Investigation and Health Risk Assessments of Potentially Toxic Elements (PTEs) In Hair-Dye Products

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ABSTRACT

The persistent presence of potentially toxic elements (PTEs) in pigments and other ingredients used in the cosmetic industry is becoming worrisome to the global environmental analysts. Hair dye products have recently been implicated as another human exposure route to PTEs. This study investigated the health risk of the presence and concentrations of PTEs in five different brands of hair dye products (A1, A2, A3, A4 and A5) using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). The concentrations of 22 PTEs; Silver, Arsenic, Boron, Cerium, Cadmium, Cobalt, Chromium, Cesium, Copper, Iron, Mercury, Magnesium, Manganese, Molybdenum, Nickel, Palladium, Lead, Sulphur, Antimony, Selenium, Silicon and Zinc were determined. The studied PTEs concentrations were ranged; Cs > Mg > Si > Fe > Pd > Pb > Ag > Zn > Mn > Se > Ni > Ce > Sb > As > Cr > B > Cu > Mo > Co > Cd > S > Hg. The average PTEs concentration ranged as (1074.149 > 882.715 > 720.246 > 689.242 >7.845) ppm for A4 >A1 >A5 > A2 > A3 respectively. The values for Ag, Ce, Cs, Fe, Mg, Mn, and Si were all above the United State Food and Drugs Administration (USFDA) limits, while those of As, B, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pd, Pb, S, and Zn were below the limits in all the samples except for Se in A2, and A3 with the values of 1.21 and 1.18 respectively. Lifetime cancer risk (LCR) values of PTEs through inhalation were in decreasing order of Cr > Co > As > Ni > Cd > Pb and were all above the limits except for Ni in A5. The values of LCR dermal analyzed for adults were found in the order of A5 > A4 > A1 > A2 > A3. In conclusion, protracted frequent use of these hair-dye products may pose cancer risks and elemental toxicity through dermal contact, ingestion and inhalation.

Keywords: Dermal Exposure, Heavy metals, Hazard Index, ICP-OES, Life-time Cancer Risk

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INTRODUCTION

PTEs are among the most significant environmental pollutants; some of them may be hazardous to human health even at extremely low concentrations due to their lengthy biological half-lives, non-biodegradability and toxicity[1]. Humans are exposed to heavy metals on a regular basis in a variety of ways and this is among the health issues that the global community is battling with. Metals with potential toxicity can be discharged into the environment by both anthropogenic and natural processes. When these substances enter the human body system, they can cause a variety of medical issues including; cancer, birth defects, allergic reactions, contact dermatitis, brittle hair, and hair loss. They can also cause neurological and developmental disorders, reproductive issues, cardiovascular diseases, skeletal, blood, immune and gastrointestinal disorders[2]. Regretfully, no research has been done on the amounts of these dangerous substances in chemical hair dyes that are sold in Ibadan. Meanwhile, hair dyes are widely used in Nigeria, as thousands of fashion-conscious people rely on them for cosmetic purposes. Determination of the health effects of these potentially harmful metals on hairdressers (and other users) is crucial since they are frequently included in hairdressing cosmetics.

The significance of this research lies in the fact that hair-stylists, barbers and their customers in Ibadan (and by extension throughout the nation) can utilize the information to make decisions about hair coloring and HDPs usage. The study's results will also provide valuable insights into the levels of heavy metals in popular hair dyes brands, human exposure routes to these PTEs and health risks associated with its long-term exposure[3]. The study will also highlight the potential carcinogenic effects on children and adults within the community of these HDPs users due to exposure to these PTEs.

The aim of this study is to identify the PTEs that are present, the concentration levels and the associated health risks of using these HDPs.

The main objectives of the study are to:

i. use inductively coupled plasma optical emission spectroscopy (ICP-OES) to ascertain the presence and concentration of specific PTEs (silver, arsenic, boron, cerium, cadmium, cobalt, chromium, cesium, copper, iron, mercury, magnesium, manganese, molybdenum, nickel, palladium, lead, sulphur, antimony, selenium, silicon and zinc) in a some popularly used chemical hair coloring products.

ii. determine the extent of exposure to these PTEs in adult inhabitants of Ibadan, and in turn, the associated non-carcinogenic (hazard quotient and hazard index) and life cancer risk.

MATERIALS AND METHODS

Sample Collection

Five samples of hair-dye brands, popularly used in Ibadan, were bought from different the local markets. The samples were labelled; A1, A2, A3, A4 and A5 as shown in Table 1.

Reagents and Materials

Measurements for total concentrations of silver, arsenic, boron, cerium, cadmium, cobalt, chromium, cesium, copper, iron, mercury, magnesium, manganese, molybdenum, nickel, palladium, lead, sulphur, antimony, selenium, silicon and zinc were carried out on inductively coupled plasma-optical emission spectrometry instrument (ICP-OES) with axial viewing configuration. Unless noted otherwise, every reagent and standard used were ultrapure reagent grade and Millipore Milli-Q water was used to produce every solution. After being thoroughly cleaned three times with deionized water, all glass and plastic items were immersed in 30 % (v/v) HNO_3 for a whole night. Following the soaking process, the plastics and glasses were dried in an oven and rinsed three times with deionized water[4,5].

The hair dye samples were collected in a clean sterile container. The collected samples were stored in a cool dry place, away from direct sunlight. 10 ml of HNO_3 was added to 1 g of each sample of the brand-name hair dyes. To ascertain the concentration of Ag, As, B, Ce, Cd, Co, Cr, Cs, Cu, Fe, Hg, Mg, Mn, Mo, Ni, Pd, Pb, S, Sb, Se, Si and Zn the sample was heated for one hour at 85 °C and later cooled to room temperature. The digested sample was diluted with deionized water to a final volume of 50 ml. The diluted sample was filtered through a 0.45 µm membrane filter to remove any particulate matter. An internal standard (Scandium) was added to the sample to monitor instrument stability and correct any form of instrumental drift.

The ICP-OES instrument was calibrated using multi-element standard solution[6].

Table 1: Selected Hair Dyes from Different Manufacturers.

Sample	Brand	Colour	Manufacturer	Country of Origin
A1	Cruset	Black	Guangzhou Rainbow Cosmetic	Thailand
A2	Tovchcolor	Green	Guangzhou Chenyi Biotechnology Ltd	China

A3	Subaru	Gold	CNGuangzhou Yucaitang Cosmetics Co., Ltd	China
A4	Subaru	White	CNGuangzhou Yucaitang Cosmetics Co., Ltd	China
A5	Subaru	Wine red	CNGuangzhou Yucaitang Cosmetics Co., Ltd	China

Cruset (black dye), Tovchcolor (green dye), Subaru (gold dye), Subaru (white dye) and Subura (wine red dye)

Sample Pre-treatment and Analysis

An analytical weighing balance was used to precisely weigh 0.5 g of the prepared samples, which were then transferred to a screw-cap polytetrafluoroethylene digestion tank. After adding 2 mL of nitric acid and 1 mL of 30 % hydrogen peroxide, the mixture was allowed to pre-digest for 12 hours at room temperature. The pots were sealed and left in a 160 °C oven for 4 hours. The pots were allowed to cool to room temperature when the digestive process was completed. The digest was prepared for ICP-OES analysis by diluting it with 10 mL of Milli-Q water. The diluted sample was filtered through a 0.45 µm membrane filter to remove any particulate matter. 1 mL of the diluted solution was added to a 5 mL vial for the measurement of Cd, Cu, Pb, As, Hg, Sb, and Ni. Next, 1 mL of 5 % thiocarbamide and 3 mL of 10 % nitric acid were added, and the mixture was allowed to react for 5 hours at room temperature to analyse other metals. The sample was introduced into the instrument using a peristaltic pump[7].

Quality Assurance and Statistical Analysis

Prior to being cleaned with deionized water, every piece of glassware utilized in this investigation was immersed in a 10 % nitric acid solution for 24 hours. The instrument was calibrated for every test that was run. The analytical procedure's accuracy was confirmed in the absence of a certified reference material using spike recovery techniques. All analytical procedures, from digestion to ICP-OES analysis, were performed after a known quantity of the test elements at three concentration levels was added to new portions of previously examined samples.

The metals' percentage spike recoveries ranged from 83.4 to 105 % and the calibration precisions within and between days were less than 13 %. Table 2 lists the circumstances under which the PTEs analysis was carried out.

The SPSS 13.0 program (SPSS Inc., Chicago, IL, USA) was used to process and analyze the statistical data. One-way ANOVA (Analysis of Variance) was used to examine the variations in heavy metal concentrations in HDPs usage among age groups. Statistical significance was defined as a p-value of less than 0.05.

Non-carcinogenic Exposure Assessment and Risk Characterization

The lifetime average daily dose (LADD) was used to assess this risk through the ingestion, inhalation, and cutaneous pathways[8]. Two hundred and fifty (250) adult male and female residents of Southwest LGA of Ibadan were given questionnaires to complete in order to assess the exposure levels to PTEs caused by the use of hair dyes. Important factors that were questioned include; weight, age at first use, frequency and duration of hair dye use.

Table 2: Recommended Conditions for Analysis on ICP-OES

Element	Flame	Wavenumber (nm)	Burner	Calibration method	Stock standard solution
Ag	Argon plasma	328.068	5 cm	Linear	1,000 µg/ml
As	Argon plasma	188.980	5 cm	Linear	1,000 µg/ml
B	Argon plasma	249.678	5 cm	Linear	1,000 µg/ml

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Ce	Argon plasma	446.021	5 cm	Linear	1,000 µg/ml
Cd	Argon plasma	214.439	5 cm	Linear	1,000 µg/ml
Co	Argon plasma	228.615	5 cm	Linear	1,000 µg/ml
Cr	Argon plasma	205.560	5 cm	Linear	1,000 µg/ml
Cs	Argon plasma	459.311	5 cm	Linear	1,000 µg/ml
Cu	Argon plasma	324.754	5 cm	Linear	1,000 µg/ml
Fe	Argon plasma	238.204	5 cm	Linear	1,000 µg/ml
Hg	Argon plasma	194.164	5 cm	Linear	1,000 µg/ml
Mg	Argon plasma	279.553	5 cm	Linear	1,000 µg/ml
Mn	Argon plasma	257.610	5 cm	Linear	1,000 µg/ml
Mo	Argon plasma	202.032	5 cm	Linear	1,000 µg/ml
Ni	Argon plasma	216.555	5 cm	Linear	1,000 µg/ml
Pd	Argon plasma	229.651	5 cm	Linear	1,000 µg/ml
Pb	Argon plasma	220.353	5 cm	Linear	1,000 µg/ml
S	Argon plasma	180.669	5 cm	Linear	1,000 µg/ml
Sb	Argon plasma	217.582	5 cm	Linear	1,000 µg/ml
Se	Argon plasma	203.985	5 cm	Linear	1,000 µg/ml
Si	Argon plasma	251.611	5 cm	Linear	1,000 µg/ml
Zn	Argon plasma	202.548	5 cm	Linear	1,000 µg/ml

Dilution = 20

Equation 1 was used to determine the PTEs intake through skin exposure to hair dyes.

$$D_{dermal} = \frac{C \times SA \times SL \times ABS \times EF \times ED}{BW \times AT} \times 10^{-6} \quad \ldots\ldots\ldots\ldots \quad \text{Equation 1}$$

Where; D_{derm} (ppm kg^{-1} day^{-1}) = average daily intake of heavy metals through skin exposure to hair dyes.

C (ppm kg^{-1}) = metal concentration in hair dye

SA (cm^2) = the skin area of scalp

SL (mg cm^{-2}) = skin absorption factor

ABS (unitless) = the depth absorption skin factor

EF (day $week^{-1}$) = exposure frequency

ED (year) = exposure duration

BW (kg) = body weight

AT (day) = average time. AT parameter is obtained using Equation 2.

$$AT = ED \times 14 \qquad \text{Equation 2}$$

The chronic risk was determined using chronic daily intake (CDI) and hazard quotient (HQ) index, based on the modified equation using[9,10]:

$$CDI = (C \text{ X } DI)/BW \qquad \text{Equation 3}$$

Where; CDI = human exposure risk through the ingestion or inhalation of hair dyes pathway (ppm/day),

C = concentration of heavy metal in hair dyes in mg L^{-1}

DI average daily intake rate (2.0 L Day^{-1} $person^{-1}$)

BW = body weight (72 kg for adults)[1]

Where; ED (year) = number of years that hair dyes are consumed. Besides, by considering the available information non-carcinogenic health risk effects were evaluated through Equation 4.

$$HQ = \frac{Ddermal}{RfD} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad \text{Equation 4}$$

Where RfD (mg $kg^{-1}day^{-1}$) = Reference Dose and HQ (unitless) is Hazard Quotient. Moreover, HI (chronic hazard index) is obtained by Equation 5, used to sum more than one HQ resulted from different elements or from different pathways[11].

$$Chronic\ Hazard\ Index = \sum_{k=1}^{n} \frac{Ddermal}{RfDk} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad \text{Equation 5}$$

Carcinogenic Analysis

By calculating the LCR using Equation 6, the carcinogenic analysis is carried out by assessing the likely cancer risks associated with PTE exposure[12]. The LCR is actually the likelihood that an individual would get any kind of cancer over their lifetime due to exposure to a specific daily quantity of a carcinogenic substance for 70 years, 24 hours a day[13,14]. The permissible limits of LCR for one or more PTEs are $10^{-6} < LCR < 10^{-4}$.

$$LCR = CDI \times CSF \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad \text{Equation 6}$$

The cancer slope factor, or CSF (ppm/day), is contaminant specific and is the risk resulting from an average lifetime exposure to one carcinogen chemical. Specifically, mercury does not have a CSF since it is not thought to induce cancer.

RESULTS AND DISCUSSION

PTEs Concentration in Hair Dye Products (HDPs)

According to figure 2, the amounts of Ag in each product ranged from 1.02 to 1.43 ppm, with the highest concentration found in A1 (black-color dye) and the lowest in A4 (gold-color dye). The most serious health effect of Ag exposure is skin coloring; which is evident in argyria[15]. Breathing issues, stomach pain, throat and lung discomfort can result from exposure to hair dyes that contain relatively high concentrations of Ag compounds (such as AgO or $AgNO_3$). USFDA has established limitations for the amount of Ag that can be present in color additives as part of the guidelines for Ag safe use. The typical range of permitted limits is 0.10 to 0.20 ppm[16]. However, there are scanty research reports on potential toxicity of Ag in hair dyes.

The concentrations of As in the hair dye brands were determined to be between 0.24 and 0.3 ppm, as shown in figure 3. The As concentration is significantly higher in the A1 (black-color dye) brand than in the A2 (green-color dye) brand, which has the lowest concentration range. USFDA has set a 3.00 ppm permissible limit for As in powder and other cosmetic goods. This implies that all of the hair color brands examined in this study had As at a concentration level below USFDA allowable limit[17]. When compared to previous published studies, the concentration values were comparably low[17,18,19]. Long-term inhalation exposure of As can cause gastrointestinal tract and urinary system malignancies, circulatory and peripheral nervous system abnormalities, certain skin impacts and an elevated risk of lung cancer. It has been reported that majority of As enters the human body in the As(III) form, while only a small quantity of As(V) can penetrate cell membranes via an energy-dependent transport pathway before it is being almost instantly reduced to As(III)[17]. Arsenobetaine, a naturally occurring organoarsenic compound found in various marine organisms is considered to be relatively non-toxic and have no carcinogenic effects in animal studies. Dimethylarsinic acid (DMA) is also considered to be non-carcinogeic while monomethylarsonic acid (MMA) is slightly carcinogenic to humans. However, inorganic As are highly carcinogenic to humans[20].

Although the boron used in hair dyes is safe, however if hair dyes containing borax (sodium borate) or boric acid is inadvertently ingested a serious medical harm can be caused. Excess boron can cause headaches, seizures, rashes, nausea, vomiting, and diarrhea. Excessive levels of boron can be fatal. The measured boron concentration ranged from 0.18 to 0.4 ppm, with an average of 0.29 ppm, as shown in figure 4. In order to ensure the safe use of color additives, USFDA has established limitations for boron as an impurity[21]. The typical range of permissible limits is 10 – 20 ppm. The concentration result therefore was deemed modest when compared to the USFDA limits[22]. However, the amount of boron in hair colors has not been reported yet.

As shown in figure 5, the Cerium concentrations in investigated samples ranged from 0.04 to 1.02 ppm. A1 brand (black-color dye) had the highest Ce concentration, whereas A4 brand (white-color dye) had the lowest concentration. Ce can constitute air pollution hazard through inhalation, since its particles can easily mix with air and moisture in the humid work environment. Lung embolisms may also result, particularly with prolonged Ce exposure. When cerium accumulates in the human body system, it might endanger the liver. Ce in hair dyes is permitted at a maximum of 0.0027 ppm[23].

The range of the Cd content was 0.02 to 0.05 ppm. As seen in figure 6, the Cd concentrations of A3 and A4 HDPs were higher than those of the other hues examined. USFDA authority has set a maximum acceptable level of 3.00 ppm for Cd as an impurity in HDPs[24]. The Cd concentrations in these samples were below the regulatory control limits set by the USFDA. There were reports of Cd values in Nigerian human care products (HCPs) ranging from 2.58 to 6.95 ppm[25]. A study discovered less than 0.002 ppm in shampoos and conditioners[26]. Cd values of 0.033 – 0.042 ppm were recorded other HCPs in another investigation[27]. Cd levels in hair treatments ranged from 4.2 – 6.8 ppm[28]. Our study had lower Cd amounts than some of the previously reported works. Nevertheless, compared to our study, other research on HCPs showed lower levels[29]. Cadmium is "carcinogenic to humans," and the US Department of Health and Human Services has classified its compounds as human carcinogens[30]. Prolonged exposure to low levels of cadmium can cause kidney damage, bone deformities and the tendency for bones to break readily; while high amounts of cadmium can cause severe stomach irritation, vomiting and diarrhea[31]. Only a small percentage of the metals consumed by humans and animals are really retained in the body; the majority are usually excreted. Cd is a strong cell toxin that can harm cells in a variety of ways, such as causing them to die or proliferate more quickly. Children may experience neurological disorders like learning impairments and hyperactivity as a result of its effects on the nervous system. Cd causes oxidative stress in brain cells, which damages proteins and leads to neurodegeneration. Cd does not need to be abundant in items to cause hypertension, as it can be found in a variety of hair dyes[32].

In figure 7, the Co concentrations in these HDPs varied from 0.003 to 0.04 ppm. The dye A5 (wine-color) has the highest amounts of Co. The lowest quantities of Co were found in black-color dye (A1). In Ghana, hair pomades had cobalt concentrations ranging from 10.667 to 25.350 ppm[33]. The Co concentrations analyzed in this study were lower than those of Ghanaian HCPs. The 2008 patch test of 25,000 European individuals revealed a positive response in 7.9 % of cases, confirming that cobalt is a skin allergen that causes allergic contact dermatitis (ACD). Sweat's ability to oxidize it is directly correlated with the flow of Co ions through the skin[34]. Itching and eczematous periungual and palmar sores are documented side effects of Co exposure[35]. Based on these results, it was suggested that cosmetics intended for skin application should either contain Co at concentrations below 1 ppm or, for increased skin protection, should not contain Co at levels above 5 ppm[36]. However, no Co amounts above 1 ppm, which is recommended for increased skin protection, were found in any of the examined samples[34].

The Cr concentration in the study samples is displayed in figure 8. The findings showed that the greatest value (0.767 ppm) was found in A3 (gold-color dye), followed by A4 (white-color dye) at 0.318 ppm, wine-color dye (A5) at 0.202 ppm, green-color dye (A2) at 0.185 ppm, and black-color dye (A1) at 0.005 ppm. Every sample that was examined fell within the USFDA's guidelines[3]. Some hair dyes from South-South Nigeria contained 2.5 – 4.2 ppm of Cr, whereas another study found 0.43 – 4.9 ppm in hair dyes used in Federal Capital Territory (FCT) in Abuja, Nigeria[11,12]. The oxidation state of the metal ions determines how hazardous chromium compounds could be. The hexavalent Cr compounds are more hazardous than the trivalent forms. Hexavalent chromium (Cr^{+6}) causes skin allergies and corrosion. The International Agency for Research on Cancer lists Cr^{+6} compounds as carcinogenic[13]. Because of its high solubility, Cr^{+6} penetrates the skin more than Cr^{+3}. The contact time has an impact on the pace at which Cr penetrates the skin[11]. Skin irritation or ulceration, allergic contact dermatitis, occupational asthma, nasal irritation and ulceration, perforated nasal septa, rhinitis, nosebleed, respiratory irritation, nasal cancer, sinus cancer, eye irritation and damage, perforated eardrums, kidney damage, liver damage, pulmonary congestion and edema, epigastric pain, and tooth erosion and discoloration are among the adverse health effects linked to hexavalent chromium exposure[37].

Cesium is the most prevalent metal in these HDPs, with concentrations ranging from 0 to 22561.9 ppm, as shown in Figure 9. White dye (A4) has the greatest Cs among the hair dye brands examined, while gold (A3) has no levels of Cs. Large doses of radioactive Cs can harm human cells due to radiation exposure. Acute radiation syndrome, which includes unconsciousness, hemorrhage, nausea, vomiting, diarrhea, and in extreme circumstances, death, may also occur. Between 900 and 1000 parts per million is the upper limit for Cs in hair dyes[38]. With the exception of A3 (gold), which has no traces, every sample examined in this study had a significantly higher concentration of Cs.

As seen in Figure 10, copper was found in trace amounts in the brands of HDPs under investigation at quantities between 0.032 and 0.066 ppm. A4 (black dye) has the highest concentration of Cu. The amounts of Cu in HCPs have been documented in comparatively few research. For example, a research discovered that shampoos sold in Pakistan had Cu amounts ranging from 0.071 to 2.387 ppm, whereas HCPs in Ghana had Cu contents between 0.70 and 12.80 ppm[40]. Although copper is a necessary component of both human and animal diet, its use in intrauterine devices (IUDs) has been linked to women's increased menstrual blood and pain[25].

The hair dye brands' iron contents were also ascertained. The studied samples had an average Fe concentration of 7.5128 ppm, with a range of 2.361 to 21.258 ppm, as shown in Figure 11. In contrast to our results, the average Fe content in hair pomade was found to be 209.8 ppm14. Fe-related side effects in the human body include headache, nausea, vomiting, dizziness, anorexia, and weight loss[41]. Furthermore, because of the quick catalysis of oxygen radicals in cells, elevated Fe levels raise the possible risk of cancer[15].

The hair dye brands' mercury contents were also ascertained. The average Hg concentration found in all tested hair dyes ranges from -0.12 to 0.119 ppm, as shown in Figure 4.12. With a concentration of 0.119 ppm, A4 (white dye) has the highest Hg content, while A3 (gold dye) has the lowest concentration range (-0.12 ppm). One part per million is the USFDA's allowable level for Hg[3]. According to the results, two brands under investigation had trace amounts of mercury. All of the samples with detectable mercury contents were found to be below the USFDA's allowable levels[2]. Additionally, the research's findings fall short of those of the earlier study. Acute or long-term exposure to topical mercury salts can cause renal, neurological, and skin damage, even though the IARC has not classified metallic or inorganic mercury compounds as carcinogenic to humans (Group 3)[6,13]. There have been reports of cutaneous abnormalities such as purpura, erythroderma, gingivostomatitis, flushing, grey or blue-black facial discolouration, burning of the face, and contact dermatitis. Furthermore, high urinary Hg concentrations (>20 ppm) have been linked to symptoms of mercury poisoning. Inorganic Hg salts are also easily absorbed through the skin and eliminated mainly by the kidneys[4].

According to Figures 13 and 14, the concentrations of manganese and magnesium in these samples varied from 0.34 to 1.55 ppm with an average of 0.786 ppm and 30.88 to 902.18 ppm with an average of 206.572 ppm. While A1 (black) had the highest Mn content, A4 (white) had higher Mg concentrations than other brands. Mg and Mn have USFDA-permissible limits of 30 and 0.1 ppm, respectively[3]. According to an analysis, hair pomades in Ghana had an average Mn concentration of 9.8 ppm[7].

The HDPs' molybdenum contents were also ascertained (Figure15). A3 had the highest Mo concentration (0.178 ppm), whereas A4 had the lowest concentration (-0.12 ppm). The USFDA recommends 0.1 ppm of Ni and Mo in cosmetics[2]. Nonetheless, it is recommended that HDPs with a Mo concentration of less than 1.0 ppm be used for skin protection, especially those that come into close contact with the skin, as 0.5 ppm of Mo concentration is sufficient to induce dermatitis[10].

Figure 16 shows the Nickel amounts in the several hair dyes that were examined. They are as follows: A4 (0.92 ppm) > A3 (0.776 ppm) > A1 (0.633 ppm) > A3 (0.588 ppm) > A5 (0.00 ppm). Ni had a USFDA-permissible limit of 5 ppm[41]. An experiment that found 0.83 to 3.11 ppm of Ni in FCT-Abuja, Nigeria, and another that found lower values of 1.5 to 7.5 ppm in hair dyes from South-South Nigeria are both consistent with the findings of this study[11,12]. When nickel comes into contact with perspiration on human skin, it can oxidize to create soluble and diffusible chemicals that can enter the stratum corneum by intracellular, transcellular, or appendageal pathways. The counter ions (acetate, chloride, nitrate, and sulphate), sweat's oxidizing ability, sex (male or female), exposure duration, and dosage are some of the variables that affect the nickel diffusion rate, which is limited to less than 1 %. Given how long cognitive materials are in touch with the skin, there may be a higher risk of developing allergic dermatitis[26].

In HDPs, palladium concentrations were also examined. According to Figure 17, A2 had the highest palladium content (2.611 ppm), whereas A5 had the lowest amount (0.301 ppm). Our samples' measured Pd levels fell under the USFDA's regulation threshold of 20 ppm[2]. Furthermore, the range of Pd concentration in hair dye samples was nearly identical to the level that had been previously reported[18].

The Lead concentration in the hair dyes under study is displayed in Figure 18. The Pb levels that were measured varied from 0.468 to 1.932 ppm. A2 had the lowest Pb levels (0.468 ppm), while A4 had the highest (1.932 ppm), followed by A1 (1.414 ppm) and A5 (1.118 ppm). Our samples' measured Pb concentrations fell below the USFDA's 20 ppm regulation limits[2]. All of the hair color products' Pb levels fell within the USFDA's maximum allowable limit (10 ppm) for external cosmetic usage. According to one analysis, South-South Nigerian hair dyes included 0.5–28 ppm of lead[41]. This investigation revealed lower concentrations than a previous study that reported ranges between 0.43 and 1.3 ppm in FCT-Abuja, Nigeria[12]. Pb contamination of black hair colors can occur when contaminated raw materials or Pb -containing pigments are used. Every day, Pb comes into touch with the skin, and part of it is absorbed through the skin[28]. High levels of Pb exposure can harm the nervous system, which can lead to kidney damage and brain disorders. Because it can easily pass through the placenta and enter the fetal brain, pregnant women and small children are especially at risk. Additionally, it can be kept in bones and passed on to babies through breastfeeding. Additionally, miscarriages, hormonal abnormalities, decreased fertility in both men and women, irregular menstruation, and delays in the onset of puberty in girls have all been connected to Pb exposure[28]. According to reports, 33 % of lead that enters a child's body and 99 % of Pb that enters an adult's body are eliminated in roughly two weeks[29].

HDPs were used to assess sulfur (Figure 19). The range of the measured S levels was -0.38 to 0.06 ppm. A5 had the highest S concentration (0.06 ppm), whereas A1 had the lowest (0.38 ppm). Our samples' measured S and Sb levels fell below the USFDA's regulation limitations of 5.00 ppm and 5.00 ppm, respectively[42].

According to Figure 20, A4 had the highest antimony concentration (1.29 ppm), whereas A5 had the lowest (-0.11 ppm). Our samples' measured Sb levels fell below the USFDA's regulation limits, which are 5.00 ppm respectively[43]. Sb absorption through the skin has not been thoroughly investigated; an in vitro percutaneous investigation suggested that 0.26 % of Sb trioxide is absorbed through human skin[44]. When antimony sulfide became uncommon, Pb sulfide and Pb oxide took its place. Antimony sulfide was used in cosmetics like rouge and black paint for eyebrows. Samples made in Egypt showed that only one sample of compact face powder had a comparatively high Sb content (5.36 ppm)[45]. Cosmetics made in Japan, such as soaps (< 0.177 ppm) and bronzing face powders (< 0.46 ppm), had low amounts of Sb[46]. The highest Sb concentrations, ranging from 0.012 to 0.21 %, were found in kohl samples (both branded and unbranded) gathered from six different regions of Saudi Arabia. These levels corroborated the findings that Sb sulfide was present in previous varieties of kohl[47]. Compared to earlier findings, our samples are significantly smaller.

The HDPs' selenium levels were also measured (Figure 21). A2 had the highest concentration of Se (1.21 ppm), whereas A4 had the lowest concentration (0.18 ppm). It was observed that our samples' Se concentration was similar to that of earlier findings[48]. The USFDA recommends 1 ppm of selenium in cosmetics[22]. Nonetheless, it is recommended that the content of Se in HDPs be less than 1.0 ppm for skin protection. Hair loss and nail brittleness or loss are the most prevalent clinical indicators of selenosis, or chronically excessive selenium consumption. Skin rash, nausea, diarrhea, exhaustion, irritability, and anomalies of the nervous system are other symptoms.

The HDPs' silicon contents were also ascertained (Figure 22). A5 had the highest concentration of silicon (140.98 ppm), while A3 had the lowest (130.45 ppm). The USFDA recommends 10 ppm of Si in cosmetics[2]. Nonetheless, it is recommended that the content of Si in HDPs be less than 1.0 ppm for skin protection. On touch, silicon irritates the skin and eyes. Inhalation will irritate the mucous membranes and lungs. Redness and wetness of the eyes are signs of eye irritation. Skin inflammation is characterized by reddening, scaling, and itching[48].

Zinc and hydrogen peroxide, as well as other substances or mixes that release hydrogen peroxide, such as carbamide peroxide as zinc peroxide, are found in hair dyes. Our samples had Zn values ranging from 0.61 to 1.87 ppm (Figure 23). Zinc is present in all samples in varying amounts; the highest concentration (1.87 ppm) was found in A2 (black dye), which did not above the USFDA restriction of 12 ppm, while the lowest concentration (0.61 ppm) was found in A5[2,3]. Overexposure to zinc can be harmful. High amounts of zinc in the hair are very uncommon and may be a sign of a zinc overdose. Excess zinc can cause gastrointestinal problems, tachycardia, impaired vision, hypothermia, and diminished heme synthesis (copper insufficiency)[49].

Variability in PTEs Concentration among Hair Dyes of Different Color Brands

Figures 1 showed the levels of concentrations of potential toxic elements in hair dye A1 to A5 in comparison to different color brands. A1 is comprises of black dye, A2 (green dye) A3 (gold dye) A4 (white dye) and A5 (wine dye). A4 (white dye) has highest average PTEs concentration of 1074.149 ppm, followed by A1 (black dye) with an average concentration of 882.715 ppm. A5

(wine dye) contains an average PTEs concentration of 720.246 ppm, followed by A2 (green dye) which has 689.242 ppm average concentration. A3 (gold dye) has the lowest average PTEs concentration of 7.845 ppm. It was observed that Ce, Mg and Si concentrations were all higher in all the HDPs. Hg was found in trace amounts in A4 and A5, with concentrations of 0.119 and 0.001 ppm, respectively, which are below allowable limits, but not in A1, A2, or A3. With a concentration of 0.06 ppm, A5 was the only hair dye brand that contained Sulphur. Sb was found in two brands (A1 and A5) in concentrations of 0.52, 1.29, and 0.33 ppm, respectively, although it was not found in A3 or A3. A1 and A4 have significantly greater Fe concentrations than A2, A3, and A5.

Table 3: PTEs Concentration in HDPs

Parameters (ppm)	**A1**	**A2**	**A3**	**A4**	**A5**
Ag	1.430^{a}	1.120^{b}	1.020^{d}	1.080^{c}	1.070^{c}
As	0.300^{b}	0.240^{e}	0.290^{c}	0.260^{d}	0.640^{a}
B	0.250^{d}	0.400^{a}	0.290^{c}	0.330^{b}	0.180^{e}
Ce	1.020^{a}	1.000^{b}	0.090^{d}	0.040^{e}	0.140^{c}
Cd	0.020^{c}	0.050^{a}	0.050^{a}	0.040^{d}	0.030^{b}

Co	0.003^{e}	0.020^{d}	0.055^{b}	0.130^{a}	0.040^{c}
Cr	0.005^{e}	0.185^{d}	0.767^{a}	0.318^{b}	0.202^{c}
Cs	19232.900^{b}	14991.200^{d}	0.000^{e}	22561.900^{a}	15661.400^{c}
Cu	0.606^{a}	0.080^{c}	0.032^{d}	0.146^{b}	0.080^{c}
Fe	7.719^{b}	2.361^{e}	3.411^{c}	21.258^{a}	2.815^{d}
Hg	-0.311^{d}	-0.263^{d}	-0.120^{c}	0.119^{a}	0.001^{b}
Mg	33.460^{c}	31.650^{d}	30.880^{e}	902.180^{a}	34.690^{b}
Mn	1.550^{a}	0.400^{d}	0.340^{e}	1.220^{b}	0.420^{c}
Mo	0.157^{b}	0.178^{a}	0.112^{c}	-0.120^{e}	0.076^{d}
Ni	0.633^{c}	0.588^{d}	0.776^{b}	0.920^{a}	0.000^{e}
Pd	0.370^{d}	2.611^{a}	1.588^{c}	2.009^{b}	0.301^{e}
Pb	1.414^{b}	0.468^{e}	0.760^{d}	1.932^{a}	1.118^{c}
S	-0.380^{b}	-0.570^{c}	-0.390^{b}	-1.340^{d}	0.060^{a}
Sb	0.520^{e}	-0.280^{d}	-0.110^{c}	1.290^{a}	0.330^{b}
Se	0.480^{c}	1.210^{a}	1.180^{b}	0.180^{e}	0.250^{d}
Si	135.730^{c}	133.890^{d}	130.450^{e}	136.150^{b}	140.980^{a}
Zn	1.870^{a}	0.790^{d}	1.120^{c}	1.240^{b}	0.610^{b}

Values are in ppm. a, b, c, d means along the same row with different superscripts are significantly different ($P<0.05$)

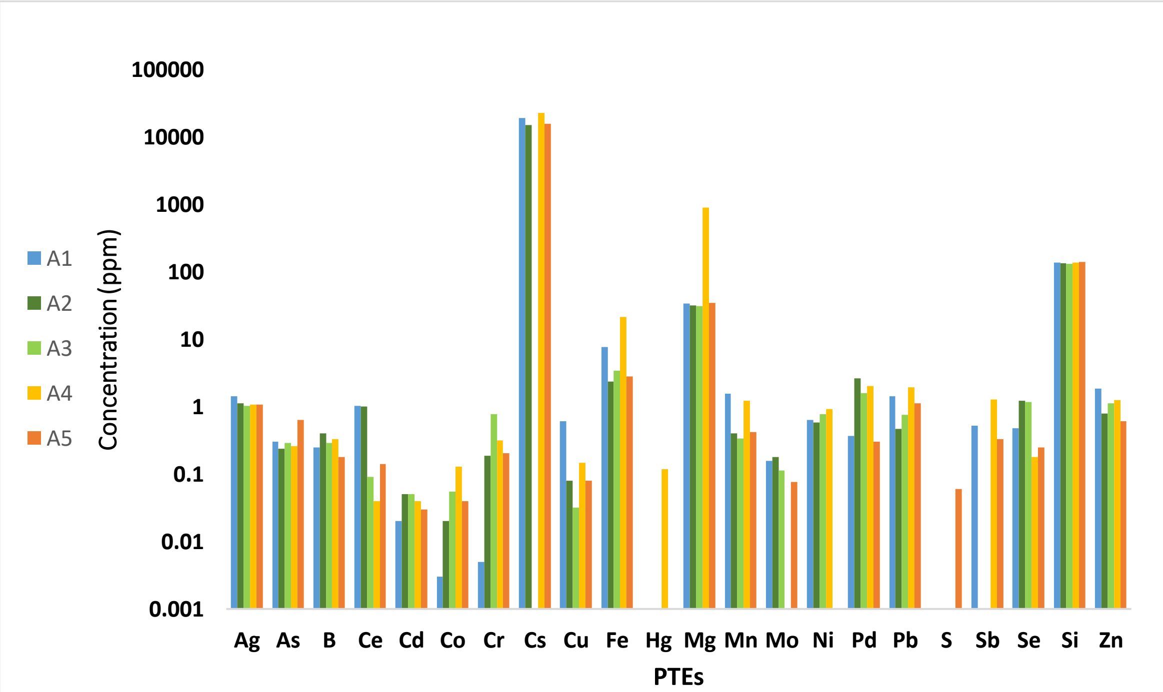

Figure 1: Concentration of PTEs in Hair Dye Products

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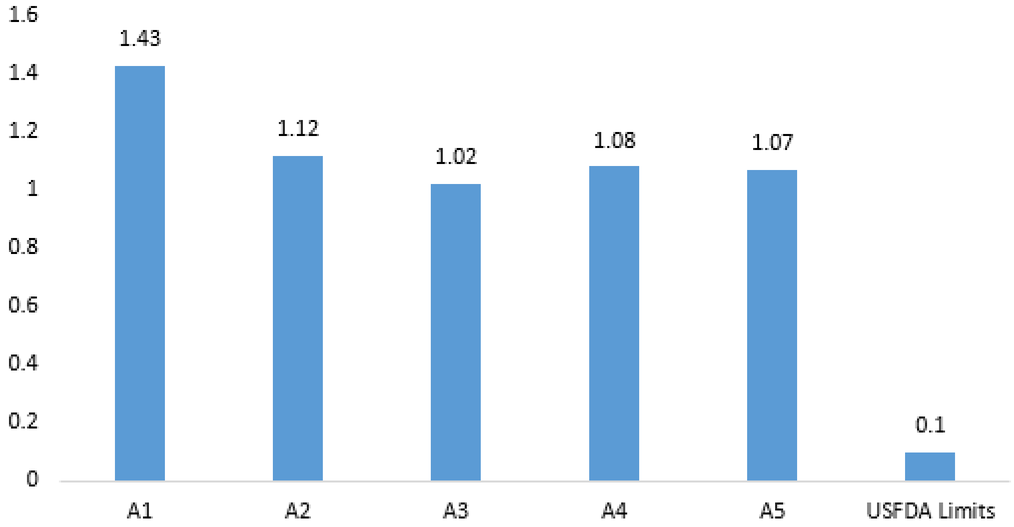

Figure 2: Level of Silver in HDPs and its USFDA limits

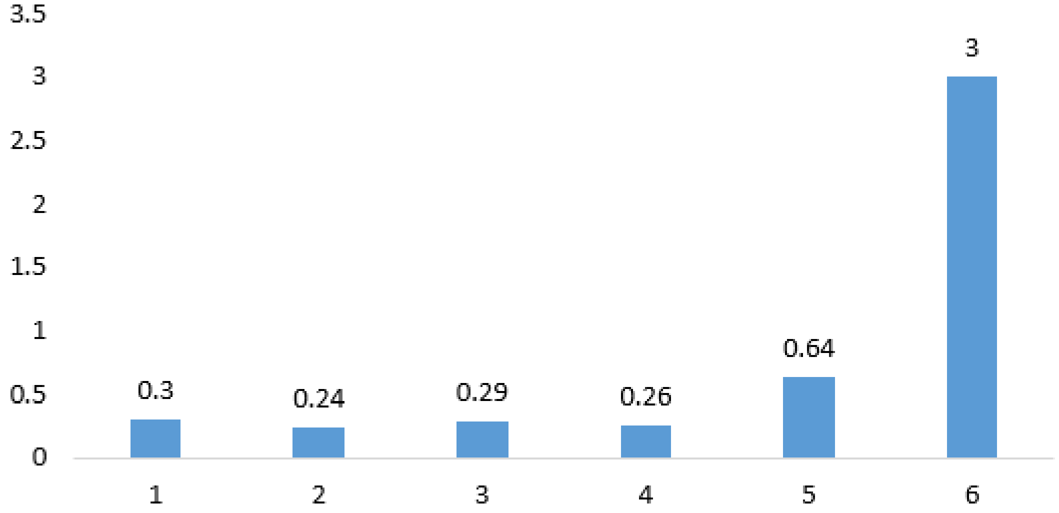

Figure 3: Level of Arsenic in HDPs and its USFDA limits

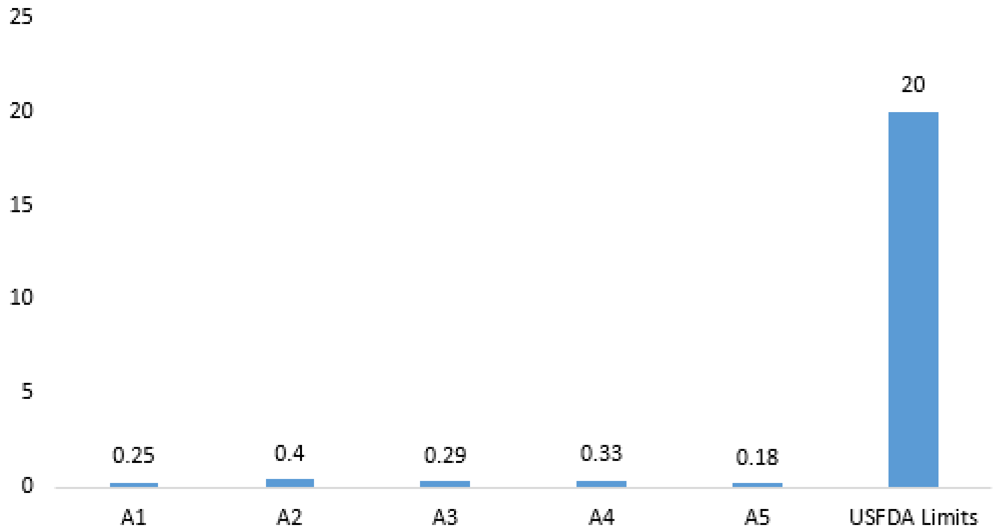

Figure 4: Level of Boron in HDPs and its USFDA limits

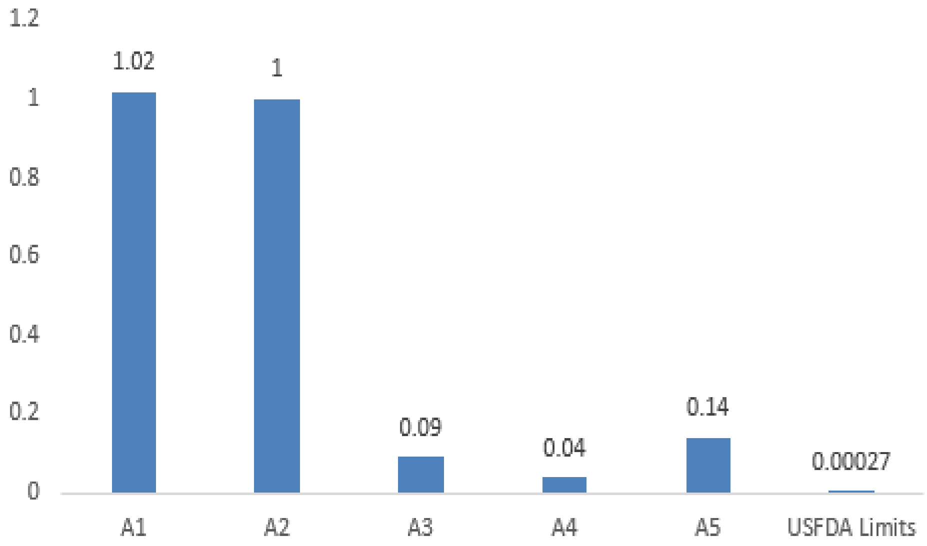

Figure 5: Level of Cerium in HDPs and its USFDA limits

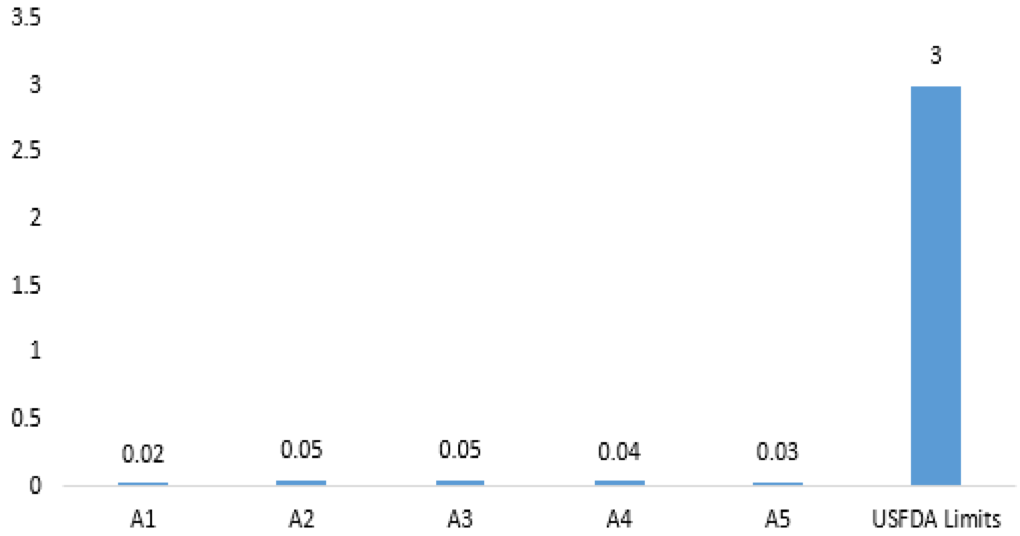

Figure 6: Level of Cadmium in HDPs and its USFDA limits

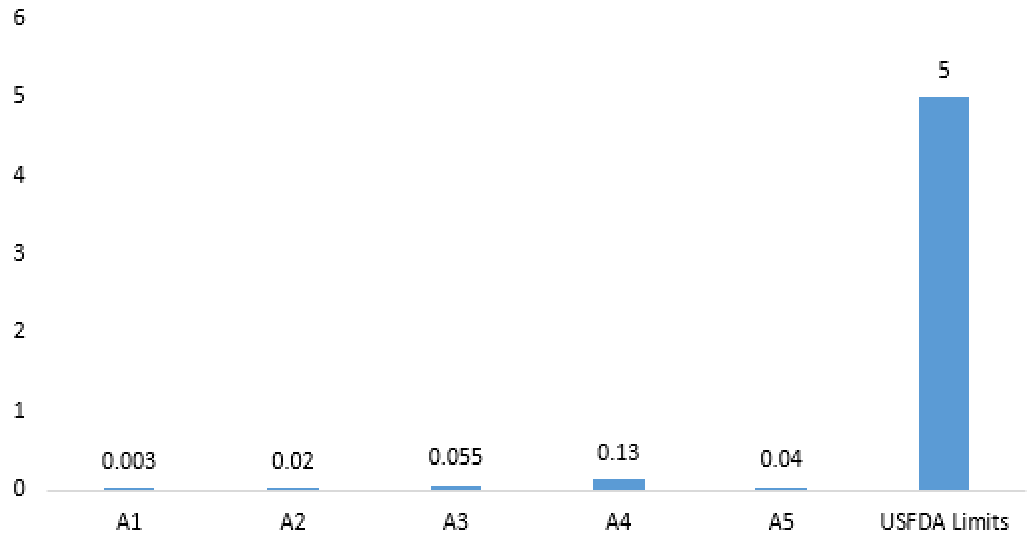

Figure 7: Level of Cobalt in HDPs and its USFDA limits

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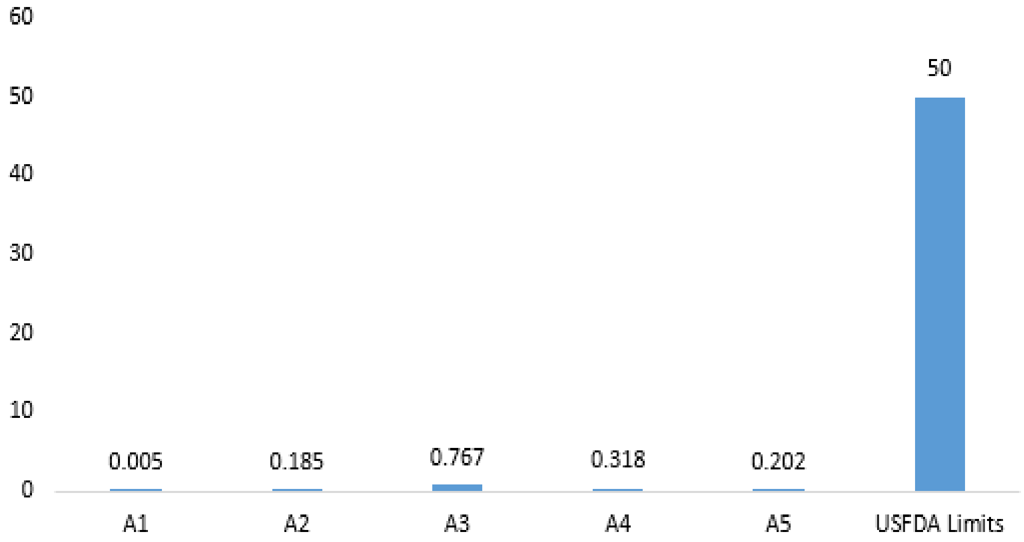

Figure 8: Level of Chromium in HDPs and its USFDA limits

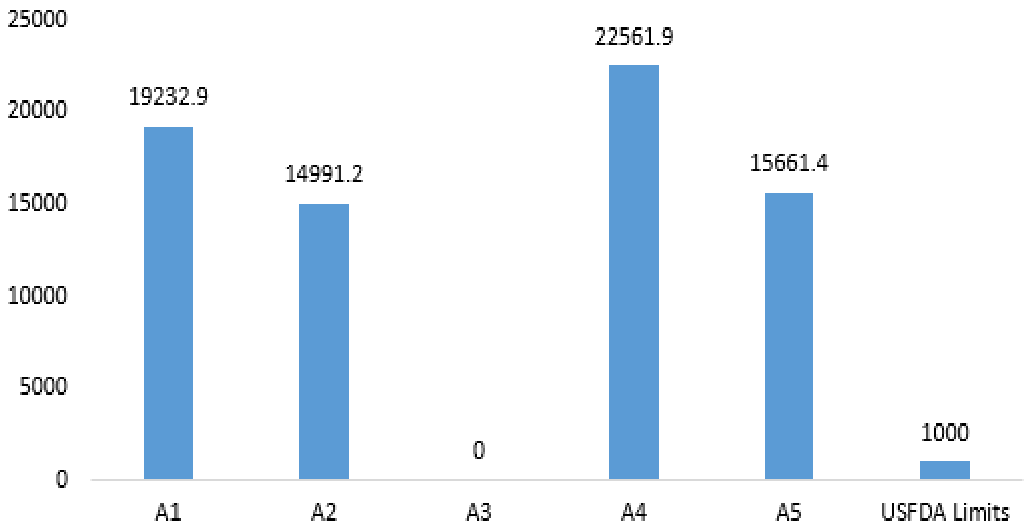

Figure 9: Level of Cesium in HDPs and its USFDA limits

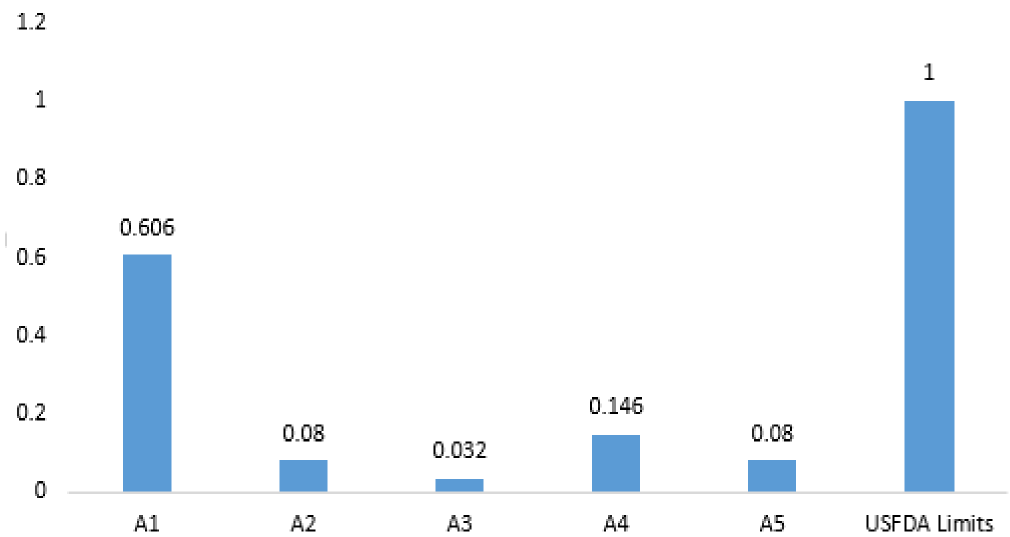

Figure 10: Level of Copper in HDPs and its USFDA limits

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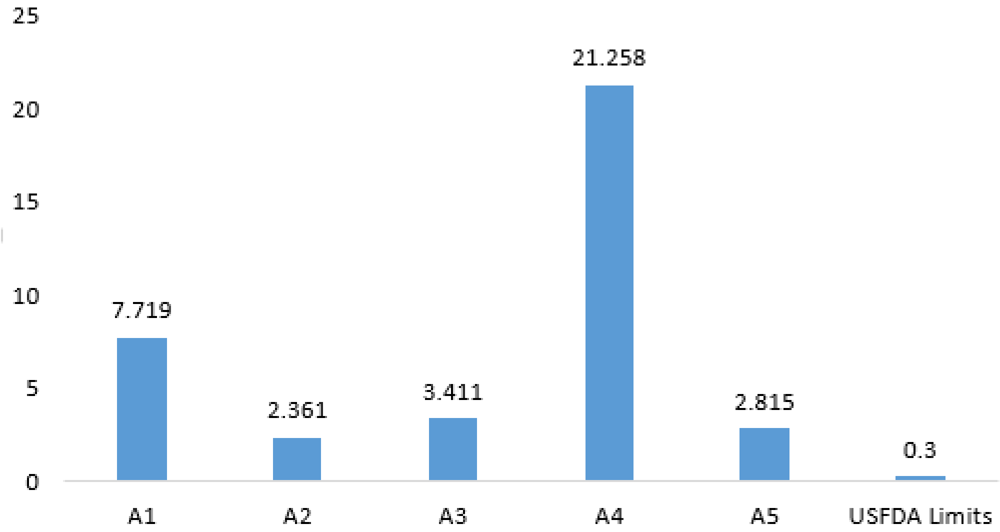

Figure 11: Level of Iron in HDPs and its USFDA limits

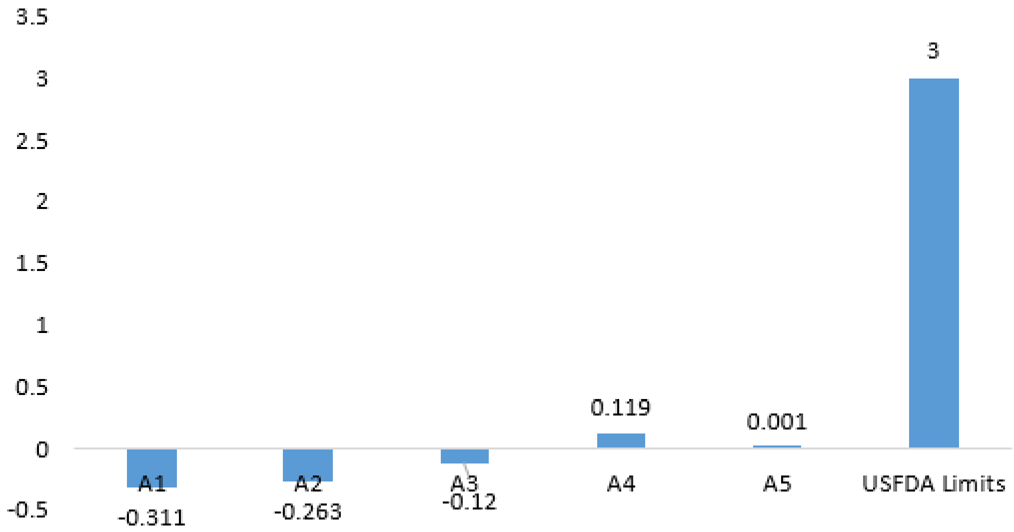

Figure 12: Level of Mercury in HDPs and its USFDA limits

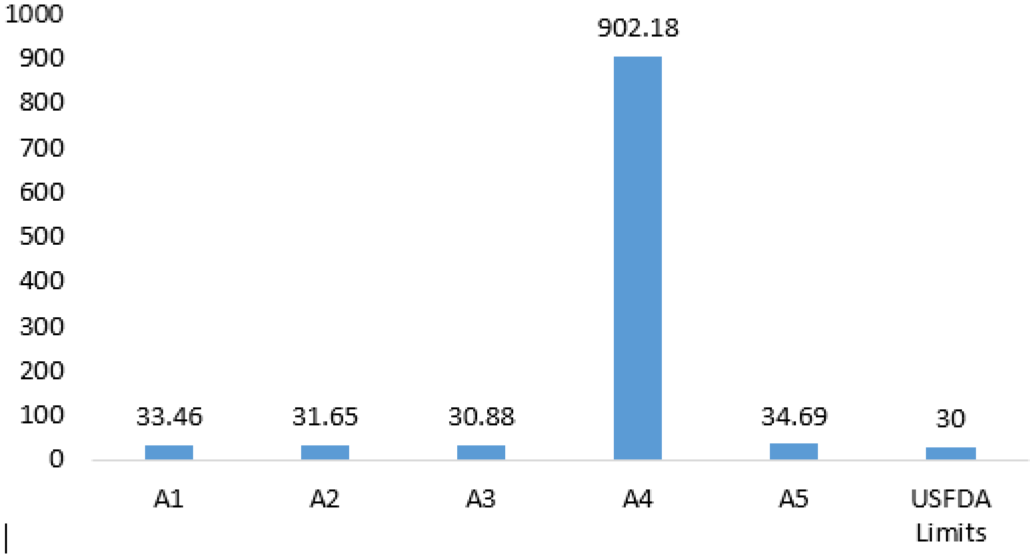

Figure 13: Level of Magnesium in HDPs and its USFDA limits

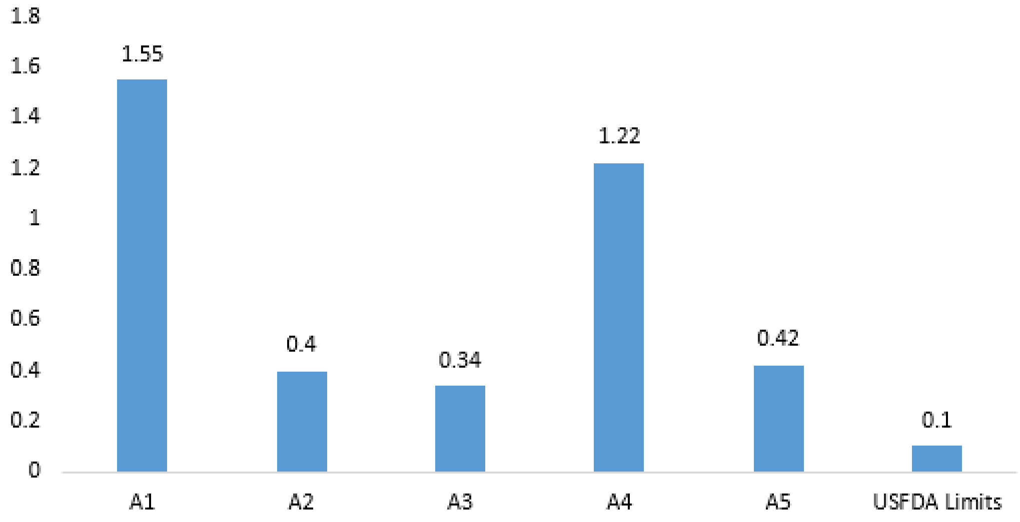

Figure 14: Level of Manganese in HDPs and its USFDA limits

Figure 15: Level of Molybdenum in HDPs and its USFDA limits

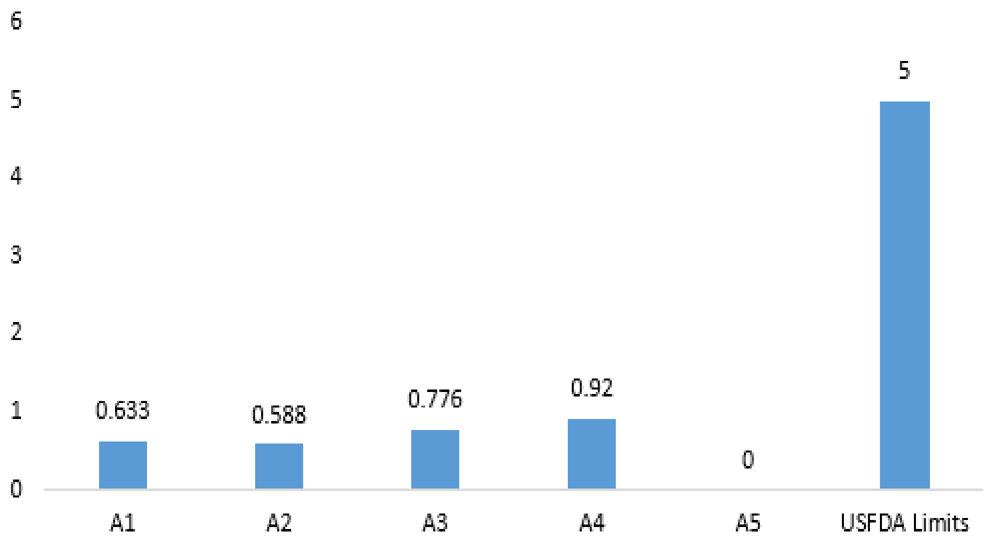

Figure 16: Level of Nickel in HDPs and its USFDA limits

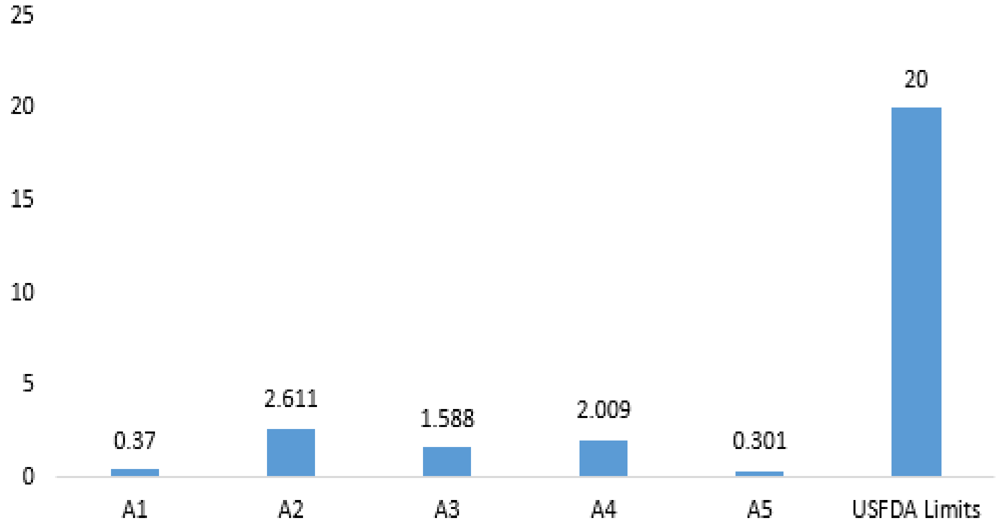

Figure 17: Level of Palladium in HDPs and its USFDA limits

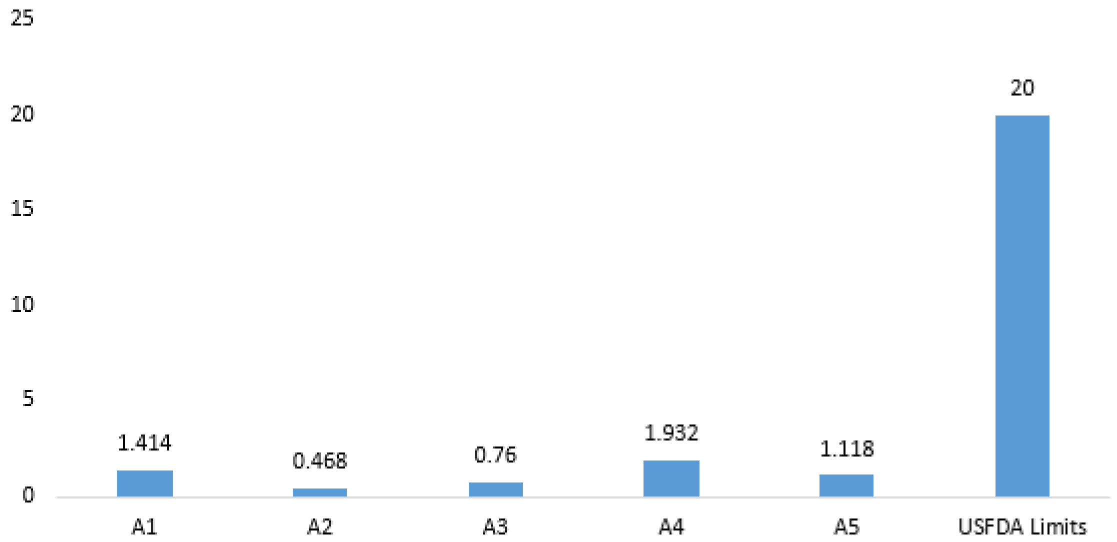

Figure 18: Level of Lead in HDPs and its USFDA limits

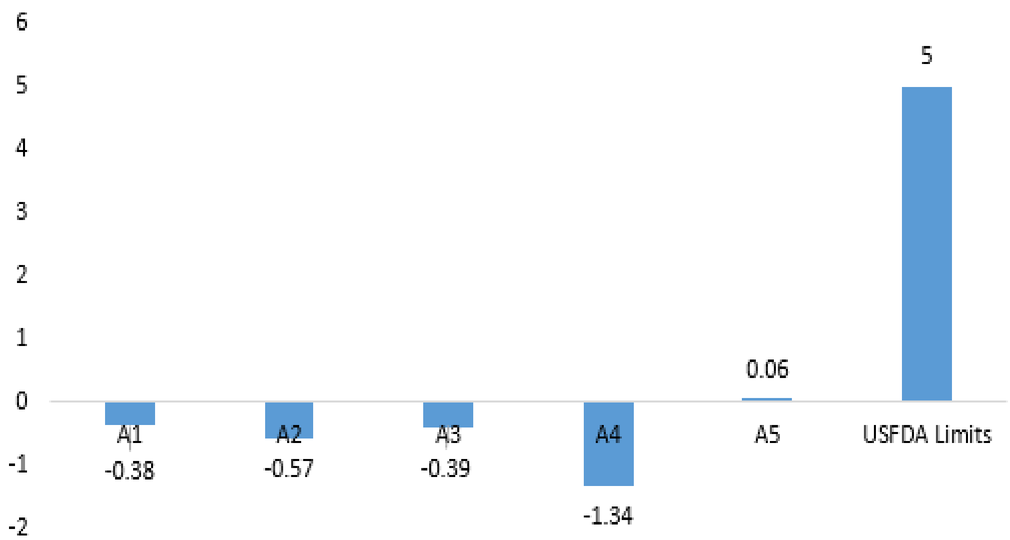

Figure 19: Level of Sulphur in HDPs and its USFDA limits

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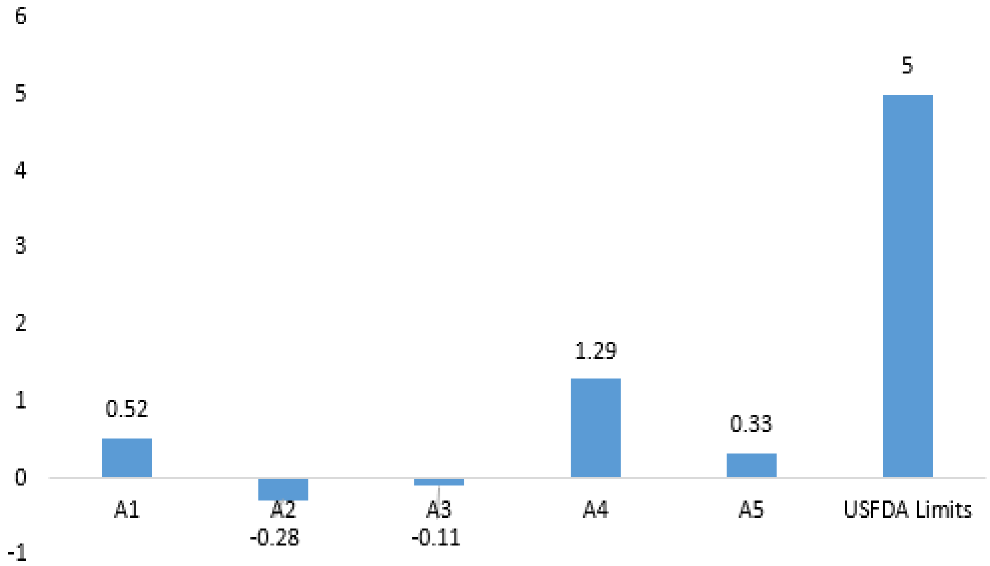

Figure 20: Level of Antimony in HDPs and its USFDA limits

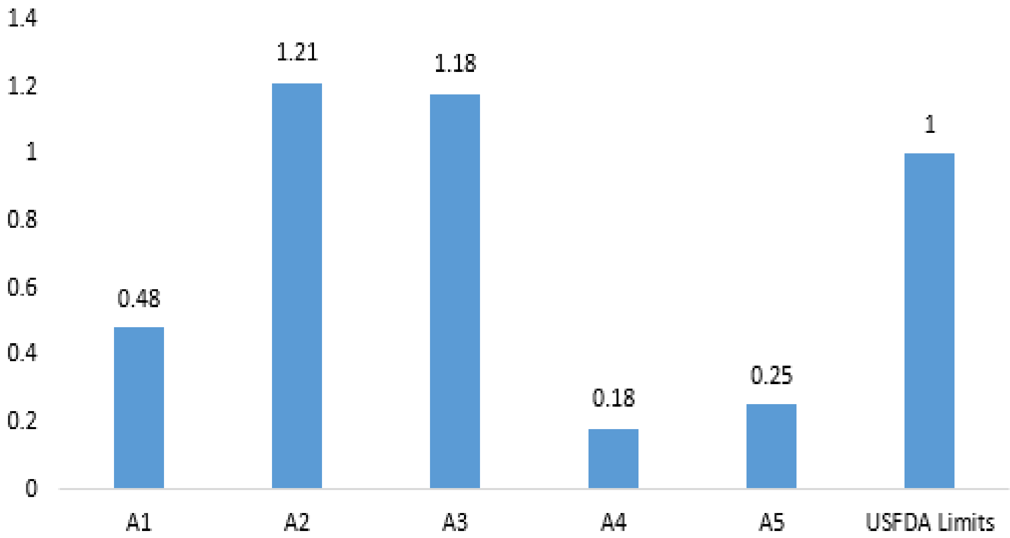

Figure 21: Level of Selenium in HDPs and its USFDA limits

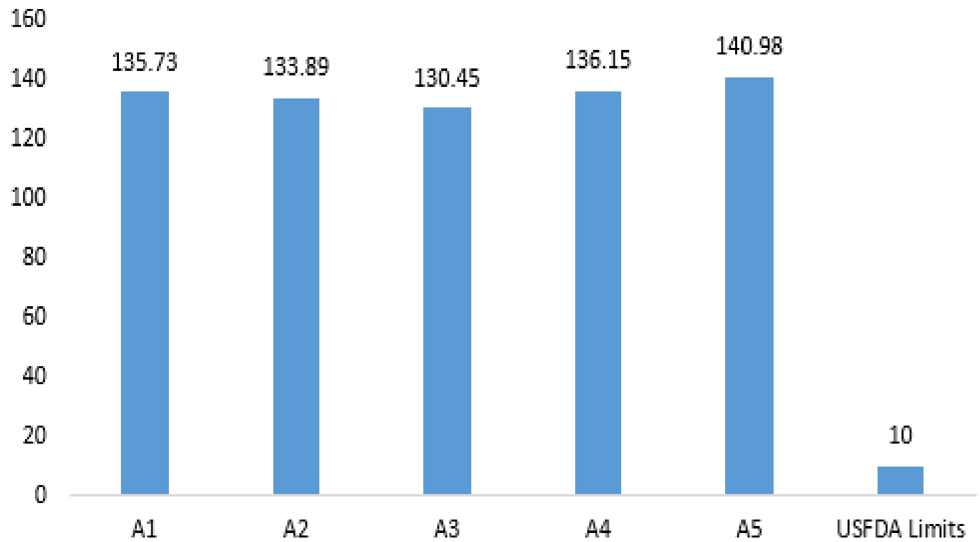

Figure 22: Level of Silicon in HDPs and its USFDA limits

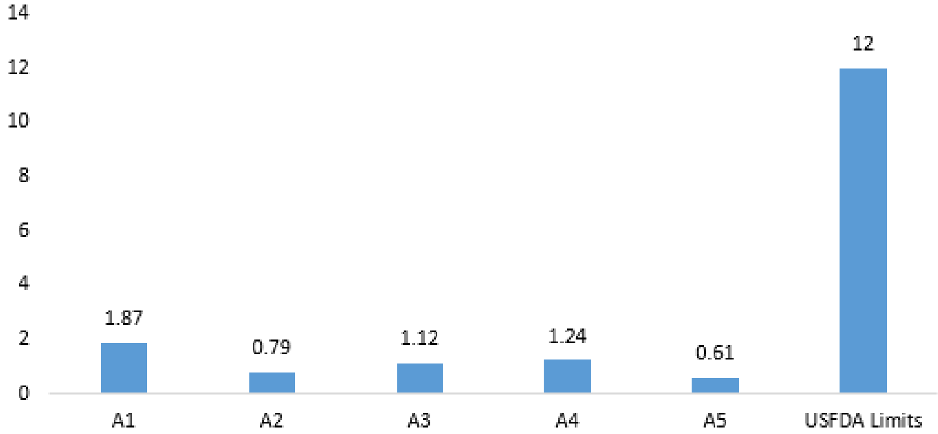

Figure 23: Level of Zinc in HDPs and its USFDA limits

Health Risk Assessments

The non-carcinogenic human health risk assessment for the PTEs in this investigation is summarized in Table 4. All of the hair dye samples had HQ_{ing} values greater than 1. All of the Pd and Si HQ_{ing} values were below allowable bounds. All of the computed HQ values for Cs and Ni were more than 1, with the exception of A3 and A5, where the value was 0.00. The risk of non-carcinogenic consequences was unacceptable for Ag, B, Cd, Cr, Fe, Mg, Ni, S, Se, and Zn in adults. Headache, diarrhea, nausea, and vomiting have all been related to elevated levels of Cr and Ni in the body[49]. Adults who have high amounts of Ag, Cd, Fe, Mg, Ni, B, Se, and Zn may experience health issues such memory loss, diminished attentiveness, and mental and physical retardation. With Ag, B, Cr, Mg, Ni, S, Pb, and Se as the main pollutants, the cumulative HI was computed and all values were greater than 1. This showed that using hair dye products included unacceptable risks of non-carcinogenic health impacts[50].

The non-carcinogenic HQ_{inh} in adults for the PTEs in this investigation is compiled in Table 5. All Ag, B, Ce, Cs, Mg, Mo, Pd, and Si had HQ_{inh} values less than 1, indicating a reasonable risk of a non-carcinogenic effect on adult human health. Since elevated levels of these PTEs in the body have been connected to headache, diarrhea, nausea, and vomiting, the HQ_{inh} values for Cd, Co, Cr, Fe, Hg, Mn, Pb, S, Sb, and Zn were all greater than 1, indicating an intolerable risk[8]. With Cd, Co, Fe, Hg, Sb, and Zn as the main pollutants, the cumulative HI was computed and all values were greater than 1. This showed that using hair dye products carried intolerable risks of non-carcinogenic health consequences[51].

The hazard quotient via dermal contact (HQ_{derm}) computation is the next stage in assessing the dangers to human health posed by PTEs in hair dye products. The results are shown in Table 6. There was no discernible health risk from the examined PTEs, and the computed HQ_{derm} for all Ag, Ce, Cs, Fe, Mg, Mn, Mo, Pd, and Si for various colors and brands was less than 1. Since elevated levels of certain PTEs in the body have been connected to headache, diarrhea, nausea, and vomiting, the HQ_{derm} values for B, Cd, Co, Cr, Cu, Hg, Ni, Pb, S, Sb, Se, and Zn were all greater than 1, indicating an intolerable danger. Furthermore, HI was computed using the obtained HQs in accordance with Equation 3.4; like HQ, a risk level will be significant when HI is greater than 1. The calculated HQ and HI had a non-significant interval to the baseline of 1, indicating that human exposure to these elements can have any negative effect. The calculated HI indices for the surveyed colors and brands were greater than 1, indicating that, when taking into account the overall health risk of all surveyed PTEs, using different colors and brands of chemical hair dyes is not safe[52].

Table 4: Hazard Quotient of Ingestion (HQ_{ing}) Pathways for the PTEs in Hair Dye for Adults

PTEs	A1	A2	A3	A4	A5
Ag	**7.82×10^{-10}**	**6.13×10^{-10}**	**5.58×10^{-11}**	**5.91×10^{-10}**	**5.85×10^{-10}**

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As	**2.73×10^{-11}**	**2.19×10^{-11}**	**2.64×10^{-11}**	**2.37×10^{-11}**	**5.84×10^{-11}**
B	**6.84×10^{-11}**	1.09×10^{-11}	**7.93×10^{-10}**	**9.03×10^{-11}**	**4.92×10^{-11}**
Ce	**2.79×10^{-11}**	**2.73×10^{-11}**	**2.46×10^{-11}**	1.09×10^{-11}	**3.83×10^{-11}**
Cd	**5.47×10^{-10}**	1.36×10^{-10}	1.36×10^{-10}	1.09×10^{-10}	**8.21×10^{-10}**
Co	**8.21×10^{-11}**	**5.47×10^{-9}**	1.50×10^{-11}	**3.58×10^{-11}**	1.09×10^{-10}
Cr	**4.56×10^{-12}**	1.68×10^{-11}	**6.99×10^{-11}**	**2.90×10^{-12}**	1.84×10^{-12}
Cs	**2.63×10^{-11}**	**2.05×10^{-16}**	0.00	**3.08×10^{-16}**	**2.14×10^{-16}**
Cu	**3.31×10^{-12}**	**4.38×10^{-10}**	1.75×10^{-11}	**7.99×10^{-11}**	**4.38×10^{-12}**
Fe	**4.69×10^{-11}**	1.43×10^{-10}	**2.07×10^{-11}**	1.29×10^{-11}	1.71×10^{-11}
Hg	**2.83×10^{-11}**	**2.39×10^{-12}**	1.09×10^{-12}	1.08×10^{-12}	**9.12×10^{-12}**
Mg	**9.15×10^{-10}**	**8.60×10^{-10}**	**8.45×10^{-10}**	**2.46×10^{-12}**	**9.49×10^{-12}**
Mn	**3.03×10^{-11}**	**7.82×10^{-10}**	**6.64×10^{-10}**	**2.38×10^{-12}**	**8.21×10^{-12}**
Mo	**2.14×10^{-11}**	**2.43×10^{-10}**	1.53×10^{-11}	1.64×10^{-11}	1.04×10^{-12}
Ni	**8.6×10^{-11}**	**8.04×10^{-11}**	1.06×10^{-12}	1.25×10^{-12}	0.00
Pd	0.00	0.00	0 .00	0.00	0.00
Pb	1.10×10^{-11}	**3.66×10^{-11}**	**5.94×10^{-11}**	**1.51×10^{-11}**	**8.74×10^{-11}**
S	**5.20×10^{-11}**	**7.80×10^{-10}**	**5.33×10^{-11}**	**1.83×10^{-12}**	**8.21×10^{-12}**
Sb	**3.55×10^{-11}**	1.91×10^{-11}	**7.52×10^{-11}**	**8.82×10^{-11}**	**2.25×10^{-11}**
Se	**2.62×10^{-12}**	**6.62×10^{-12}**	**6.46×10^{-12}**	**9.85×10^{-12}**	1.30×10^{-12}
Si	0.00	0.00	0.00	0.00	0.00
Zn	**4.93×10^{-12}**	**7.20×10^{-12}**	1.02×10^{-12}	1.13×10^{-12}	**5.56×10^{-12}**
HI	**2.63×10^{-16}**	**2.05×10^{-16}**	**3.08×10^{-16}**	**2.14×10^{-16}**	**1.89×10^{-12}**

Bold figures indicate values greater than 1.

Table 5: Hazard Quotient of Inhalation (HQ_{inh}) Pathways for the PTEs in Hair Dyes for Adults

PTEs	**A1**	**A2**	**A3**	**A4**	**A5**
Ag	0.00	0.00	0.00	0.00	0.00
As	1.64×10^{-11}	1.31×10^{-11}	1.58×10^{-11}	1.42×10^{-11}	**3.50×10^{-11}**
B	0.00	0.00	0.00	0.00	0.00

Ce	0.00	0.00	0.00	0.00	0.00
Cd	**2.73×10^{-11}**	**6.84×10^{-11}**	**6.84×10^{-11}**	**5.47×10^{-11}**	**4.10×10^{-11}**
Co	**8.21×10^{-10}**	**5.47×10^{-10}**	1.50×10^{-10}	**3.55×10^{-11}**	1.09×10^{-11}
Cr	**9.12×10^{-10}**	**3.37×10^{-10}**	1.39×10^{-10}	**5.80×10^{-10}**	**3.68×10^{-10}**
Cs	0.00	0.00	0.00	0.00	0.00
Cu	**3.31×10^{-11}**	**4.38×10^{-11}**	**4.38×10^{-11}**	**7.99×10^{-11}**	**4.38×10^{-11}**
Fe	**8.45×10^{-11}**	**2.58×10^{-11}**	**3.73×10^{-11}**	**2.32×10^{-11}**	**3.08×10^{-11}**
Hg	**5.67×10^{-11}**	**4.79×10^{-11}**	**2.19×10^{-11}**	**2.17×10^{-11}**	1.82×10^{-11}
Mg	0.00	0.00	0.00	0.00	0.00
Mn	**4.24×10^{-11}**	1.09×10^{-11}	**9.30×10^{-11}**	**3.33×10^{-11}**	1.14×10^{-11}
Mo	0.00	0.00	0.00	0.00	0.00
Ni	1.73×10^{-11}	1.60×10^{-11}	**2.12×10^{-11}**	**2.51×10^{-11}**	0.00
Pd	0.00	0.00	0.00	0.00	0.00
Pb	1.54×10^{-11}	**5.12×10^{-11}**	**8.32×10^{-11}**	**2.11×10^{-11}**	1.22×10^{-11}
S	**2.08×10^{-11}**	**3.12×10^{-11}**	**2.13×10^{-11}**	**7.33×10^{-11}**	**3.28×10^{-11}**
Sb	**7.11×10^{-11}**	**3.83×10^{-11}**	1.50×10^{-11}	1.76×10^{-11}	**4.51×10^{-11}**
Se	**5.25×10^{-11}**	1.32×10^{-11}	1.29×10^{-11}	1.97×10^{-11}	**2.62×10^{-11}**
Si	0.00	0.00	0.00	0.00	0.00
Zn	**2.04×10^{-11}**	**8.65×10^{-11}**	1.22×10^{-11}	1.35×10^{-11}	**6.67×10^{-11}**
HI	1.11×10^{-11}	**6.35×10^{-11}**	1.24×10^{-11}	**6.96×10^{-11}**	**7.01×10^{-11}**

Bold figures indicate values greater than 1.

Table 6: Hazard Quotient of Dermal (HQ_{derm}) Pathways for the PTEs in Hair Dyes for Adults

PTEs	A1	A2	A3	A4	A5
Ag	0.00	0.00	0.00	0.00	0.00
As	1.36×10^{-11}	1.09×10^{-11}	1.32×10^{-11}	1.18×10^{-11}	**2.92×10^{-11}**
B	**3.42×10^{-11}**	**5.47×10^{-10}**	**3.96×10^{-10}**	**4.51×10^{-10}**	**2.46×10^{-10}**
Ce	0.00	0.00	0.00	0.00	0.00
Cd	**2.73×10^{-10}**	**6.84×10^{-10}**	**6.84×10^{-10}**	**5.47×10^{-10}**	**4.10×10^{-10}**

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Co	**4.10×10^{-11}**	**2.73×10^{-11}**	**7.52×10^{-11}**	1.77×10^{-11}	**5.47×10^{-11}**
Cr	**2.28×10^{-11}**	**8.44×10^{-11}**	**3.49×10^{-11}**	1.45×10^{-11}	**9.21×10^{-11}**
Cs	0.00	0.00	0.00	0.00	0.00
Cu	1.65×10^{-10}	**2.19×10^{-10}**	**8.76×10^{-10}**	**3.99×10^{-10}**	**2.19×10^{-10}**
Fe	0.00	0.00	0.00	0.00	0.00
Hg	**4.25×10^{-11}**	**3.59×10^{-11}**	1.64×10^{-11}	1.62×10^{-11}	1.36×10^{-11}
Mg	0.00	0.00	0.00	0.00	0.00
Mn	0.00	0.00	0.00	0.00	0.00
Mo	0.00	0.00	0.00	0.00	0.00
Ni	**4.33×10^{-11}**	**4.02×10^{-11}**	**5.31×10^{-11}**	**6.29×10^{-11}**	0.00
Pd	0.00	0.00	0.00	0.00	0.00
Pb	**4.83×10^{-11}**	1.60×10^{-11}	**2.60×10^{-11}**	**6.61×10^{-11}**	**3.82×10^{-11}**
S	**2.60×10^{-11}**	**3.90×10^{-10}**	**2.66×10^{-10}**	**9.17×10^{-10}**	**4.10×10^{-10}**
Sb	1.77×10^{-11}	**9.58×10^{-11}**	**3.76×10^{-11}**	**4.41×10^{-11}**	1.12×10^{-11}
Se	1.31×10^{-11}	**3.31×10^{-11}**	**3.23×10^{-11}**	**4.92×10^{-11}**	**6.57×10^{-11}**
Si	0.00	0.00	0.00	0.00	0.00
Zn	**5.11×10^{-11}**	**2.16×10^{-11}**	**3.06×10^{-11}**	**3.39×10^{-11}**	1.66×10^{-11}
HI	1.69×10^{-11}	1.18×10^{-11}	**2.04×10^{-11}**	**8.13×10^{-11}**	1.20×10^{-11}

Bold figures indicate values greater than 1.

Lifetime Cancer Risk (LCR) for PTEs through Ingestion, Inhalation and Dermal Pathways

The International Agency for Research on Cancer lists As, Cr, Co, Pb, and Ni as carcinogenic PTEs[13]. Table 5, 6 and 7 summarizes the estimated lifetime cancer risk (LCR) values for the metals (As, Cd, Cr, Co, Pb, and Ni) found in this investigation. PTEs can enter the body in three main ways: through the skin, through ingestion, or through inhalation. PTEs build in the body for a long time since they are not biodegradable. Consequently, they affect intracellular pathways in addition to changing how cells function[6]. Consequently, contaminants that lead to oxidative stress, DNA damage, and cell death exacerbate disorders associated with cancer[53]. The calculation of the possible cancer risk to users resulting from exposure to PTEs from hair dye products is known as lifetime cancer risk, or LCR. The USEPA states that the permissible range for LCR is between 1×10^{-6} and 1×10^{-4} [2,3].

According to Table 7, the LCR values of PTEs obtained from ingestion ranged from 0.00 to 21.1×10^{-9}. They were found to be in decreasing order of As > Cr > Cd > Pb > Ni > Co. A few of these values exceeded the 1.0×10^{-6} to 1.0×10^{-4} safe range that the USEPA recommends [2]. With the exception of Ni in A5, the projected cancer risk for As, Cr, Cd, and Pb was higher than the permissible levels. All of the Co values were zero. A3 (gold) has the lowest cancer risk by ingestion, while A1 (black) is the most carcinogenic of the hair dyes examined based on cumulative lifetime cancer risk (LCR). Furthermore, all six PTEs had estimated LCR values above the allowable limit of 1.0×10^{-4}, with the exception of Co, which suggested a carcinogenic risk for those who consumed these hair dyes[53].

The LCR values of PTEs obtained by inhalation are shown in Table 8. They were all over the permissible limits, with the exception of Ni in A5, and were discovered in the following decreasing order: Cr > Co > As > Ni > Cd > Pb. All of the Pb levels were 0.00. A2 has the lowest cancer risk through inhalation, while A4 is the most carcinogenic of the hair dyes examined based on cumulative lifetime cancer risk (LCR). Furthermore, all six PTEs had projected LCR values above the allowable limits of 1.0×10^{-4}, with the exception of Pb, suggesting that inhaling these hair dyes could cause cancer[53,54].

The cumulative LCR of dermal values obtained, present in Table 9 gave values of 11.3×10^{-5}, 9×10^{-5}, 7.1×10^{-7}, 16.4×10^{-5} and 20×10^{-4}, respectively, for A1, A2, A3, A4 and A5. Therefore, the values of LCR dermal of PTEs analyzed for adults were found in the order of A5 > A4 > A1 > A2 > A3. Mean values of 8.7×10^{-4}, 17.6×10^{-5}, 22.8×10^{-5}, 0.00, 0.00 and 14.7×10^{-5} respectively, were observed for As, Cd, Cr, Ni, Co, and Pb. As a result, the LCR dermal values of PTEs examined for adults were found to be in the following order: Cr > Cd > Pb > As > Ni > Co. The lifetime cancer risk was found to be higher than the allowable limits for all of the PTEs that were examined, with the exception of Ni and Co, indicating that hair dye products may have a lifetime cancer risk. Because this value is below the threshold at which cancer risk is deemed problematic, the LCR of Ni and Co may therefore be regarded as negligible and the cancer risk can be disregarded. Because of their cutaneous sensitivity to Cr, Cd, Pb, and As, the hair dye samples examined in this investigation did, in fact, provide a carcinogenic risk.

Table 7: Lifetime Cancer Risk (LCR) for PTEs through Ingestion Pathways

	As	Cd	Cr	Ni	Co	Pb	ΣLCR
A1 (black)	**1.2×10^{-9}**	**8.2×10^{-9}**	**6.8×10^{-9}**	**1.6×10^{-9}**	0.00	**3.3×10^{-9}**	**21.1×10^{-9}**
A2 (green)	**9.9×10^{-7}**	**2.1×10^{-7}**	**2.5×10^{-7}**	**1.5×10^{-7}**	0.00	**1.1×10^{-7}**	**17.1×10^{-7}**
A3 (gold)	**1.2×10^{-8}**	**2.1×10^{-8}**	**1.0×10^{-8}**	**1.9×10^{-8}**	0.00	**1.8×10^{-8}**	**8×10^{-8}**
A4 (white)	**1.1×10^{-8}**	**1.6×10^{-8}**	**4.4×10^{-8}**	**2.3×10^{-8}**	0.00	**4.5×10^{-8}**	**13.9×10^{-8}**
A5 (wine)	**2.6×10^{-9}**	**1.2×10^{-9}**	**2.8×10^{-9}**	0.00	0.00	**2.6×10^{-9}**	**9.2×10^{-9}**

Bold figures for LCR indicate values >1.0 x 10^{-6}, ΣLCR = cumulative cancer risk.

Table 8: Lifetime Cancer Risk (LCR) for PTEs through Inhalation Pathways

	As	Cd	Cr	Ni	Co	Pb	ΣLCR
A1	**2.5×10^{-6}**	**6.9×10^{-6}**	**1.1×10^{-6}**	**2.9×10^{-6}**	**1.6×10^{-6}**	0.00	**15×10^{-6}**
A2	**2.0×10^{-8}**	**1.7×10^{-8}**	**4.3×10^{-8}**	**2.7×10^{-8}**	**1.1×10^{-8}**	0.00	**11.8×10^{-8}**
A3	**2.4×10^{-7}**	**1.7×10^{-7}**	**1.8×10^{-7}**	**3.6×10^{-7}**	**3.0×10^{-7}**	0.00	**12.5×10^{-7}**
A4	**2.1×10^{-7}**	**1.4×10^{-7}**	**7.3×10^{-7}**	**4.2×10^{-7}**	**7.0×10^{-7}**	0.00	**21×10^{-7}**
A5	**5.3×10^{-9}**	**1.0×10^{-9}**	**4.6×10^{-9}**	0.00	**2.1×10^{-9}**	0.00	**13×10^{-9}**

Bold figures for LCR indicate values > 1.0 x 10^{-6}, ΣLCR = cumulative cancer risk.

Table 9: Lifetime Cancer Risk (LCR) for PTEs through Dermal Pathways

	As	Cd	Cr	Ni	Co	Pb	ΣLCR
A1	**1.5×10^{-4}**	**5.5×10^{-4}**	**1.4×10^{-4}**	0.00	0.00	**2.9×10^{-4}**	**11.3×10^{-5}**
A2	**1.2×10^{-5}**	**1.4×10^{-5}**	**5.1×10^{-5}**	0.00	0.00	**1.3×10^{-5}**	**9×10^{-5}**
A3	**1.5×10^{-7}**	**1.4×10^{-7}**	**2.1×10^{-7}**	0.00	0.00	**2.1×10^{-7}**	**7.1×10^{-7}**
A4	**1.3×10^{-5}**	**1.1×10^{-5}**	**8.7×10^{-5}**	0.00	0.00	**5.3×10^{-5}**	**16.4×10^{-5}**
A5	**3.2×10^{-4}**	**8.2×10^{-4}**	**5.5×10^{-4}**	0.00	0.00	**3.1×10^{-4}**	**20×10^{-4}**

Bold figures for LCR indicate values >1.0 x 10^{-6}, ΣLCR = cumulative cancer risk

CONCLUSION

The studied PTEs concentrations were ranged as; Cs > Mg > Si > Fe > Pd > Pb > Ag > Zn > Mn > Se > Ni > Ce > Sb > As > Cr > B > Cu > Mo > Co > Cd > S > Hg across all hair dye products analysed. The concentration values for Ag, Ce, Cs, Fe, Mg, Mn, and Si were all within the USFDA permissible limits. The concentration values of As, B, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pd, Pb, S, and Zn were observed to be above than the permissible limits in all the samples except for Se in A1, A4 and A5 with values of 0.48, 0.18 and 0.25 respectively.

The calculated HQ and HI had a non-significant interval to the baseline of 1, indicating that human exposure to these elements can have any negative effect. The calculated HI indices for the surveyed colors and brands were greater than 1, indicating that, when taking into account the overall health risk of all surveyed PTEs, the consumption of various white (Subaru) and black (Cruset) chemical hair dyes is not safe.

Customers using these hair dyes in Ibadan, Nigeria, are anticipated to face clear carcinogenic and non-carcinogenic dangers, based on the data obtained. The LCR presents a danger of cancer with repeated and prolonged use of these hair dyes through hand-dermal contact, ingestion, and inhalation.

RECOMMENDATIONS

Based on the outcome of this study, the following are hereby recommended:

1. Long term (2 – 3 years) frequent (or incessant) use of hair dyes should be discouraged, especially for people with cancer family history.

2. To better protect the health of customers, consumer protection agencies must regularly regulate the amounts of PTEs in hair dye products sold in Nigerian supermarkets.

Suggested Areas for Further Research

1. Further study on organic components such as; parabens and total hydrocarbon contents of the hair dye products is highly suggested, using appropriate analytical tools. Energy.

2. Dispersive X-ray spectroscopy (EDX) in hair dyes should be studied further to unveil and display the elemental match-up with the dye colors.

Declaration of Competing Interest:

The authors declare that they have no conflict(s) of interest. All authors have read, understood, and have complied as applicable with the statement on "Ethical Responsibilities of Authors" as found in the Instructions for Authors in this journal.

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