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RESEARCH ARTICLE

Safety concerns of lead chromate in enamel paints: A study based on the Sri Lankan enamel paints industry after the lead paint regulatory enforcement

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Abstract: Although lead (Pb) paint testing has been carried out in a large number of studies in Sri Lanka, little work appears to have been done to investigate the chromium (Cr) levels, variation of Pb and Cr levels through different production batches of paint manufacturers and the possible sources of unusually higher Pb and Cr levels in paints. Thirty-six enamel paints manufactured after the lead paint regulatory enforcement, were randomly purchased from six popular brands in Sri Lanka to assess their Pb and Cr levels. Heavy metals in liquid paints were acid digested for the analysis by flame atomic absorption spectrometry (FAAS). From the thirty-six paints analysed (six colours from six brands) one yellow and one green paint showed highest Pb and Cr levels. Reported Pb levels in yellow and green paints were 11545 ± 6 ppm and 4060 ± 9 ppm and Cr levels were 2681 ± 2 ppm and 960 ± 7 ppm, respectively. These yellow and green paints were labelled as safe although they exceeded the Pb regulatory limit. Pb and Cr in the other 34 samples were below Sri Lankan regulatory limits. For paints with both Pb and Cr, Pb and Cr mole ratio was 1.079:1, suggesting the possible presence of lead chromate ($PbCrO_4$) in certain paints although the manufactured paints adhered to safety standards. Batch-wise manufacturing variation was also reported. Thus, formulation of national policies and their proper implementation is necessary for manufacturing safe paints in Sri Lanka.

Keywords: Chromium, government regulations, lead, lead chromate, yellow and green enamel paints.

INTRODUCTION

Heavy metals are considered to be one of the globally distributed priority pollutants because of their toxicity, persistence in nature, and ability to be incorporated into food chains (Jha *et al*., 2016). Deteriorated residential paints are one of the most common sources of heavy metals in the environment and the resulting issue is a global matter of concern (Meyer *et al*., 2008). Paints contain not only Pb but also other heavy metals such as chromium (Cr), cadmium (Cd), nickel (Ni) and zinc (Zn) (Oligo *et al*., 2017). In the priority list of hazardous substances, Pb is ranked second and Cr ranked seventeenth by Agency for Toxic Substances and Disease Registry (ATSDR, 2013). Pb has no function in the human body and is a carcinogenic heavy metal (ATSDR, 2020). Health authorities have concluded that there is no threshold value for the blood Pb level below which its concentration can be considered safe (Wani *et al*., 2015). Toxicity of Cr is dependent upon the oxidation state and the solubility. Cr(III) has very low human toxicity, whereas exposure to high levels of Cr(VI) can produce a variety of acute and chronic effects although Cr is necessary for humans in minute amounts (ATSDR, 2012).

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Enamel paints are used frequently for household decoration and paints with high Pb and Cr levels still continue to be sold in Sri Lanka without considering the government regulations as has been documented by a number of investigators (Rubesinghe *et al*., 2013; 2015; Rathnamalala *et al*., 2015). When houses with paints containing heavy metals such as Pb and Cr deteriorate or are remodelled without taking proper heavy metal controlling precautions, the heavy metals can become available in dust and soil. These contaminated dust and soil are often the most significant sources of human exposure while children are the most vulnerable group. (WHO, 1995; Meyer *et al*., 2008; Hossain *et al*., 2013). Children's bodies are more rapidly growing and developing, thus sustainable permanent damages can occur if toxic exposures occur during critical growth stages (WHO, 2010). Painters are also vulnerable to heavy metals exposure because more significant exposure can result due to airborne fine particles during painting activities contributing to severe health problems (Brosché *et al*., 2014).

Large number of scientific studies on Pb-based paints have been carried out globally because the exposure to Pb is a growing global public health concern. Most of the scientific literature revealed that the production and trade of Pb-based paints are still widespread globally and that Pb-based paints are still widely used in many low and middle-income developing countries (Connora *et al*., 2018). According to the World Health Organization data in 2017, human exposure to Pb accounted for 1.06 million deaths and 24.4 million years of healthy life lost (disability-adjusted life years) worldwide due to long-term effects on health while the highest burden has been reported in low- and middle-income developing countries (WHO, 2017).

In response to concerns over the continued use of Pb in paints, their use has been restricted by government regulations of most of the countries (CPSIA, 2008; Kumar & Gottesfeld, 2008; PDENR, 2013; NEA, 2014). Decades earlier the International Labour Organization publicised a convention on the prohibition of the use of Pb-based compounds in residential paints (ILO, 1921). Sri Lanka consumer affairs authority has also stated by a gazette notification that the Pb in enamel paints should not exceed 600 milligrams per kilogram ($mgkg^{-1}$) and the regulation was come into the effect on 2013 January 01 (CAA, 2011).

It is well known that Pb has been intentionally added to paints as Pb pigments, drying agents, and as anti-corrosive agents or they may present as impurities from raw materials. The commonly used Pb pigments include lead chromate, lead oxide, lead molybdate, and lead sulphate. Paints often contain driers such as lead octoate which make paints dry faster. Pb compounds such as lead tetroxide are also added to the paints used on metal surfaces to inhibit rust or corrosion. Fillers and other ingredients used in the manufacturing of paints may contribute Pb to the paint as contaminants. However, there are readily available non-hazardous substitutes for all Pb compounds including titanium dioxide, barium sulfate, and silicon or aluminum oxides worldwide.

Chromium has also been intentionally added as Cr pigments and they may also be present as impurities from raw materials. The most commonly used chrome yellow pigment is lead chromate ($PbCrO_4$). Lead chrome greens [$PbCrO_4$: $KFe(Fe(CN)_6)$] are also added as green pigments. Chromium oxide (Cr_2O_3) is a dull green inorganic pigment which is also used in all types of paints (Abel, 1999; Kumar & Gottesfeld, 2008; Gupta & Gauri, 2013; IPEN, 2014).

$PbCrO_4$ is a relatively inexpensive yellow inorganic pigment which was extensively used in the paint industry. Intentional additions of metallic raw material (e.g. $PbCrO_{4)}$ impurities present in raw materials or contaminations during paint manufacturing process are the possible sources of these metals into consumer paints (UNEP & WHO, 2011; IPEN, 2014). Although the global paint industry is growing rapidly with expanding economy, most recent influences on paint developments are related to environmental considerations and need to strictly adhere to health and safety legislations (Shim *et al*., 2011). There is therefore an urgent need to ensure that paints are manufactured using only non-hazardous materials.

In Sri Lanka, the awareness on public health impact of exposure to Pb in enamel paints is continuously growing, but relatively no attention has been devoted to assess the batch-wise variations of hazardous metal levels in enamel paints within a year. A large number of research studies have carried out on Pb levels in enamel paints, but there is lack of data for Cr levels in enamel paints although there is a mandatory restriction on the Cr level in enamel paints (SLSI, 2010).

This investigation was designed to help fill the gaps in knowledge of Pb and Cr levels in enamel paints. It is focused on the investigation of consistency of Pb and Cr levels with regulatory standards, possible sources of unusually higher Pb and Cr levels in paints and finally to make recommendations to stop the use of hazardous compounds in manufacturing paints.

METHODOLOGY

Selection of samples

In this study, purposive random sampling of enamel paints ready for sale in retail shops in Colombo district, Sri Lanka was done. The selection of enamel paint brands and the colours were based upon the results of a questionnaire survey carried out among randomly selected paint uses and retailers.

Collection of samples

All the samples subjected to the analysis were collected during the period from November 2014 to April 2015 having being manufactured between 2014 January and 2015 April, after the Pb paint regulation came into effect. The selected paint brands are controlling 97% of the paint market share in Sri Lanka. These manufactures have also indicated that they are in the process of eliminating the use of hazardous compounds in enamel paints or have eliminated (Rathnamalala, 2015; Rubasinghe, 2015).

A total of thirty-six enamel paint samples (n = 36) from six colours (red, yellow, white, black, brown, and, green) of six brands, hereafter named as A, B, C, D, E, and F, were collected. On the analysis revealing that one yellow paint manufactured on 2014 March 27 and one green paint manufactured on 2014 January 13 by two manufactures (Brands A and B) reported the highest Pb and Cr levels, analyses were repeated for ten samples of those two particular paints. Five samples from the same batch which contained highest Pb and Cr levels and five samples from different batches were purchased from different locations and analysed.

Reagents and materials

All the reagents used were prepared from analytical grade chemicals. All solutions were prepared in double distilled water. Nitric acid (≥ 70%, Sigma Aldrich), sulphuric acid (≥ 98%, Sigma Aldrich) ammonium acetate (≥ 99%, Fluka), potassium permanganate (≥ 99%, Fluka) and hydroxylamine hydrochloride (≥ 99%, Fluka) were used for sample digestion. Lead chromate (≥ 98%, Sigma Aldrich) was used for the recovery analysis of Pb and Cr. All the plastic and glassware were cleaned by soaking overnight in HNO_3 solution (5% v/v) and then rinsed with double distilled water before use.

Lead standard stock solution (1000 $mgkg^{-1}$) was prepared by dissolving 0.162 g of $Pb(NO_3)_2$ (≥ 99.0%, Sigma Aldrich) in 1 mL of water, then adding 1 mL of HNO_3 and diluting to 100 mL with water. Chromium standard stock solution (1000 $mgkg^{-1}$) was prepared by dissolving 0.377 g of K_2CrO_4 (≥ 99%, Sigma Aldrich) in 10 mL of water and diluting to 100 mL. The working solutions of each metal were prepared daily by serial dilutions of the stock solutions with double distilled water prior to the analysis. The linear dynamic range of each metal determined was 2.0–10.0 ppm.

Instrumentation

An oven (Thermo Scientific, US) capable of maintaining temperature of 110 ± 5 °C was used for evaporating solvents from paint samples. An electric muffle furnace (Advantec EL 280) capable of maintaining temperature from 450 °C to 550 °C was used for ashing the charred paint samples. A hot plate (IKA® RH basic 1) capable of maintaining surface temperature from 70 °C to 200 °C was used for sample charring and acid digestions.

All measurements were carried out with a 932 AB Plus model flame atomic absorption spectrophotometer (GBC Scientific Ltd., Canada). The instrumental parameters were adjusted according to the manufacturers' recommendations. A lead hollow cathode lamp was used as the radiation source for determination of Pb and the wavelength was set at 283.3 nm resonance line. The air - acetylene flame was used. A chromium hollow cathode lamp was used as the radiation source for determination of Cr and the wavelength was set at 357.9 nm resonance line. The nitrous oxide – acetylene flame was used.

Sample preparation, analysis and quality control

Samples were prepared for the analysis of Pb and Cr according to ASTM D 3335-85a: 2009 (ASTM, 2009) and ASTM D 3718-85a:2010 (ASTM, 2010), respectively. The analysis was conducted on liquid coatings. The liquid paint samples were mixed thoroughly in a can using a clean single-use stirrer until homogeneous and a representative paint sample was drawn for the analysis. An aliquot of the representative paint sample was initially charred on a hot plate to remove solvents. The charred sample was then ashed at 475–500 °C in a muffle furnace for 2 h. For the analysis of Pb, ashed samples were digested with 20 mL of 50 % (v/v) HNO_3 on the hot plate. The resulted solution was filtered through a Whatman No.1 filter paper into a 50 mL volumetric flask and washed with ammonium acetate solution, then the volume was adjusted to 50 mL. The digestion of an ashed sample for Cr content was carried out with 10 mL of a mixture of 0.2 g $KMnO_4$ in 100 mL of 50 % (v/v) H_2SO_4 in an acid decomposition vessel at 105 °C for 1½ hours. Then the contents were filtered through a Whatman No.1 filter paper into a 50 mL volumetric flask. Hydroxylamine hydrochloride solution was added dropwise to the filtrate until the permanganate colour has been discharged, then diluted to volume with distilled water. Paint samples were analysed using flame atomic absorption spectrophotometer after the digestions and dilutions. Five replicates of the same sample were digested and analysed to calculate the mean value. The absorbance values of sample solutions were measured against the blank solution. The difference between the absorbance of the samples and blank solutions at respective wavelengths was used as the analytical parameter for quantifications. Calibration curves were constructed by plotting the analytical signal versus the metal ion concentration in a series of working standards prepared in the range of 2.0–10.0 ppm.

The accuracy of the methods was evaluated by percent recovery of Pb and Cr. White paint of brand D found to contain no detectable levels of Pb and Cr was spiked with 156 ppm, 468 ppm, and 935 ppm of $PbCrO_4$ for the recovery analysis. Repeatability of analysis was expressed in terms of standard deviation. Limit of detection of instrument for each metal was determined using a statistical approach. Ten blank samples fortified at lowest acceptable concentration were digested and analysed by FAAS to calculate the limit of detection (LOD) at respective wavelengths of each metal ion. The LOD was calculated as 3s + , where, s = standard deviation for the blanks fortified with known amount of standard solution and = mean measured value of blank samples. The calculated LOD values of Pb and Cr was 5.4 ppm and 5.8 ppm per dry weight of the paint, respectively.

Pb and Cr levels in non-volatile portion of the liquid paints were expressed in parts per million (ppm) on the dry weight of the paint and results were presented as arithmetic means ± standard deviation of five replicates. Rejection of outliers' test/Q-test was employed at 95 % confidence limit to take decisions if any outlying experimental data are available.

RESULTS AND DISCUSSION

Pb levels in analysed paint samples

Total Pb level in ppm in enamel paints was compared by brand and colour to assess their compliance with national and international regulatory standards. The Pb levels of 90 ppm and 600 ppm were chosen because 600 ppm on dry weight is the current regulatory limit of Pb in enamel paints in Sri Lanka (CAA, 2011) and in some other countries, e.g., Singapore and China (Clark *et al*., 2009) while 90 ppm on dry weight of paints is the current regulatory limit in the United States (CPSIA, 2008), Philippines (PDENR, 2013), Nepal (Gottesfeld *et al*., 2014) and India (Kumar & Gottesfeld, 2008). Data on individual samples are presented in Table 1.

Table 1 summarizes the Pb levels in 36 paint samples analysed in this study. Only two samples had the Pb levels greater than 600 ppm. Yellow paint from brand A (A-Yellow) was nearly 20 times greater while the green paint from brand B (B-Green) was 7 times greater than the Sri Lankan standards. Altough Pb levels in these two paints exceeded the current regulatory limit, A-Yellow paint was labelled as 'SLS 539' and B-Green paint as 'Lead safe' which violate the government regulations. In addition to these two samples, six other samples exceeded the US regulatory limit of 90 ppm. Interestingly, four out of the eight samples exceeded US standard were yellow paints, two were green paints, one red paint and one brown paint. Rest of the samples are safer in terms of Sri Lankan and US standards.

Table 1: Mean Pb levels of six different colours of six different brands

Brand	Pb level (± standard deviation of five replicates), ppm on dry weight					
	White	Black	Yellow	Red	Green	Brown
A	< 5.4	< 5.4	11545 ± 6	< 5.4	96 ± 1	< 5.4
B	36 ± 3	< 5.4	366 ± 2	97 ± 0.8	4060 ± 9	204 ± 1
C	23 ± 2	< 5.4	156 ± 1	25 ± 2	53 ± 2	38 ± 5
D	< 5.4	< 5.4	< 5.4	< 5.4	19 ± 4	58 ± 3
E	22 ± 3	21 ± 5	98 ± 2	18 ± 3	19 ± 2	22 ± 2
F	41 ± 4	56 ± 2	46 ± 3	48 ± 3	47 ± 1	44 ± 3

Limit of detection of Pb = 5.4 ppm

Cr levels in analysed paint samples

Total Cr level in ppm in analysed samples were compared by brand and colour to assess their compliance with regulatory limit in Sri Lanka. According to the specifications for enamel paints made by the Sri Lanka Standards Institution, the maximum permissible Cr content in enamel paints is 250 ppm on dry weight of paints (SLSI, 2010). Data on individual samples are presented in Table 2.

Table 2: Mean Cr levels of six different colours of six different brands

Brand	Cr level (± standard deviation of five replicates), ppm on dry weight					
	White	Black	Yellow	Red	Green	Brown
A	< 5.8	< 5.8	2681 ± 2	< 5.8	19 ± 4	< 5.8
B	< 5.8	< 5.8	83 ± 5	< 5.8	960 ± 7	42 ± 3
C	< 5.8	< 5.8	< 5.8	< 5.8	< 5.8	< 5.8
D	< 5.8	< 5.8	< 5.8	< 5.8	< 5.8	< 5.8
E	< 5.8	< 5.8	< 5.8	< 5.8	< 5.8	< 5.8
F	< 5.8	< 5.8	< 5.8	< 5.8	< 5.8	< 5.8

Limit of detection of Cr = 5.8 ppm

Only five samples had detectable levels of Cr and all of them were manufactured by brands A and B. In addition to the yellow and green samples from both brands, brown sample from brand B had detectable levels of Cr. Out of the 36 samples, only two samples exceeded the Sri Lankan regulatory standard and these two samples had reported high Pb levels as well.

Both Pb and Cr were detected in only five paint samples from all the paints analysed (A-Yellow, A-Green, B-Yellow, B-Green, B-Brown). The origin of Pb and Cr in the paints was investigated.

For the five samples with Pb and Cr present, the correlation between the number of millimoles of Pb and Cr was investigated (Figure 1).

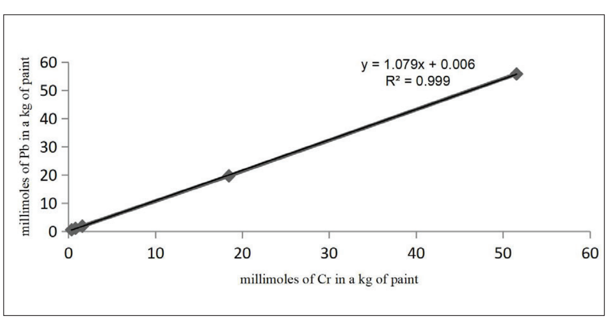

Figure 1: Variation of millimoles of Pb in a kg of paint vs millimoles of Cr in a kg of paint

As shown in Figure 1 there is a linear relationship between millimoles of Pb and millimoles of Cr in a kg of paint where the ratio of millimoles of Pb to millimoles of Cr in a kg of paint is 1.079, suggesting Pb and Cr may be present in the form of $PbCrO_4$.

Since $PbCrO_4$ is insoluble, the recovery of Pb and Cr from a $PbCrO_4$ spiked paint sample was determined. Since D-White paint has no detectable levels of Pb and Cr, it was selected as the base material and spiked with a known amount of $PbCrO_4$ (935 ppm), such that the recovered Pb and Cr levels be approximately 600 ppm and 150 ppm. The analysis was replicated five times.

Table 3 presents the Pb and Cr recovery from $PbCrO_4$ spiked paint sample.

Table 3: Pb and Cr levels of $PbCrO_4$ spiked paint sample (D-White paint spiked at 935 ppm $PbCrO_4$)

Trial	Recovered concentration (ppm)		Recovered amounts in 10^{-3} moles kg^{-1}		Mole ratio
	Pb	Cr	n_{Pb}	n_{Cr}	n_{Pb}/n_{Cr}
1	598	148	2.89	2.85	1.01
2	601	151	2.90	2.90	1.00
3	599	149	2.89	2.86	1.01
4	598	149	2.89	2.86	1.01
5	599	152	2.89	2.92	0.989

n_{Pb} - number of moles of Pb; n_{Cr} - number of moles of Cr

As shown in Table 3, it is clear that if $PbCrO_4$ is present in the paint samples it can be quantified with sufficient accuracy and precision.

Investigation of batchwise variations of Pb and Cr levels in selected paints

As shown in Tables 1 and 2, A-Yellow paint which was manufactured on 2014 March 27and B-Green paint which was manufactured on 2014 January 13 contained excessive levels of Pb and Cr. Therefore, batchwise variations of Pb and Cr levels in the different production batches of A-Yellow and B-Green paints was investigated. Five samples from same batch of each colour were purchased from different locations and results were found to be consistent for both Pb and Cr. Pb and Cr levels in paints of five different batches of each colour purchased from different locations were below regulatory limits, Tables 4 and 5.

For the five A-Yellow paints manufactured on 2014/03/27 and the five B-Green paints manufactured on 2014/01/13, the Q statistical test was performed at 95 % confidence limit (Qcritical for 5 determinants at 95 %

Table 4: Pb and Cr levels of different manufacturing batches of A-Yellow enamel paints

Sample No	Manufactured date	[Pb], ppm on dry weight	[Cr], ppm on dry weight	n_{Pb}/n_{Cr}, ratio
A-Yellow 1	2014/01/08	< 5.4	96 ± 2	-
A-Yellow 2	2014/02/03	< 5.4	< 5.8	-
A-Yellow 3	2014/03/21	12 ± 1	< 5.8	-
A-Yellow 4	2014/03/27	11545 ± 6	2681 ± 2	1.082
A-Yellow 5	2014/03/27	11528 ± 4	2657 ± 9	1.090
A-Yellow 6	2014/03/27	11534 ± 5	2698 ± 7	1.074
A-Yellow 7	2014/03/27	11552 ± 7	2682 ± 8	1.082
A-Yellow 8	2014/03/27	11516 ± 9	2695 ± 6	1.073
A-Yellow 9	2014/08/16	< 5.4	< 5.8	-
A-Yellow 10	2015/01/02	8 ± 1	< 5.8	-

Limit of detection of Pb = 5.4 ppm; limit of detection of Cr = 5.8 ppm; n_{Pb} – number of moles of Pb; n_{Cr} – number of moles of Cr

Table 5: Pb and Cr levels of different manufacturing batches of B-Green enamel paints

Sample No	Manufactured date	[Pb], ppm on dry weight	[Cr], ppm on dry weight	n_{Pb}/n_{Cr}, ratio
B-Green 1	2014/01/13	4060 ± 9	960 ± 7	1.062
B-Green 2	2014/01/13	4097 ± 6	956 ± 6	1.077
B-Green 3	2014/01/13	4088 ± 7	974 ± 8	1.054
B-Green 4	2014/01/13	4074 ± 5	968 ± 6	1.057
B-Green 5	2014/01/13	4096 ± 4	980 ± 3	1.050
B-Green 6	2014/08/11	< 5.4	< 5.8	-
B-Green 7	2014/12/20	< 5.4	6 ± 1	-
B-Green 8	2015/01/03	< 5.4	< 5.8	-
B-Green 9	2015/01/13	< 5.4	< 5.8	-
B-Green 10	2015/01/27	< 5.4	< 5.8	-

Limit of detection of Pb = 5.4 ppm; limit of detection of Cr = 5.8 ppm; n_{Pb} – number of moles of Pb; n_{Cr} – number of moles of Cr confidence limit = 0.710). Since none of the suspected metal levels for A-yellow and B-Green paints was found as outliers, all the determinants of both the colours were retained.

According to Tables 4 and 5, there is an obvious tendency to have larger batchwise manufacturing variations and thus the products with different heavy metal levels in the consumer market. The consistency of results of Pb and Cr from the same batch clearly indicates the reliability of analysis procedures (Tables 1, 2, 4 and 5). The high levels of Pb and Cr are inherent to the batch which may have been caused from impurities in the raw materials or some irregularities in the production process. Furthermore, it can be suggested that the $PbCrO_4$ is present in yellow paints of brand A manufactured on 2014 March 27 and in green paints of brand B manufactured on 2014 January 13. The resulting Pb levels and Cr levels in all other paints can be due to small impurities in other paint components or contaminations during paint manufacturing.

On the other hand, A-Yellow and B-Green paints have been manufactured close to the Sri Lankan New Year season, the peak season when most of the paints manufactured are used, suggesting that manufactures would have increased production volumes with available raw materials without paying much attention to maintain the quality required due to the increased demand. This observation hence critically suggests the random use of $PbCrO_4$ in certain paints by some of the manufactures. The label notations on paint containers that provide Pb content in the paint also have provided misleading information in some cases, because paints claiming 'SLS 539' and 'lead safe' notations contained the highest Pb and Cr levels.

From the rest of 31 samples, 10 had no detectable levels of Pb, which include two white paints, four black paints, a yellow paint, two red paints and a brown paint. Brand D had four lead free paints while all the paints from brands E and F contained Pb. Considering the low levels of Pb present in other 21 samples, out of which only three samples have exceeded the US standard, it is reasonable to presume that Pb in these paints originated from the raw materials, although in some cases, Pb may have been added to improve the quality of the paint within the safe limits in Sri Lanka. However, the Pb content of such paints is generally below 45 ppm. In 2014, Gottesfeld *et al*. studied Pb in new paints in Nepal and have suggested that unusually higher Pb levels are an indication of the presence of one or more intentionally added lead compounds during paint manufacturing. Considering the above fact, it is clear that the paints with considerable Pb and Cr levels tested may contain hazardous compounds that are intentionally added.

Comparison of results with some other studies in Sri Lanka

Results for enamel paints in studies by the Centre for Environmental Justice (CEJ), a Sri Lankan Non-Governmental Organization, are presented in Table 6.

From September 2012 to January 2013, the investigators have purchased 94 solvent-based enamel paint cans representing 57 brands sold in Sri Lankan market and have found that only 50 % of the analysed paint samples had Pb levels below 600 ppm. A quarter of all paints analysed had Pb levels above 10000 ppm and 37 % of the samples contained very low Pb levels, below 90 ppm. They have also observed that 16 out of 22 of yellow samples, all of the 6 green samples and 12 out of 27 red samples contained Pb levels above 600 ppm. Ten out of 31 white paint samples contained Pb levels above 600 ppm (Rubesinghe *et al*., 2013).

A study on Pb levels in enamel paints conducted by CEJ in June 2015 has demonstrated that 43 % of the analysed paint samples were below 90 ppm, whereas 54 % of the analysed paint samples were below the 600 ppm regulatory limit. The highest Pb level found was

Table 6: Pb levels (on dry weight) in different colours of enamel paints

Colour	Rubesinghe *et al*. (2013)				Rathnamalala *et al*. (2015)			
	Number of samples			Max. Pb, ppm	Number of samples			Max. Pb, ppm
	Total	≥ 90 ppm	≥ 600 ppm		Total	≥ 90 ppm	≥ 600 ppm	
White	32	13	10	39000	10	1	0	520
Green	6	6	6	56000	11	10	5	44000
Yellow	22	18	10	129000	16	13	11	40000
Red	27	20	17	131000	18	7	6	13258

44000 ppm. Thus, researchers have found that paints with high Pb levels can be found in the market violating the legal standards (Rathnamalala *et al*., 2015).

When comparing the findings from above two studies with the current study, it reveals that there is a larger reduction of Pb levels in different colours from 2013 to 2015, after the regulation came into effect. The biggest reduction between 2013 and 2015 can be seen in the white paints as all of the white paints either did not exceed 90 ppm or 600 ppm. However, one significant observation from data in Table 6 is that yellow and green paints tend to have higher Pb levels compared to other colours and still continue to be manufactured with exceedingly high Pb levels.

Comparison of present study results with some recent international studies

Although most countries have taken regulatory actions to eliminate the use of Pb in paints and the need for its worldwide ban has been emphasised, enamel paints with dangerously high Pb levels are still available in many countries. Gottesfeld *et al*. (2014) studied Pb levels in new paints in Nepal. A total of 75 paint samples have been purchased and analysed in 2012. Investigators found that 76 % of all paints tested contained Pb levels greater than 90 ppm. According to the results reported, maximum Pb levels in analysed black, white, brown, red, green, and yellow paints were 6800, 16000, 19000, 67000, 68000 and 200000 ppm, respectively. The highest Pb levels were found in yellow paints followed by green paints while black and white paints reported lower Pb levels (Gottesfeld *et al*., 2014).

In 2015, Environment and Social Development Organization (ESDO) in Bangladesh conducted research on Pb in new enamel paints. The researchers found that 43 of 56 red, yellow and white enamel paints analysed (77 %) contained Pb levels above 90 ppm. Only thirteen of all samples analysed (23 %) contained Pb levels below 90 ppm. Thirty two of 38 red and yellow paints (84 %) contained Pb levels greater than 90 ppm. Nineteen of all paints analysed (34 %) had dangerously high Pb levels greater than 10000 ppm. According to the results the reported highest Pb levels in analysed white, red, and yellow paints were 9600, 27000, and 85000 ppm, respectively. The highest Pb level was recorded in yellow paints and the researches have observed a least Pb level reduction in yellow paints with time compared to the Pb levels in other colours (ESDO, 2015)

Clark *et al*. studied Pb levels in enamel paints in Lebanon, Paraguay and Russia. All the analysed paint samples have been manufactured in 2011. They have found that 63 % of all analysed paints contained Pb levels greater than 90 ppm, whereas 59% of paints exceeded the 600 ppm limit and an average of 29 % of samples contained exceedingly high Pb levels, ≥ 10000 ppm. The researchers have found that red and yellow paints contained much higher Pb levels compared to Pb levels in white paints. The highest Pb levels in white, red, and yellow paints, respectively were 2780, 131000, and 236000 ppm in Lebanon, 5100, 64600, and 169000 ppm in Paraguay and 3400, 35400, and 27200 ppm in Russia. Fifty-five (55 %) and 57 % of red and yellow paints had reported Pb levels greater than 10000 ppm (Clark *et al*., 2015). Maximum Pb levels reported in white, red, and yellow paints in each country along with the results from the current study are presented in Table 7.

Table 7: Highest Pb levels reported in white, red, and yellow enamel paints in different countries (Gottesfeld *et al*., 2014; Clark *et al*., 2015; ESDO, 2015).

Colour	Highest Pb content, ppm on dry weight					
	Lebanon, 2011	Paraguay, 2011	Russia, 2011	Nepal, 2012	Bangladesh, 2015	Sri Lanka, 2014
White	2780	5100	3400	16000	96000	41
Red	131000	64600	35400	67000	27000	97
Yellow	236000	169000	27200	200000	85000	11545

Comparison of research findings in different countries with the current study indicates the presence of much lower Pb levels in white, red, and yellow paints manufactured in Sri Lanka. It therefore suggests that Sri Lanka is technologically advanced in manufacturing safe paints. However, some of the paint manufactures are still producing paints with high Pb levels, and the government as well as paint manufactures should take it as important to produce lead free paints in the whole of the Sri Lankan enamel paint industry. Although there is a large number of research studies carried out on Pb levels in enamel paints worldwide, there is a lack of data for Cr levels in enamel paints and consistency of the Pb and Cr levels through different production batches of manufacturers.

The Cadmium and Nickel levels in all the paints sampled for the current study were also analysed during this investigation but were not detected in any of the samples.

CONCLUSION

Results of the present study show that more than 94 % of paints (34 samples out of 36 paint samples analysed) produced by branded manufactures in Sri Lanka adhered to safe standards without using high levels of unsafe $PbCrO_4$. However, approximately 6 % of enamel paints with high Pb and Cr levels were sold in Sri Lanka without considering the government regulations and safety concerns. $PbCrO_4$ is present in yellow paints of brand A and green paints of brand B and is intentionally added to the different production batches. Therefore, it can be concluded that there are larger batchwise manufacturing variations in different production batches of some of the manufacturers. Finally, this study critically suggests that Pb and Cr containing compounds, especially $PbCrO_4$ should be prioritised for substitution with safer raw materials available on the market. The need for formulating national policies to regularly monitor the quality of products before they reach the consumers and provide lead paint reformulation guidelines at national-level providing information about alternatives, their assessments and reformulation processes, is emphasized.

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