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Revisiting some overlooked registered Thai traditional medicine preparations: an alert to a regulatory affair

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Abstract

Objective: This study evaluated the heavy metal identity and content of registered Thai Traditional medicine (TTM) preparations in Thailand to ensure consumer safety.

Methods: Both qualitative and quantitative information about the elemental composition of the heavy metal content in each TTM crude drug and the heavy metal content in some registered TTM preparations in Thailand was performed. Seven kinds of mineral-based TTM crude drugs, namely realgar, orpiment, Chinese powder, Sen, vermilion, natural vermilion, and cinnabar, were analyzed with X-ray diffraction and scanning electron microscopy and energy-dispersive spectroscopy techniques to determine the type of metal and elemental composition to confirm their chemical formulas. Furthermore, the number of heavy metals, such as arsenic (As), lead (Pb), and mercury (Hg), was in three samples of realgar-containing preparations; one sample of Sen-containing preparation, and eight samples of cinnabar-containing preparations. Heavy metals were determined with inductively coupled plasma-optical emission spectrometry.

Results: It was observed that realgar and orpiment consisted of arsenic sulfide (AsS) and arsenic trisulfide (As₂S₃), respectively. Both crude drugs contained approximately 50% of As. Vermilion, natural vermilion, and cinnabar consisted of mercuric sulfide (HgS), with Hg accounting for approximately 66%. Sen consisted of Pb (II, IV) oxide (Pb₃O₄) with an approximate Pb percentage of 80%. However, Pb was absent in Chinese powder and consisted mainly of calcium carbonate (CaCO₃). A traditional detoxification procedure can reduce the amount of As and Hg in processed crude drugs by at least 20%.

Conclusions: Pb was higher in some TTM preparations, and no CaCO₃ was detected in Chinese powder. Our results raise concerns on both safety and efficacy to consumers and alert public health policymakers that they should implement regulations so that the quality (authenticity) and quantity of elemental medicine used in traditional medicine are correctly labeled and within permissible limits to prevent threats to consumers.

Keywords: Arsenic, Lead, Mercury, Realgar, Orpiment, Cinnabar

Background

Today, traditional medicine (TM) is regaining popularity worldwide, especially in China, India, and ASEAN countries as a primary healthcare system. It is cost-effective, easily accessible, and widely available (Gogtay *et al.* 2002; Bodeker *et al.* 2005). Thai Traditional medicine (TTM) has increased in parallel with modern medicine,

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particularly in treating chronic diseases. Plants, animals, and minerals are the primary sources of traditional Thai Materia Medica, which was inherited since the Sukhothai period (Subcharoen and Chuthaputti 2005). Nonetheless, some mineral-based materials that are still being used as active ingredients in TTM preparations might cause severe health problems since they contain highly toxic metals, such as arsenic (As), lead (Pb), and mercury (Hg) (Subhadhirasakul et al. 1993). Exposure to high-dose of heavy metals, particularly Hg and Pb, may cause profound health implications, such as abdominal colic pain, bloody diarrhea, and kidney failure (Bernhoft 2012; Tsai et al. 2017). Moreover, carcinogenic metals such as As can disrupt DNA synthesis and repair (Clancy et al. 2012; Koedrith et al. 2013). Chances of DNA damage and neuropsychiatric disorders are high when exposed to higher doses of heavy metals (Gorini et al. 2014). The toxic mechanism of heavy metals functions using similar pathways, usually via reactive oxygen species generation, enzyme inactivation, and suppression of the antioxidant defense system (Balali-Mood et al. 2021). Even though it was believed that some traditional processes could weaken the poison of the medicines (Nagarajan et al. 2014) there was no clear documentation related to toxicological information for both qualitative and quantitative properties of materials. These medicine systems have survived because no alternative is available, and they appear to be effective (Mulholland 1979).

For the last two decades, the Thailand Ministry of Public Health has attempted to encourage the use of TTM applications corresponding to the 9th National Economic and Social Development Plan (2002–2006) to obtain sustainable TTM utilization in Thailand (Subcharoen and Chuthaputti 2005; NESDB 2005). According to the Thailand Food and Drug Administration (Thai FDA) prescribed medicines registration regulations, herbal products could not be contaminated with heavy metals, including As, cadmium (Cd), and Pb not more than 4 ppm, 0.3 ppm, and 10 ppm, respectively (Thai FDA 2004), which is following the criteria in Thai Herbal Pharmacopoeia. However, this limit is not applied to a particular traditional recipe intended to add a crude mineral drug as an active ingredient. For external preparations containing these materials, the limits are set at higher levels, i.e., the limit of lead-containing TTM crude drugs in external preparations should not exceed 13% of the total weight (Thailand FDA policy). Heavy metals commonly found as trace elements in TM preparations are As, Pb, zinc (Zn), Hg, and iron (Fe) (Uddin et al. 2013). The mineral-based materials that comprise As or arsenic oxide are “realgar” (arsenic disulfide; As_2S_2) and “orpiment” (arsenic trisulfide; As_2S_3). Mineral-based materials

consisting of Pb are “Chinese powder” (basic lead carbonate; $2PbCO_3 \cdot Pb(OH)_2$) or “sen” (lead oxide; Pb_3O_4). Mineral-based materials containing Hg as mercuric(II) sulfide (HgS) are “vermilion,” “natural vermilion,” and “cinnabar” (Picheansoonthon and Jirawongs 2013).

Many registered TTM preparations for internal and external use are currently available in Thailand. They consist of harmful heavy metals, which are highly toxic and might cause severe health problems for drug consumers and have poorly defined drug prescriptions for practical customer usage (Ernst 2002). Therefore, an investigation of TTM currently available on the market regarding heavy metal-containing details for qualification and quantification should be documented. The explicit specification of TTM would enable consumers to know the kinds and amounts of heavy metals involved in their applications. Moreover, research knowledge from heavy metals in TTM would provide a good guideline for TTM regulations considered by the FDA. An FDA approval regulation for TTM applications would produce the TTM standard and bring about the affirmation of sustainable development of TTM usage in the future.

Various types of heavy metals containing crude drugs and their therapeutic properties are commercially available (Uddin et al. 2013; Picheansoonthon and Jirawongs 2013). Some commonly used TTM and their uses are listed in Table 1. Arsenic-containing crude drugs are the most widely used. “Realgar” is an arsenic sulfide compound whose chemical formula depends on its appearance; for example, solid (As_2S_2), gas (As_4S_4), and monoclinic crystal (AsS). According to its orange-red color, realgar is also known as ruby sulfide or ruby As. It has been used as the active ingredient in treating the common cold, tonsillitis, abdominal pains, spasms, sedation, ulcers, heatstroke, and many others (Pharmacopoeia of China 2005). Realgar is usually used together with orpiment in TTM recipes. In TM, realgar-compound formulas are more frequently used than realgar alone (Kumar et al. 2006; Liu et al. 2008). It is predicted that formulas consisting of more than one active ingredient would have synergistic therapeutic effects, as they would simultaneously act on different pharmacological targets (Wu et al. 2011). Orpiment is also an AsS compound with the formula As_2S_3 , which is found in volcanoes and hot springs. It is also known as auripigment, King’s yellow, and King’s gold because of its yellow-orange color. Orpiment is very toxic with a bitter taste. In ancient times, orpiment was used for writing letters and externally treating snake venom, centipede poison, and scabies. As-containing preparations are used for wound healing and purging purulent abscesses. The realgar or orpiment external specification used for the mineral-based drug prescribed that the As-content should not be more than

Table 1 The most common use of the Thai traditional medicine used in the present study

Thai traditional medicine	Medicinal use	Reference
Realgar	Enhances complexion, reduces fat, useful to treat asthma, bronchitis, anti-cancer agent, impurities of blood, considered spermatic and masculine	Smith (1871); Mookerji (1984); Wu et al. (2011)
Orpiment (As ₂ S ₃)	To treat blood cancer and sexually transmitted diseases, applied topically to treat laryngitis in children	Yang et al. (1999); Maneekul and Samranjit (1998, 2001)
Chinese Powder (2PbCO ₃ .Pb(OH) ₂)	To treat worm, diarrhea, scabies, carbuncle, and sore	Liu et al. (2013)
Sen (Pb ₃ O ₄)	Applied topically to treat eczema, tinea, and epidermal infections	Liu et al. (2013)
Vermilion (HgS)	Used to recover liver, lung and bone functions, and used in cosmetics and medicine	Picheansoonthon (2014); Kalisinska et al. (2019)
Cinnabar (HgS)	Used in treatment of neurological disease, insomnia, palpitations, and epilepsy. One of the ingredient used for sedative therapy and managing of exterior infections in children and infants	Picheansoonthon (2014); Jain et al. (2019)

5% of the total weight of the crude drug (Picheansoonthon 2014).

Lead-containing crude drugs are also significantly used in TTM. Chinese powder is a lead monoxide compound with the formula PbO. This compound is usually used in the glass and ceramic industries. It was used as face powder and a component in sunscreen by Chinese and Japanese women because it reflects sunlight. In TTM, zinc oxide has been used as an active ingredient for the external treatment of dermatitis, such as rod, pus, and abscess. Sen, also known as red lead or minium, is the lead oxide compound with the chemical formula Pb₃O₄. Its appearance is a red powder usually used in the glass and coloring industries. This compound can protect iron oxidation and form iron rust. However, Sen or red lead compound is very toxic, especially for the neurological and digestive systems. In TTM, this compound is rarely used and requires particular caution. The pharmacopoeia for external use of lead-containing TTM drugs recommended that prescribing not be more than 13% of total crude drug weight.

Another heavy metal widely used in crude drugs is Hg. Vermilion, natural vermilion, and cinnabar are HgS compounds, consisting of HgS as a major component and appear as a brilliant red color. Cinnabar tastes sweet but is very toxic. It has been used as an active ingredient in TTM for treating neurological disease, insomnia, palpitations, and epilepsy. Natural cinnabar is found with free Hg, typically around volcanoes and hot springs. Vermilion, natural vermilion, and cinnabar have a cooling effect, commonly used to maintain healthy lungs and liver, detoxify the lungs, liver, and viscera, and treat bone disease (Picheansoonthon 2014). Furthermore, the toxicity of heavy metal-containing preparations, such as vermilion, natural vermilion, arsenic oxide, and cinnabar, are reduced using a particular folk medicine method by

mixing them with the juice of a lime or bergamot, heating until concentrated, and drying. Another approach to reducing Hg toxicity is by mixing with copper, brass, Pb, or silver to decrease its toxicity before using it for the next step (Picheansoonthon 2014).

This study examined “realgar and orpiment,” “Chinese powder and Sen,” and “vermilion, natural vermilion, and cinnabar” for “As,” “Pb,” and “Hg”-containing crude drugs, respectively. All three realgar-containing sample preparations, one Sen-containing sample preparation, and eight cinnabar-containing sample preparations obtained from nine drug stores were determined by the inductively coupled plasma-optical emission spectrometry (ICP-OES) technique to determine the As, Pb, and Hg contents in the samples. X-ray diffraction (XRD) and scanning electron microscopy, and energy-dispersive spectroscopy (SEM-EDS) techniques analyzed the elemental composition of both processed and unprocessed materials. Research findings are relevant to the safety and quality standards of the TTM preparations by the Thailand FDA.

Methods

The samples of mineral-based TM crude drugs and preparations were purchased from nine traditional registered pharmacies in Bangkok, Thailand. In this study, seven kinds of heavy metal-containing crude drugs: realgar, orpiment, Chinese powder, Sen, vermilion, natural vermilion, and cinnabar, were selected for elemental composition analysis. Three realgar-containing sample preparations, one Sen-containing sample preparation, and eight cinnabar-containing sample preparations were analyzed for As, Pb, and Hg amounts by ICP-OES techniques. Three batches of each kind purchased from three different pharmacies were analyzed (n=3). The realgar and orpiment samples were anticipated to be composed









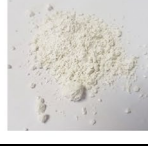



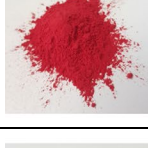
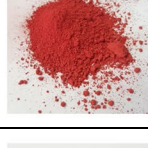
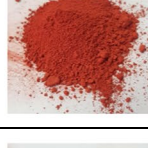



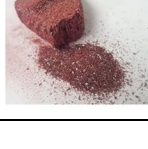

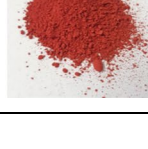
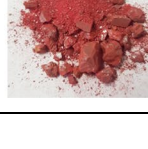
of AsS (As_2S_2) and arsenic trisulfide (As_2S_3). The Chinese powder and Sen samples were anticipated to be composed of basic lead carbonate ($2PbCO_3 \cdot Pb(OH)_2$) and lead oxide (Pb_3O_4), respectively. The vermilion, natural vermilion, and cinnabar samples were all anticipated to be composed of mercuric sulfide (HgS). All heavy metal crude drug samples used in this research were obtained from different sources; the descriptions and pictures for each sample are shown in Table 2. The TTM methods of sadhu (traditional detoxification performed by a TTM Practitioner) were investigated. Orpiment and vermilion samples were further processed following standard

TTM processing procedures to reduce drug toxicity, as described in the section on detoxifying mineral-based crude drugs in the traditional manner. Then, processed orpiment and vermilion were subjected to XRD and SEM-EDS analyses.

Analysis of the elemental composition of mineral-based crude drugs

All crude drug samples were sent for analysis with an X-ray diffractor (Bruker AXS Model D8-discover, VÂN-TEC superspeed detector), scanning electron microscope observation, and energy-dispersive electron microscopy

Table 2 Samples of various Thai traditional medicines collected with their characteristic features

Sample Name	Description	Sample 1	Sample 2	Sample 3	Sample 4
Realgar (As_2S_2)	Chunk and fine powder Orange-yellow colour Dry texture				—
Orpiment (As_2S_3)	Chunk and fine powder Yellow color Rough/ metallic texture				—
Chinese Powder ($2PbCO_3 \cdot Pb(OH)_2$)	Fine powder White color Dry texture				—
Sen (Pb_3O_4)	Fine powder Light-dark orange color Dry texture				—
Vermillion (HgS)	Chunk and fine powder Dark pinkish color Dry texture				—
Cinnabar (HgS)	Chunk and fine powder Maroon color Metallic texture				
Natural Vermillion (HgS)	Chunk and fine powder Dark pinkish color Dry texture				—

(SEM–EDS; SEM: JEOL Ltd., model JSM-6610LV and EDS: Oxford, model X-Max^N) at the Scientific and Technological Research Equipment Center (STREC, Chulalongkorn University, Bangkok, Thailand). XRD is a non-destructive technique used to characterize crystalline samples by measuring the X-ray diffraction pattern at different X-ray radiation angles. The result displays the XRD pattern like a fingerprint of periodic atomic arrangement reflex crystalline structure, according to analysis with the standard compound database. The XRD analysis operated at a voltage of 40 kV and a current of 40 mA with an angle of 5–80 degrees and increments of 0.02 degrees/step. The XRD patterns obtained were analyzed using standard compound databases.

Scanning electron microscopy and energy-dispersive X-ray spectrometer (SEM–EDS or SEM–EDX) observation is a surface analysis technique that uses X-ray radiation coupled with EDS to detect the characteristic X-ray patterns of each element represented in weight percentage. Each crude drug sample was captured in triplicate, with all elements analyzed (normalized). The parameters used in SEM–EDS analysis were acquired at 20 kV and a working distance of 11 mm.

Procedure for detoxification of mineral-based crude drugs in the traditional manner

This study selected orpiment and vermilion to be refined by a Licensed TTM Practitioner following the TTM processing procedure: 20 g of the pulverized crude drug were gently heated in a clay pot. Then, one tablespoon of chopped kaffir lime peel and a mixture of lime juice and kaffir lime juice (two tablespoons each) were added to the pot after the pulverized crude drug. Then, the sticky, viscous mixture was constantly and continuously stirred until it became dry powder. Next, the kaffir lime peels were removed from the mixture, and the processed medicine was further ground into a very fine powder. The processed orpiment and vermilion were reanalyzed for their metal composition with the SEM–EDS technique.

Heavy metal analysis in mineral-based preparations

The determination of As, Pb, and Hg content for selected registered TTM preparations, including three realgar-containing sample preparations, one Sen-containing sample preparation, and eight cinnabar-containing sample preparations, was investigated by ICP-OES. The samples were sent for analysis at the International accreditation laboratory: Asia Medical and Agricultural Laboratory and Research Center Co., Ltd. (AMARC, Bangkok, Thailand).

Data analysis

All values were expressed as mean \pm standard deviation. The data were analyzed by Microsoft Excel.

Results

XRD and SEM–EDS analysis of TTM crude drugs

The chemical formula of the main component in each kind of crude drug obtained by X-ray diffractometer (Additional file 1: Figs S1–S7) and the weight percentages of the corresponding main elements determined by SEM–EDS are shown in Table 3. As anticipated, realgar and orpiment contained arsenic sulfide (AsS) and arsenic trisulfide (As₂S₃), respectively (Additional file 1: Figs S1, S2). Vermilion, natural vermilion, and cinnabar were composed of mercuric sulfide (HgS) as the main component (Additional file 1: Figs S5–S7). However, one vermilion sample did not detect any Hg or sulfur component. The XRD result revealed that calcium carbonate (CaCO₃) comprised the main component. Moreover, no Pb existed in any Chinese powder samples, and all XRD results indicated that the primary component in each sample was calcium carbonate (CaCO₃). One sample had the trace element hydrocerussite Pb₃(CO₃)₂(OH)₂. (Additional file 1: Fig S3). As anticipated, all Sen samples contained lead (II, IV) oxide (Pb₃O₄), and two showed trace amounts of lead (II) oxide (PbO). (Additional file 1: Fig S4). The SEM–EDS results were all consistent with the XRD results.

Table 3 The chemical formula of the main component(s) in each kind of crude drug obtained by XRD and weight percentage of corresponding main elements determined by SEM–EDS ($n = 3$, $*n = 2$)

Crude drug	Component(s)	Element	%weight \pm SD
Realgar	AsS	As	54.99 \pm 4.54
		S	21.76 \pm 1.60
Orpiment	As ₂ S ₃	As	49.57 \pm 3.04
		S	30.84 \pm 1.14
Chinese powder	CaCO ₃	Ca	30.81 \pm 1.20
		C	16.21 \pm 0.14
		O	52.98 \pm 1.13
Sen	Pb ₃ O ₄ , PbO	Pb	80.16 \pm 1.13
		C	8.74 \pm 1.29
		O	11.10 \pm 0.28
Vermilion*	HgS	Hg	65.92 \pm 0.15
		S	22.27 \pm 0.17
Natural vermilion	HgS	Hg	65.54 \pm 2.23
		S	22.24 \pm 0.85
Cinnabar	HgS	Hg	67.49 \pm 3.33
		S	19.81 \pm 4.54

SEM-EDS analysis of processed TTM crude drugs

The weight percentages of the main elements contained in the processed orpiment and vermilion, determined by SEM-EDS, are shown in Table 4. The percentage of As and Hg in the processed products was reduced by 26% for orpiment and 19% for vermilion compared with unprocessed crude drugs.

ICP-OES analysis of registered TTM preparations

As anticipated, As, Pb, and Hg were determined relatively high in realgar, Sen, and cinnabar preparations. The amounts of As in realgar-containing preparations were 0.35%, 0.03%, and 0.44% (Table 5). The level of Pb in Sen-containing preparations was 16.70%. The levels of Hg in cinnabar-containing preparations were between 0.0011% and 1.04%, except for sample 8, in which Hg was not detected (Table 5).

Table 4 Weight percentage of main elements contained in processed orpiment and vermilion, determined by SEM-EDS (n = 3)

Crude drug	Element	%weight ± SD		%Reduction
		Unprocessed	Processed	
Orpiment	As	49.57 ± 3.04	36.41 ± 1.51	26.5
	S	30.84 ± 1.14	21.17 ± 1.25	31.4
Vermilion	Hg	65.92 ± 0.15	52.82 ± 5.90	19.9
	S	22.27 ± 0.17	10.49 ± 1.33	52.9

Discussion

Realgar, orpiment, and cinnabar are relatively common traditional medical materials used in both TTM and Chinese TM (CTM). According to the Chinese Pharmacopoeia 2015, realgar and cinnabar mainly consist of arsenic (II) sulfide (As₂S₂) and mercuric sulfide (HgS), respectively. Orpiment is also a well-known Chinese medicine composed of arsenic trisulfide (As₂S₃). However, because of its high toxicity, orpiment is no longer included in the Chinese Pharmacopoeia. By comparison, “Chinese powder” and “Sen” (Thai names) are fewer common materials. Records of using lead-containing Chinese medicines are pretty scarce. Vermilion and natural vermilion are cinnabar-containing crude drugs used in TTM. All mercuric sulfide compounds are highly toxic materials, such as vermilion, natural vermilion, and cinnabar. Therefore, they were processed for all TTM recipes to detoxify and reduce their harmfulness before use. In this study, the analysis results of the crude drugs were mainly as anticipated. However, all samples of Chinese powder contained CaCO₃ as opposed to Pb compounds. Rutherford et al. (2003) identified five Asian products containing undeclared scheduled substances. For most registered TTM preparation samples, the As and Pb contents in realgar and Sen-containing preparations did not exceed the FDA limits since they were less than 5% and 16%, respectively. However, the Pb content exceeded the limit in three of the eight cinnabar-containing preparations. In preparation 6 and 7, the limits were exceeded by approximately 20 and 200 times, respectively. Pb is a highly poisonous metal affecting almost every organ in the body, with the nervous system being affected the most (Wani et al. 2015). Furthermore, prolonged Pb

Table 5 Determined concentration levels of arsenic, lead, and mercury in registered TTM preparation samples by ICP-OES

Preparation		Heavy metal content (ppm)		
		Arsenic (As)	Lead (Pb)	Mercury (Hg)
Realgar containing preparations	1	3483.54	6.58	0.80
	2	334.29	ND	ND
	3	4445.28	7.72	0.77
Sen-containing preparation	1	0.24	167,048.73	5.87
Cinnabar-containing preparations	1	0.06	< 1.00	1236.85
	2	2.50	18.31	254.89
	3	0.19	< 1.00	21.21
	4	0.21	< 1.00	10.94
	5	0.45	8.80	10.84
	6	1.19	278.38	4703.62
	7	1.21	24,136.37	10,408.60
	8	0.34	< 1.00	ND

ND = not detected

exposure causes anemia and increases blood pressure in the elderly and middle-aged people. Some children and high-risk individuals could likely be exposed to excessive dosages of these heavy metals due to their use in TTM. A 5.75% higher amount of Pb than the accepted range in traditional herbal medicines was reported by Luo et al. (2020). An earlier study by Coghlan et al. (2015) documented that the As levels detected were 10 times higher than the daily limit for medicines in the TCM samples. Moreover, since a higher percentage of people self-prescribe TTM, they are exceeding the limits of heavy metals. Thus, these consumers possess a higher risk of heavy metal poisoning (Cooper et al. 2007).

The accurate characterization of the chemical species of heavy metals in TTM is the prerequisite for understanding its efficacy and side effects. It is achieved through employing standard processing procedures, and the purity of the final product must be confirmed by specific analytical tests (Wu et al. 2011). Detection methods in this research, including XRD, SEM–EDS, and ICP-OES, are suitable for heavy metal analysis in different aspects. The XRD technique is the preferred method for identifying the lattice crystal structure or compound identification of a crude drug compound based on the X-ray diffraction pattern database. The percentage weight for each element in the crude drug obtained from the SEM–EDS in the present study documented most TTM components as anticipated, except for Chinese powder that had no detectable Pb but CaCO₃ instead. The results agreed with all the techniques used for heavy metal detection/quantification in the collected samples. It is suspected that CaCO₃ would be a fake Chinese powder in our case. This result suggested that consumers may be exposed to fraudulent products resulting in unsafe or ineffective products.

It was observed that sadhu, a traditional detoxification process of orpiment and vermilion performed by a Licensed TTM Practitioner, reduced the amount of heavy metal. Thus, this step could be added to decrease heavy metal intake in people. Acid washing is a favored method for eliminating heavy metals that mainly employ hydrochloric acid for chelation (Rao et al. 2008; Fedje et al. 2013). Due to disadvantages associated with hydrochloric acid treatment, citric acid can be used instead as a chelating agent (Bassi et al. 2000). Another environmentally friendly approach to flush heavy metals is to use fruit juice and waste (mainly Citrus fruits) as they contain citric acid and other flavonoids that can chelate heavy metals and flush out toxic metals, decreasing overall toxicity (Zhang et al. 2020). It is also documented that flavonoids can act on heavy metals to convert them to metal chelates, making them less toxic (Srivastava and Goyal 2010). The detoxification of heavy metals, such as

vermilion, natural vermilion, arsenic oxide, and cinnabar, are done in Thai folk medicine by mixing them with sour fruit juice and then heating them to obtain dry heavy metals (Picheansoonthon 2014). The dried heavy metals are combined with the TTM and are used for further treatment. In Sri Lanka, common As preparations are detoxified either by triturating with *Citrus medica* fruit sour juice or other juice, such as *Zingiber officinale*, *Sesbania sesban* L., and *Eclipta alba* L. In contrast, cinnabar trituration is done with *Citrus limon* L. or *Allium sativa* L. (Sujatha Pushpakanthi Hewageegana et al. 2021).

The public health risk management of TTM needs to ensure these formulations are well characterized and follow stringent guidelines to overcome these impediments. This would also restrict excessive intake of dangerous heavy metals through nonprescription medicines or supplements. Utmost care should be taken while selecting the raw materials to ensure they are the same that have to be used in TTM. The labels on these TTMs should correctly mention the chemical formula of the products and the quantity of each compound to make it easier for people to decide what is best suited. Incomplete disclosure of product formulas, especially for main ingredients or ingredients containing controlled substances, should not be encouraged. Medicines that contain low-risk ingredients often only require the manufacturer to declare what is contained within their products. However, there should be a regulation to disclose what ingredients are present in the formulation (Fan et al. 2012).

Furthermore, labeling in a language that is understood by most of the people using it would further reduce the safety concerns. Lack of English labeling, mainly when the Chinese Proprietary medicine (CPM) products are imported from Asian countries, such as China, Korea, or Japan, often leads to confusion (Yee et al. 2005). Moreover, local ingredients and those with similar common names should be mentioned on the label. The above practices would increase confidence in people and encourage them to use complementary and alternative medicine.

Conclusions

The As and Pb content levels in the TTM were within the permissible range in realgar- and Sen-containing preparations. However, the amount of Pb was higher in three of the eight cinnabar-containing preparations. They were as high as 20–200 times the amount approved by the Thai FDA and can present a consumer health risk. Moreover, Chinese powder did not contain Pb as anticipated. Instead, it had CaCO₃, which must have decreased its efficacy. Therefore, certain patient groups, such as the elderly, infants, and individuals with cardiovascular diseases who might use this TTM for long periods, should be aware, as they are more

vulnerable to toxicities. Our results recommend that public health policymakers implement regulations for authentication analysis qualitatively and quantitatively of elemental medicine used in TM products to prevent threats to consumers. Furthermore, the labels on these products should correctly mention the chemical formula and quantity of each ingredient in a language understandable by most people.

Abbreviations

TTM: Thai traditional medicine; TM: Traditional medicine; FDA: Food and drug administration; XRD: X-ray diffraction; ICP-OES: Inductively coupled plasma-optical emission spectrometry; SEM: Scanning electron microscopy; SEM-EDX: Scanning electron microscopy and energy-dispersive X-ray spectrometer; SEM-EDS: Scanning electron microscopy and energy-dispersive spectroscopy.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s42269-022-00903-z>.

Additional file 1. Fig S1. XRD fingerprint of realgar. **Fig S2** XRD fingerprint of orpiment. **Fig S3.** XRD fingerprint of Chinese powder. **Fig S4** XRD fingerprint of Sen. **Fig S5** XRD fingerprint of Vermilion. **Fig S6** XRD fingerprint of Natural vermilion. **Fig S7** XRD fingerprint of Cinnabar.

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Author contributions

SV performed conceptualization. SV, CS and DR were involved in data curation. SV and DP were involved in methodology. DR and CS were involved in writing—original draft. DR, NP and SV were involved in writing—review and editing. All authors have read and approved the manuscript.

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Availability of data and materials

The authors declare that the data supporting the findings of this study are available within the article.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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