, contributing to their carcinogenic potential.[19]

Mutagenicity: Sudan I has been shown to be mutagenic in various in vitro and in vivo tests. The dye is metabolized into reactive intermediates that can bind to DNA and cause mutations, which is a key mechanism in cancer development. This mutagenic activity increases the likelihood of Sudan dyes contributing to cancer formation.

Human Carcinogenicity Risk: While direct evidence of Sudan dyes causing cancer in humans is limited, the carcinogenic potential of Sudan I and other Sudan dyes, especially through chronic exposure, raises significant concerns.[20,21] The International Agency for Research on Cancer (IARC) classified Sudan I as a Group 2B carcinogen, indicating that it is possibly carcinogenic to humans.[20]

5.0 ANALYTICAL METHODS FOR DETECTION OF SUDAN DYES

Sudan dyes (e.g., Sudan I, II, III, IV) are synthetic azo colorants that have been banned in food products due to concerns over their carcinogenic properties. Despite the ban, Sudan dyes continue to be found as adulterants in various food products such as spices, oils, sauces, and others. The detection of these dyes in food is important for ensuring food safety. Reliable detection of these dyes requires effective sample preparation and selection of suitable analytical methods as shown in the following section

Sample Preparation Methods

Effective extraction and cleanup of Sudan dyes from food matrices are essential before analysis. Typical steps include:

Solid-Liquid Extraction (SLE): Dyes are extracted from spices, oils, and sauces using organic solvents such as acetonitrile and hexane.

Ultrasonic-Assisted Extraction: Ultrasound enhances dye release, reducing extraction time and improving recovery.

Pressurized Liquid Extraction: Uses elevated temperature and pressure to improve extraction efficiency.

Solid-Phase Extraction (SPE): Used for cleanup and concentration, reducing matrix interference.[22]

5.1 Spectroscopic and Screening Methods

UV-Visible Spectroscopy

UV-Vis spectroscopy is used for rapid screening of Sudan dyes in food products, but it has limitations in sensitivity and selectivity compared to chromatographic techniques.

Surface-Enhanced Raman Scattering (SERS)

SERS combined with chemometric analysis has been explored to quantify Sudan I–IV dyes. This method provides rapid, portable quantification with reduced sample preparation.[23]

Chromatographic Techniques

High-Performance Liquid Chromatography (HPLC)

HPLC with UV/Vis Detection:

This is the most commonly used method, separating Sudan dyes on reversed-phase columns (usually C18) and detecting them via UV absorbance, often around 480-506 nm. HPLC with electrochemical detection has also been used for improved sensitivity.[23]

Liquid Chromatography-Mass Spectrometry (LC-MS/MS)

LC-MS/MS is the gold standard for confirmatory testing of Sudan dyes due to its high sensitivity and selectivity. It separates dyes chromatographically and detects them based on mass fragmentation. Tandem MS with electrospray ionization has been employed to detect Sudan dyes in low levels in food matrices.[24,25]

Thin Layer Chromatography (TLC)

TLC is a simple and low-cost qualitative method for detecting Sudan dyes in food. After extraction, samples are applied to a plate and developed; spots corresponding to dye standards indicate contamination.[26,27]

5.2 Comparison of Techniques

Details captured in table 2 show that Chromatographic techniques such as HPLC with UV/Vis and LC-MS/MS offer high sensitivity and specificity, making them the preferred methods for regulatory testing. Alternative methods such as TLC, UV-Vis, and SERS provide lower-cost screening alternatives. Regular monitoring using these techniques ensures compliance with food safety standards.

Table 2 Comparison of different techniques for detecting Sudan dyes in food samples

Method	Sensitivity	Selectivity	Cost	Typical Use
TLC	Low	Low	Low	Preliminary Screening
HPLC-UV	Moderate	High	Moderate	Routine analysis
HPLC with Electrochemical	High	High	Moderate	Enhance Sensitivity
LC-MS	Very High	Very High	High	Confirmatory analysis
UV-VIS Spectrophotometry	Low	Low	Low	Rapid Screening
SER	Moderate-high	Moderate	Moderate	Rapid quantification

6.0 HEALTH RISK AND PUBLIC SAFETY IMPLICATIONS

Studies on Sudan dye contamination in palm oil and garri have consistently highlighted the toxicological and carcinogenic risks of these dyes. Sudan dyes, especially Sudan I, have been classified as potential human carcinogens by the International Agency for Research on Cancer. The primary health risks associated with consuming food adulterated with Sudan dyes include:

Carcinogenicity: Sudan dyes, particularly Sudan I, are linked to liver and kidney cancer in animal models. There is concern about the potential for these dyes to cause similar effects in humans, especially with chronic exposure.[17]

6.1 Regulatory and Public Health Efforts

The adulteration of palm oil and garri with Sudan dyes has prompted calls for stronger regulatory measures and public health interventions. Although Sudan dyes are banned for use in food products in Nigeria, enforcement remains weak, and adulteration continues to be widespread in local markets. Several studies have called for:

Stronger Regulatory Oversight: Nwachoko et al.[17] stressed the need for improved regulation and enforcement of food safety standards in Nigeria. The study suggested that authorities such as the National Agency for Food and Drug Administration and Control (NAFDAC) should implement more rigorous testing and monitoring programs.

Public Awareness Campaigns: These campaigns should focus on informing both consumers and food producers about the health risks and the legal consequences of adulteration.

7.0 CONCLUSION

From the foregoing it is obvious that Sudan II and Sudan III dyes have been detected in edible oils and garri sold in parts of the Niger Delta. These illegal dyes are known health hazards that can pose serious risks to consumers if present above safe limits. Analytical methods such as high-performance liquid chromatography with ultraviolet detection (HPLC- UV), liquid chromatography with mass spectrometry (LC- MS), and UV- visible spectrophotometry have proven effective for detection and quantification of these contaminants in food matrices. These techniques offer sensitivity and specificity, enabling researchers and regulators to identify even low levels of Sudan dyes in complex food samples.

However, current monitoring in the region remains a challenge that should be surmounted. There is a need to expand laboratory capacity so that more routine testing can occur. Laboratories should adopt validated methods such as HPLC- UV or LC- MS for regular surveillance, and quality control protocols should be standardized across testing centres. Training of analysts in proper sample preparation and instrument operation will improve reliability of results.

From a regulatory standpoint, authorities must strengthen enforcement of food safety laws that prohibit the use of synthetic azo dyes in foods. Clear maximum residue limits for Sudan dyes should be established in line with international standards and communicated to food producers and traders. Regular inspection of markets and food processing sites, coupled with sanctions for non- compliance, will deter intentional adulteration.

Public awareness campaigns are also needed so that consumers can recognize the dangers of contaminated products and make safer choices.

In a nutshell, the fight against Sudan II and Sudan III contamination in the Niger Delta requires a combination of advanced analytical surveillance, stronger regulatory frameworks, and robust public enlightenment campaigns via talk shows, rallies and townhall meetings. With coordinated action among scientists, regulators, and community stakeholders, it is possible to reduce the prevalence of these contaminants in staple foods and protect public health.

REFERENCES

1. Njiru, J. M., Njeru, E., Kang'iri, J., Lunani, I., Rotich, H., Muriira, G., ... & Nyaboga, E. N. (2025). Food fraud in selected sub-Saharan Africa countries: a wake-up call to national regulatory bodies to support enforcement and food safety. Frontiers in Food Science and Technology, 5, 1499271.
2. Nyorkeh, R., Teye, E., Essuman, E. K., Haughey, S. A., Logan, N., & Elliott, C. T. (2024). 18 Year analysis of RASFF notifications on Sudan dye adulterated cases in palm oil (2004 to 2022) and the principles of the technique for its detection. Sustainable Food Technology, 2(5), 1235-1245.
3. Khalid, N., Norlin/Abdul Rahman Khalid (Nor Aid), & Yan, C. W. (2025). The Palm Oil Export Market.
4. Teye, E., Amoah, R. S., Adu, M. O., & Darko, D. (2017). Evaluation and developing simple techniques for assessing Gari adulteration. Journal of Food Security, 5(5), 162-168.
5. Abid, H. M. R., Aslam, S., Alwan, N., & Khalid, N. (2025). Current readiness on food fraud risk mitigation in

developing countries: a review. Agriculture & Food Security, 14(1), 9.
6. Joel, N., Oluchi, N., & Elijah, A. I. (2019). Effect of palm oil inclusion on the quality of garri produced from white and yellow cassava (Manihot esculenta cranz) roots. Annals: Food Science & Technology, 20(3).
7. Oguntibeju, O. O., Esterhuyse, A. J., & Truter, E. J. (2009). Red palm oil: nutritional, physiological and therapeutic roles in improving human wellbeing and quality of life. British journal of biomedical science, 66(4), 216-222.
8. Kanu, C. E., & Ajoku, B. C. (2020) Perceived Impact of Oil Spill on Cassava Production in Oguta Local Government Area of Imo State, Nigeria. International Journal of Recycling of Organic Waste in Agriculture (2020)9: 309-321
9. Francis, F. J. (2002). Food colorings. Colour in food: Improving quality, 16, 297-330.
10. Coultate, T., & Blackburn, R. S. (2018). Food colorants: Their past, present and future. Coloration Technology, 134(3), 165-186.
11. Burrows, JD, A. (2009). Palette of our palates: a brief history of food coloring and its regulation. Comprehensive Reviews in food science and food safety, 8(4), 394-408.
12. Martuscello, A. (2026).The New Red Scare: The Shocking Truth Behind the FDA's Unethical Regulation of Red 40 and Other Synthetic Food Dyes. Pace Law Review, 46(2), 89.
13. Chang, C. C. (2025). Discussing how to restore the corporate image after a food safety incident. British Food Journal, 127(10), 3615-3629.
14. Henry, E., Aniekan, S., & Christine, A. (2022). Effect of Sudan II Adulteration of Palm Oil on the Serum Enzyme, Bilirubin Concentration and Renal Function Biomarkers of Albino Wistar Rats. Enzyme Engineering.
15. Prabha, K., Nivashini, K. L., Madhumita, S., Kanishka, S. S., & Prasadh, S. H. (2024). Overview of adulterants in granulated food products using image processing. In Challenges in Information, Communication and Computing Technology (pp. 437-442). CRC Press.
16. Onyeaka, H.; Ekwebelem, O.C.; Eze, U.A.; Onwuka, Q.I.; Aleke, J.; Nwaiwu, O.; Chionuma, J.O. Improving Food Safety Culture in Nigeria: A Review of Practical Issues. Foods 2021, 10, 1878. https://doi.org/10.3390/foods10081878
17. Nwachoko N, Odinga T, Brantley AU, Ibanibo TE. Toxicological effects of Sudan III azo dye in palm oil on liver enzyme and non- enzyme markers of albino rat*. International Journal of Nutrition and Food Sciences, 9(4):104- 111, 2020
18. Platzek T., Lang,C., Grohmann,G., Gi, U S and Balye W. (1999) Formation of a Carninigenicaromatic amine from am Azo dye by human skin bacteria In Vivo. Human and Experimental Toxicology. 18(9), 552-559
19. Santa Cruz Biotechnology, Material Safety Data sheet. Sudan Dyes.Chemwatch.
20. Stiborova, M., H Schmeiser, H., Frei, E., Hodek, P., & Martinek, V. (2014). Enzymes oxidizing the azo dye 1-phenylazo-2-naphthol (Sudan I) and their contribution to its genotoxicity and carcinogenicity. Current Drug Metabolism, 15(8), 829-840.
21. Rebane, R., Leito, I., Yurchenko, S., & Herodes, K. (2010). A review of analyti cal techniques for determination of Sudan I–IV dyes in food matrixes. Journal of Chromatography A, 1217(17), 2747-2757.
22. Cornet, V., Govaert, Y., Moens, G., Van Loco, J., & Degroodt, J. M. (2006). Development of a fast analytical method for the determination of Sudan dyes in chili-and curry-containing foodstuffs by high-performance liquid chromatography− photodiode array detection. Journal of Agricultural and Food Chemistry, 54(3), 639-644.
23. Di Anibal, C. V., Odena, M., Ruisánchez, I., & Callao, M. P. (2009). Determining the adulteration of spices with Sudan I-II-II-IV dyes by UV–visible spectroscopy and multivariate classification techniques. Talanta, 79(3), 887-892.
24. Genualdi, S., MacMahon, S., Robbins, K., Farris, S., Shyong, N., & DeJager, L. (2016). Method development and survey of Sudan I–IV in palm oil and chilli spices in the Washington, DC, area. Food Additives & Contaminants: Part A, 33(4), 583-591.
25. Wang, L., Zheng, J., Zhang, Z., Wang, T., & Che, B. (2013). Determination of eight Sudan dyes in chili powder by UPLC-MS/MS. Engineering, 5(10), 154-157.
26. Gold, I. L., Imoisi, O. B., & Akpose, O. I. (2023). Thin layer chromatographic techniques for detection of Sudan dyes in palm oil. Journal of Chemical Society of Nigeria, 48(2).
27. NS, S. (2026). Biotechnology and Biodiversity. In Law Relating to Biotechnology, 2nd Ed. Perspectives from USA, UK, EU and India (pp. 93-170). Singapore: Springer Nature Singapore.
28. Schummer, C., Sassel, J., Bonenberger, P., & Moris, G. (2013). Low-level detections of Sudan I, II, III and IV in spices and chili-containing foodstuffs using UPLC-ESI-MS/MS. Journal of agricultural and food chemistry, 61(9), 2284-2289.