Scientific Insights in the Preparation and Characterisation of a Lead-based *Naga Bhasma*

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Nagarajan, *et al.*: Science of Preparation of Naga Bhasma

***Naga bhasma* is one of the herbo-metallic preparations used in *Ayurveda*, a traditional Indian System of Medicine. The preparation of *Naga bhasma* involves thermal treatment of *'Naga'* (metallic lead) in a series of quenching liquids, followed by reaction with realgar and herbal constituents, before calcination to prepare a fine product. We have analysed the intermediates obtained during different stages of preparation to understand the relevance and importance of different steps involved in the preparation. Our results show that *'Sodhana'* (purification process) removes heavy metals other than lead, apart from making it soft and amenable for trituration. The use of powders of tamarind bark and peepal bark maintains the oxidation state of lead in *Jarita Naga* (lead oxide) as Pb^{2+}. The repeated calcination steps result in the formation of nano-crystalline lead sulphide, the main chemical species present in *Naga bhasma*.**

Key words: *Sodhana* (purification), *naga bhasma*, lead, lead oxide, lead sulphide, calcination

Ayurveda, an ancient system of medicine, has been practiced in India since time immemorial. Plants, minerals, molecules from animal sources are used for the preparation of *Ayurvedic* drugs. *Bhasmas* are one of the main components in *Ayurvedic* system of medicine and are used to treat various chronic ailments and maintain good health of an individual. *Bhasmas* are herbo-metallic ashes in which the metal is calcined along with various herbal ingredients to form complexes[1,2]. These complexes should neither contain free metal nor contain free organic constituents, whose presence in *bhasma* indicates improper calcination[3]. Lead is one of the seven metals used for preparation of *bhasma*. Several studies have reported the presence of heavy metals like lead, mercury, arsenic and others in high amounts in *bhasma*[4-6]. Owing to its insoluble nature, lead sulphide (PbS) is the least toxic form of lead[7].

Naga bhasma, an *Ayurvedic* lead-based herbo-metallic medicine, has its history of medicinal applications dating several centuries back. *Naga bhasma*, with its predominant chemical species being PbS, administered at 6 mg/kg body weight was found to be nontoxic in animal model[7]. *Naga bhasma* has specific regenerative potential on germinal epithelium of testes in $CdCl_2$ administered albino rats[8]. In addition to treating diabetes mellitus, *Naga bhasma* has been prescribed for certain disorders related to liver, spleen and skin. Few clinical trials have also shown that *Naga bhasma* considerably reduces blood glucose level in diabetic patients[9]. Singh *et al.* reported the presence of hydrogenated amorphous carbon in *Naga bhasma*, an indication for possible presence of organic moieties[10]. Preparation protocol plays a major role in deciding the therapeutic efficacy as well as the toxic effects of *bhasma*s. According to *Ayurvedic* experts, nonconformity to the preparation protocol causes toxicity, probably due to incomplete transformation of free metal[11]. *Naga bhasma* procured from different manufacturers revealed differences in their composition, which could be attributed to different procedures adopted for preparation[3,12]. Hence, a standard operating procedure (SOP) for the preparation of *Naga bhasma* is essential to standardise the preparation[13]. Understanding the physico-chemical changes that occur during various stages of preparation, through characterisation of intermediates, will promote conformity to preparation

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protocol. This paper focuses on such a study for preparation of *Naga bhasma*.

MATERIALS AND METHODS

Preparation of *Naga bhasma*:

Naga bhasma was prepared using the procedure described in *Ayurvedic* Formulary of India[14]. The process flow diagram for the preparation of *Naga bhasma* is shown in fig. 1. The first step in the preparation of *Naga bhasma* is *sodhana* (a purification step), which involves sequential quenching in *tila thaila* (gingelly oil), *takra* (butter milk), *kanjika* (rice gruel), *gomuthra* (cow's urine) and *kulatha kasaya* (horse gram decoction). About 2 kg of metallic lead was melted and immersed in 2 l of treating liquid. The quenched material was filtered out and this was repeated thrice with each treating liquid listed above. The *Naga* obtained at this stage is called *Suddha Naga*.

About 500 g of *Aśvatthacūrṇa* (peepal bark powder) and 500 g of *cincātvakcūrṇa* (tamarind bark powder) were mixed with 2 kg of *Suddha Naga* and heated until fine powders were formed. This is referred to as *Jarita Naga*. About 1.8 kg each of *Jarita Naga* and *manashila* (realgar; arsenic sulphide) were mixed with 1.5 l of *kanjika* and triturated well. This mixture was made into *cakrikas*, (thin flat disks), sun dried and subjected to *puta*. In traditional literature, *puta* refers to a process of controlled heating and cooling (calcination) of herbo-mineral mixture to achieve *bhasmikaran* or ashing. The material to be subjected to *puta* was taken in an earthen vessel and closed with another inverted earthen vessel. The interface between the two vessels was sealed with a clay-smeared cloth. This arrangement is known as *Saravasamputa*. *Puta* process for preparation of *Naga bhasma* involves 50 cycles of *arddha gajaputa* and 10 cycles of *gajaputa*, performed in a brick-lined calcination chamber measuring 90×90×90 cm. In a typical *Arddha gajaputa* step, *saravasamputa* was placed inside a heap of 125-150 cow dung cakes such that, equal number of cow dung cakes were above and below the *Saravasamputa*. The cow dung cakes were ignited to supply the thermal energy required for calcination. The *gajaputa* step is similar to *arddha gajaputa*, which utilises double the number of cow dung cakes (250-300) for calcination. The intermediate obtained after each *arddha gajaputa* and *gajaputa* step was triturated with a mixture of purified *manashila* (realgar; arsenic sulphide) and sufficient quantity (1.5 l) of *kanjika*. This mixture was sun dried to prepare *cakrikas* (thin flat disks) for subsequent *arddha gajaputa* and *gajaputa* steps.

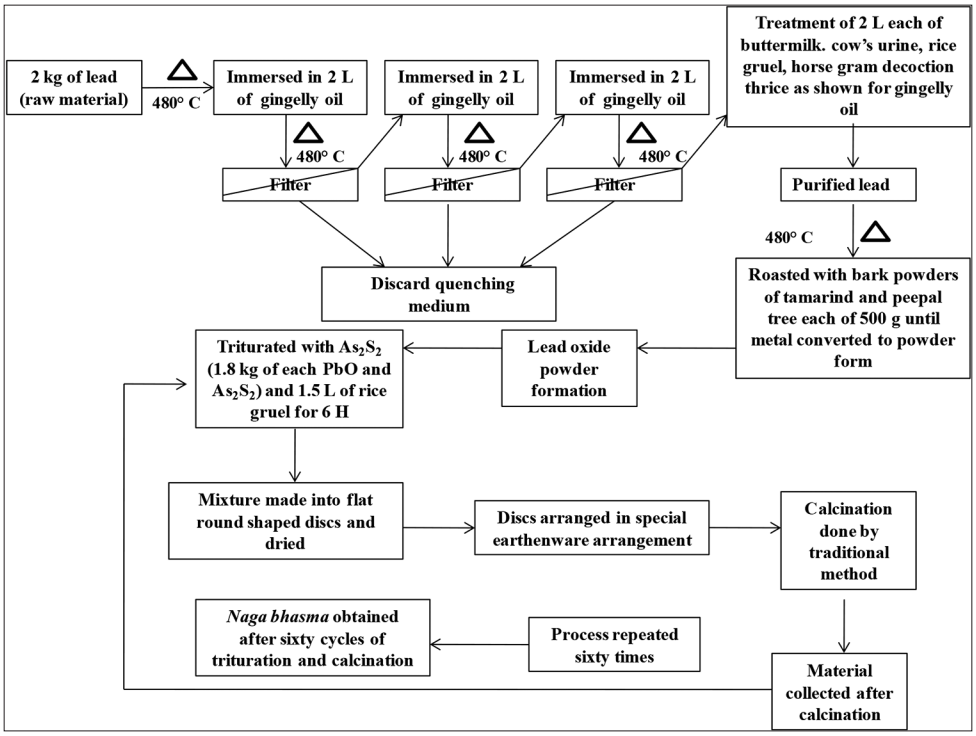

Fig. 1: Flow sheet for the preparation of Naga bhasma.

Elemental analysis:
An X-ray fluorescence spectrometer (S8 Tiger, Bruker AXS, Germany) equipped with 4 kW, Rh anode X-ray tube was used to determine the elemental composition. The aluminium cups (sample holder) were filled with 2 g of boric acid, on top of which 1 g of the sample was added. These were pelletised using a 25-tonne hydraulic press to obtain 34 mm diameter pellets of moderate thickness.

Powder X-ray diffraction analysis:
A powder X-ray diffractometer (D8 Focus, Bruker AXS, Germany) equipped with Cu anode (40 kV, 30 mA) and photo scintillation detector was used to record the diffraction patterns of the samples. Scan was performed over an angular range (2θ) of 10-60° at the rate of 0.01°/sec.

Morphological analysis:
The surface morphology of samples was observed using a cold Field Emission Scanning Electron Microscope (JSM 6701F, Jeol, Japan) at an acceleration voltage of 3 kV. A small quantity of the sample was sprinkled on a carbon tape mounted on a brass stub and sputter coated with gold, before imaging.

Spectroscopic analysis:
Fourier Transform Infrared (FTIR) spectra of the samples were recorded between 4000 and 400/cm in FTIR spectrometer (Spectrum 100, Perkin Elmer, USA). The samples were prepared by mixing with KBr and pelletising them for analysis using diffuse reflectance accessory.

Electrospray ionisation mass spectrometry:
For identification of key compounds present in the bark of *Tamarindus indica* and *Ficus religiosa*, their aqueous extracts were analysed by liquid chromatography/electrospray ionisation mass spectrometry (LC/ESI-MS) using Bruker UHPLC 3000 chromatography coupled to quadrupole ToF mass selective detector (micrOTOF-QII). The experimental conditions used for LC-MS analysis of *Tamarindus indica* and *Ficus religiosa* were followed as per procedure described by Krishnamachary *et al.*[15].

RESULTS AND DISCUSSION

Table 1 show the elemental composition of various intermediates obtained during *samanya sodhana*, from which it is was observed that the relative mass percentage of lead in the intermediates increased during the *samanya sodhana* treatment. The raw material (lead) contained other metals like iron, ruthenium, silicon, molybdenum as impurities. The treating liquids used (gingelly oil, butter milk, cow's urine, rice gruel and horse gram decoction) have been shown to form soluble-chelates with metals, leading to their removal. This resulted in the increase of relative mass percentage of lead from 97.13% in the raw material to 98.98% in the intermediate obtained after treatment with the horse gram decoction. Elemental composition of *Jarita Naga*, given in Table 2, shows that more than 90% of lead exists in oxide form.

Tables 3 show the elemental composition of *cakrikas* and the intermediate obtained after the first cycle of *Arddha gajaputa*. It is interesting to note that the arsenic content present in the *cakrikas* due to addition of realgar is reduced to below detectable limit after the first cycle of *Arddha gajaputa*.

Fig. 2 shows the scanning electron micrographs

TABLE 1: ELEMENTAL COMPOSITION OF RAW MATERIAL AND INTERMEDIATES OBTAINED DURING *SODHANA*

Element	Elemental composition in mass percentage					
	Raw material	*Taila*-treated sample	*Takra*-treated sample	*Kanjika*-treated sample	*Gomuthra*-treated sample	*Kulatha kasaya*-treated sample
Pb	97.13	98.97	98.27	99.33	98.49	98.98
Fe	0.45	ND	0.16	ND	0.18	ND
Ru	0.27	ND	ND	ND	ND	ND
Ca	0.27	ND	ND	ND	ND	ND
Si	0.26	0.06	0.26	ND	0.25	0.09
Na	0.25	ND	ND	ND	ND	ND
K	0.20	ND	0.04	ND	ND	ND
Mo	0.18	ND	ND	ND	ND	ND
As	ND*	ND	ND	ND	ND	ND

*ND=Not detected by X-ray fluorescence spectroscopy

TABLE 2: ELEMENTAL COMPOSITION OF *JARITA NAGA*

Sample	Elemental composition in mass percentage						
	PbO	CaO	K_2O	MgO	P_2O_5	Fe_2O_3	SiO_2
Jarita Naga	94.21	2.79	1.08	0.43	0.25	0.26	0.15

TABLE 3: ELEMENTAL COMPOSITION OF CAKRIKAS FOR THE FIRST *ARDDHA GAJAPUTA* CYCLE AND THE INTERMEDIATE AFTER FIRST *ARDDHA GAJAPUTA* CYCLE

Sample	Composition in mass percentage							
	Pb	O	Ca	K	Mg	S	Si	As
Cakrikas	13.04	35.08	0.30	0.45	3.56	12.55	4.78	19.99
Intermediate after 1st cycle of Arddha gaja puta	30.92	25.32	0.51	0.73	0.31	5.27	10.54	ND*

*ND=Not detected by X-ray fluorescence spectroscopy

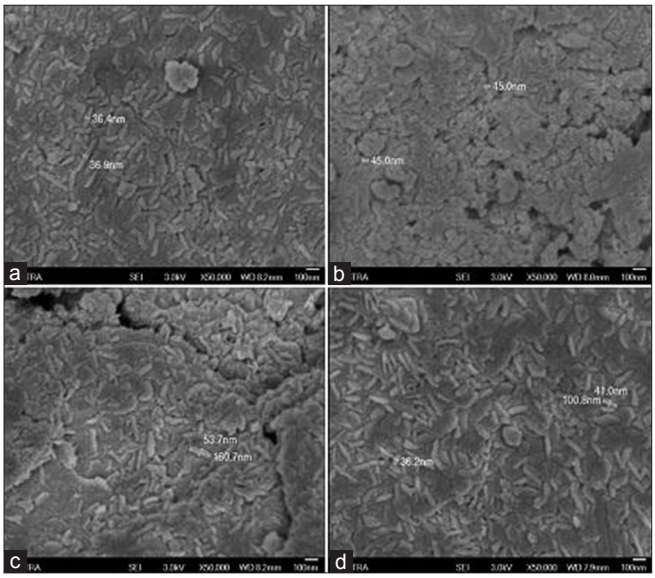

Fig. 2: Surface morphology of the intermediates obtained during various stages of sodhana.
(a) Taila-treated intermediate; (b) gomutra-treated intermediate; (c) kanjika-treated intermediate; (d) kulatha kasaya-treated intermediate.

of the intermediates obtained after each stage of *sodhana* during the preparation of *Naga bhasma*. These micrographs help to understand the changes in gross morphology during various stages of *sodhana*. It may be observed that there are substantial changes in the morphology of intermediates during *sodhana* (fig. 2). A common feature in the micrographs of intermediates is the appearance of rod-shaped, nanoscale structures on the surface. The width of the nanostructures lies between 30 and 50 nm, while the length ranges between 100 and 160 nm. High thermal stresses induced in the material during quenching are expected to form microcracks leading to increased surface area[16,17]. *Sodhana* has also led to substantial softening of the material transforming ductile lead to a brittle form, enabling ease of subsequent processing.

The characterisation of bark of *Tamarindus indica* and *Ficus religiosa* is essential to identify the key organic components present in them and their possible role in the preparation of *Naga bhasma*. The LC-MS/MS spectra of aqueous extract of bark of *Tamarindus indica* are shown in fig. 3. It was observed that the aqueous extract contained characteristic markers (proanthocyanidin B1 Dimer, proanthocyanidin C1, catechin and bergenin) reported for *Tamarindus indica* (fig. 3a-d). Bergenin has been reported to possess immumomodulatory effects. Also the polyphenols from *Tamarindus indica* possess excellent chelating ability that can serve to form complexes with metal ions.

Fig. 4 shows the LC-MS/MS spectra of aqueous extract of bark of *Ficus religiosa*. It was observed that the extract contained proanthocyanidin B1, proanthocyanidin C1, chlorogenic acid, kaempferol-3-galactoside-6''-rhamnoside-3'', caffeic acid and epicatechin, which are characteristic markers for *Ficus religiosa* (fig. 4a-f). The proanthocyanidins, chlorogenic and polyphenols from *Ficus religiosa* can form metal ion chelates. The flavonoids epicatechin and kaempferol present in *Ficus religiosa* are well-known antioxidants and antiinflammatory agents.

Fig. 5a shows the X-ray diffraction pattern of *Jarita Naga*, which is observed to be a crystalline material with diffraction peaks at 2θ of 26.5°, 30.5° and 54.0° characteristic of lead oxide (PbO). The analysis of various oxides present in *Jarita Naga* revealed the presence of PbO to the extent of 94.21%, with other oxides being CaO, K_2O and MgO (Table 2). These minerals may be incorporated from the bark of *Tamarindus indica* and *Ficus religiosa* during treatment of purified lead with the plant ingredients. The FTIR spectra of *Jarita Naga* reveal the presence of absorption band around 640/cm, which may be attributed to Pb–O bond (fig. 5b). This correlates very well with the X-ray diffraction patterns and elemental analysis.

From the spectroscopic and diffraction analyses of *Jarita Naga*, it is observed that the treatment of intermediate after *sodhana* with the powders of peepal bark and tamarind bark results in oxidation of metallic lead to lead oxide (*Jarita Naga*). The modification of

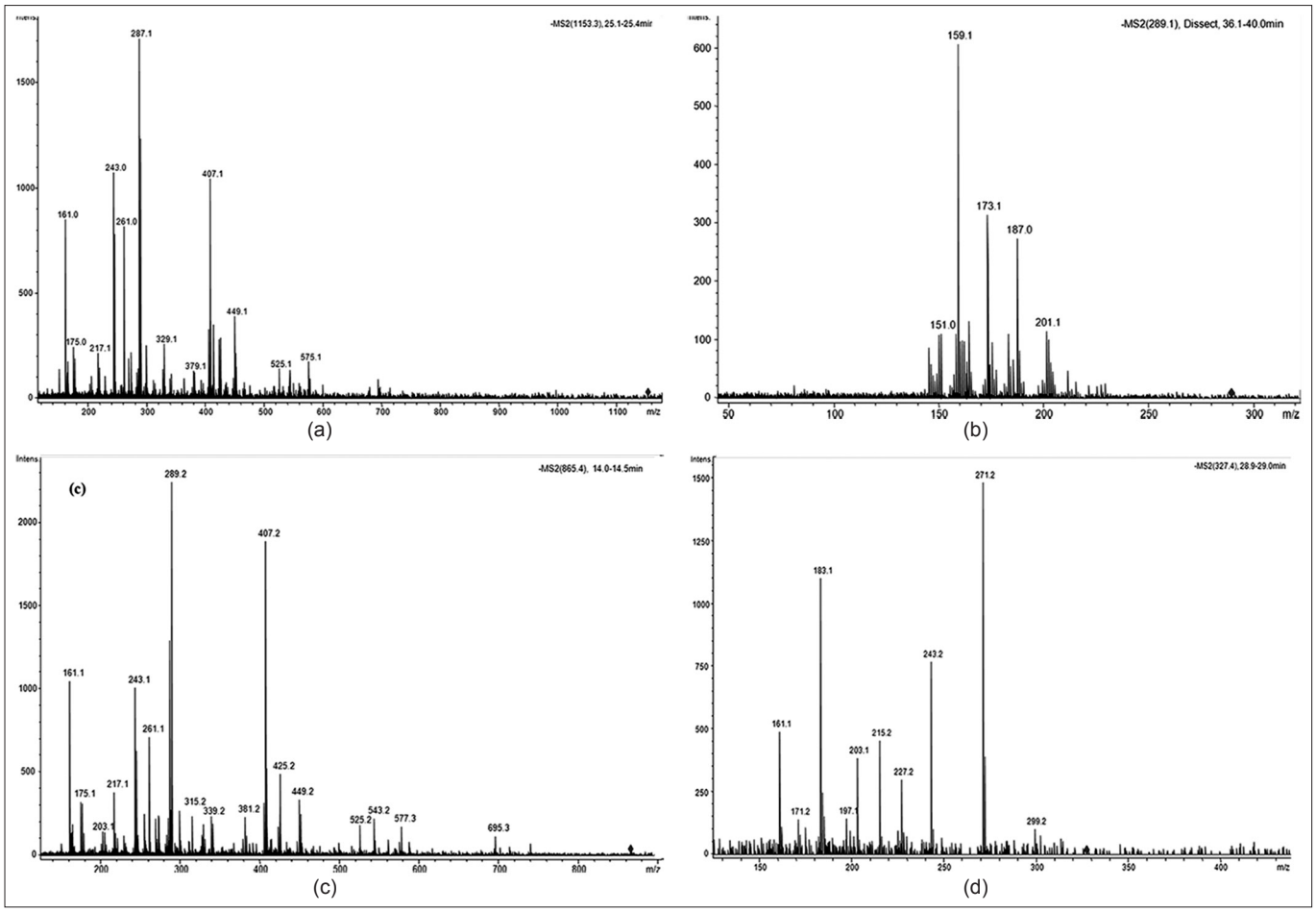

Fig. 3: LC-MS/MS pattern of aqueous extract of bark of *Tamarindus indica*.
(a) Proanthocyanidin B1 Dimer; (b) proanthocyanidin C1; (c) catechin and (d) bergenin.

morphology of metallic lead as a result of *sodhana* facilitated the oxidation reaction induced by treatment with these plant ingredients. When molten lead is exposed to air for longer duration of time without these plant ingredients, the same gets converted to its oxides, PbO and PbO_2. Of these two forms of lead oxide, PbO is useful for further transformation to *Naga bhasma*. The use of peepal bark and tamarind bark in the preparation of *Jarita naga* might have been probably aimed at reducing PbO_2 to PbO.

As evident from the XRF, XRD and FTIR results, major constituent of *Jarita Naga* is PbO. The *cakrikas* for the first *arddha gajaputa* cycle were made by grinding *Jarita Naga* (PbO) with realgar (As_2S_2) and *kanjika* (rice gruel). During this step, PbO is converted to PbS and As_2O_3 is formed through a slow reaction. The use of *kanjika* (rice gruel) facilitates wet grinding, leading to increased contact between the solid reagents (*jarita naga* and realgar) through decrease of particle size and increase of surface area[17-20]. The elemental compositions of *cakrikas* for first cycle of *arddha gajaputa* (made by grinding *jarita naga* with realgar and *kanjika*) and the intermediate after the first *arddha gaja*puta cycle are compared in Table 3.

A comparison of elemental composition of *cakrikas* for the first *arddha gajaputa* cycle and the intermediate from the first *arddha gajaputa* cycle (Table 3) indicates that though arsenic was present in the *cakrikas* that were subjected to *arddha gajaputa*, the intermediate obtained after first *arddha gajaputa* cycle did not contain arsenic. This may be understood from the study of temporal variation of temperature during a typical *arddha gajaputa* cycle shown in fig. 6. High temperature prevails during calcination facilitating conversion of arsenic sulphide (As_2S_2) to arsenic oxide (As_2O_3) and the conversion of PbO to PbS[21]. The boiling point of arsenic oxide (As_2O_3) is about 465° and hence would have vaporised during the *Arddha gajaputa* cycle where

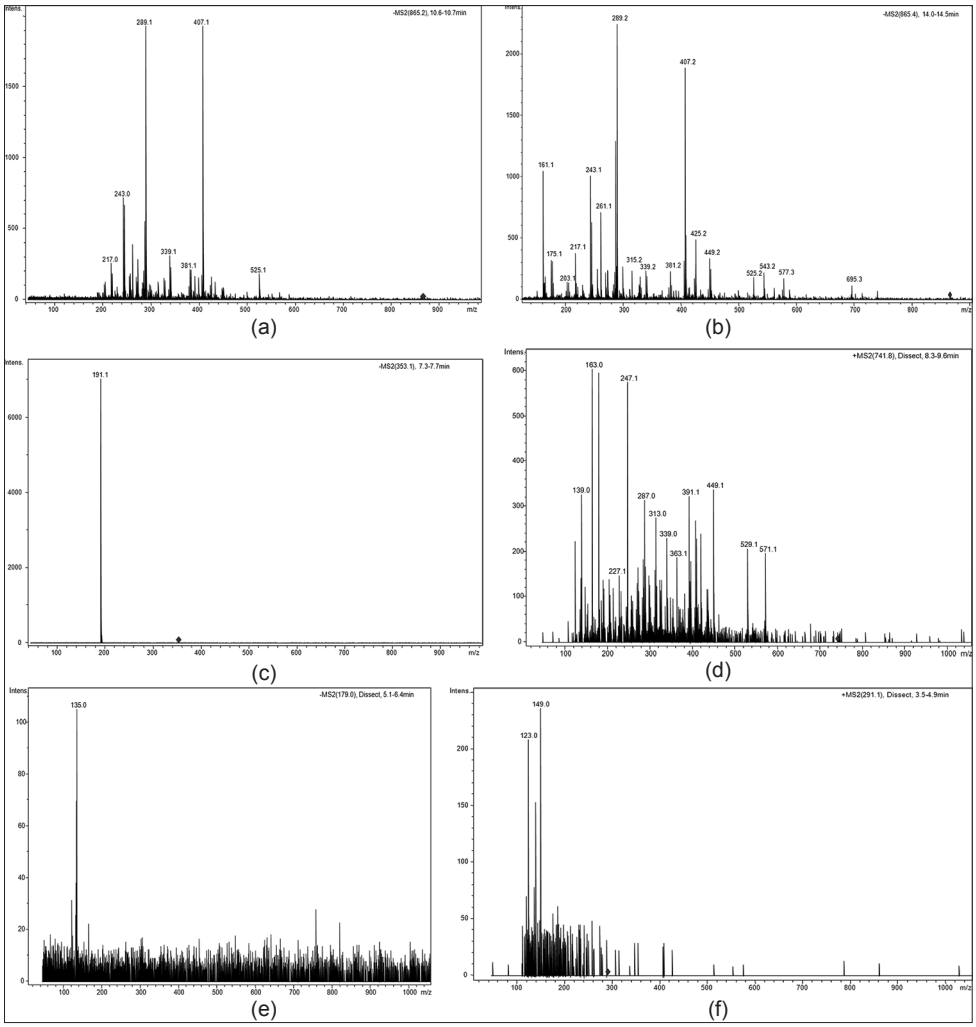

Fig. 4: LC-MS/MS pattern of aqueous extract of bark of *Ficus religiosa*.
(a) Proanthocyanidin B1; (b) proanthocyanidin C1; (c) chlorogenic acid; (d) kaempferol-3-galactoside-6′′-rhamnoside-3′′; (e) caffeic acid and (f) epicatechin.

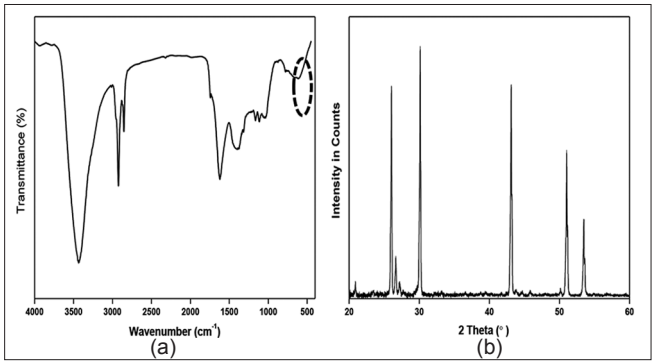

Fig. 5: Characterisation of jarita Naga.
(a) X-ray Diffraction pattern and (b) FTIR spectrum of jarita Naga.

temperature of above 800° was reached (fig. 6). This is confirmed from the X-ray diffraction patterns of the intermediate after the first *Arddha gajaputa* cycle, which shows diffraction peaks characteristic of PbS only (fig.7).

PbS is known to react with PbO when heated, leading to formation of metallic lead and sulphur dioxide[22].

$$PbS+2PbO \rightarrow 3Pb+SO_2$$

The addition of realgar during each *gaja puta* cycle may probably be aimed at suppressing the above reaction. The addition of realgar in excess quantity reacts with any unreacted PbO transforming the same to PbS. This ensures that the intermediates do not contain elemental lead.

Fig. 8 shows the powder X-ray diffractogram obtained after different *Arddha gajaputa* cycles. It was observed that the intermediates were crystalline PbS and with increase in *arddha gajaputa* cycle, there was increase in degree of crystallinity. Fig. 9 shows the morphology of the intermediates obtained after different *arddha gajaputa* cycles exhibiting

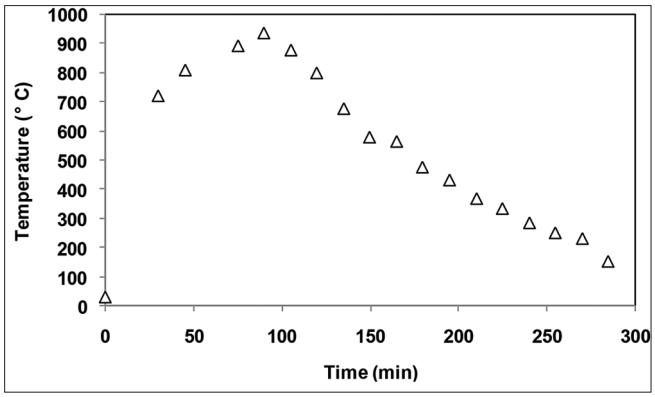

Fig. 6: Temporal variation of temperature during Arddha gajaputa. The maximum temperature of 937° was observed at about 90 min.

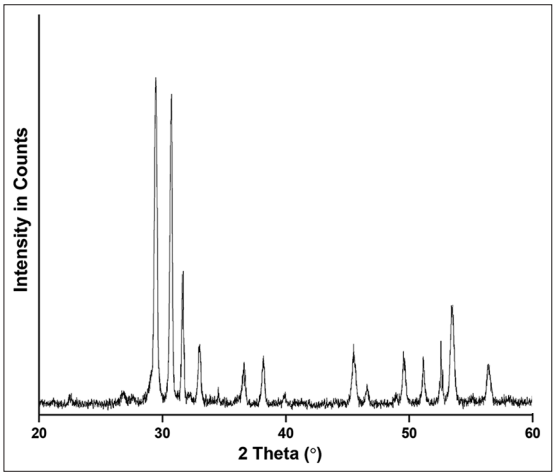

Fig. 7: X-ray Diffraction pattern of intermediate obtained after first *arddha gajaputa* cycle showing the presence of lead sulphide.

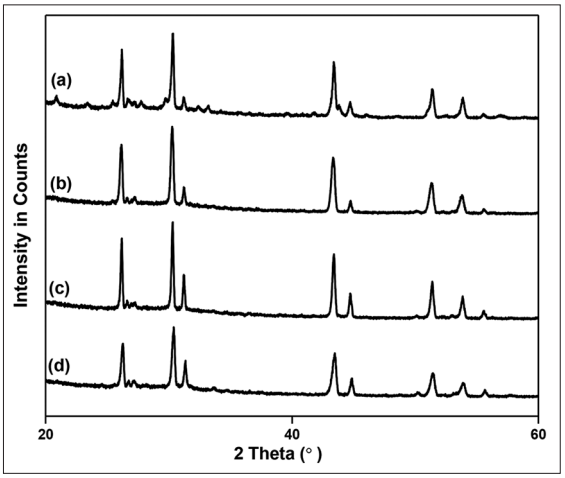

Fig. 8: X-ray diffraction patterns of intermediate obtained after different *arddha gajaputa* cycles.
(a) 20th *puta* cycle, (b) 25th *puta* cycle, (c) 30th *puta* cycle and (d) 35th *puta* cycle.

nanoscale features. The average size of the nanoparticles was observed to decrease, accompanied by an increase in monodispersity during subsequent *arddha gajaputa* cycles. Some of our results are in qualitative agreement with those reported in literature for preparation of *naga bhasma*[7,21]. Comparison of characteristics of intermediates could not be carried out due to lack of such information in earlier works. The existing *bhasma* preparation techniques follow different procedures for *Naga bhasma* and the protocol may differ in terms of raw materials utilised, variety of plants used and number of calcination cycles performed[7,13,21]. The present study has followed the standard preparation protocol mentioned in *Ayurvedic* Formulary of India and scientifically validated the steps involved in the preparation[14].

In conclusion, it is evident from the present study that the treatment of raw material (crude metallic lead) with various treating liquids removes heavy metals such as lead, iron, molybdenum, copper and aluminium through chelation, apart from causing substantial changes in morphology. In addition, *sodhana* (purification) steps improve the processability of lead facilitating further treatment. Initial preparation of *jarita naga* (PbO) from *naga* (Pb) enables the conversion of lead to PbS through the formation of intermediate (PbO). The use of realgar during *arddha gajaputa* cycles enables the conversion of PbO to PbS along with elimination of arsenic as arsenic oxide vapours. Calcination steps play a predominant role in attaining monodispersity of the *bhasma* particles. Each steps of the preparation should be done with utmost care to get the good quality of *bhasma*. It is also important to understand each and every step to set up the gold standards for *bhasma* preparation. This work has resulted in better understanding of the preparation protocol through chemical, crystallographic and morphological characterisation of intermediates. The role of herbal ingredients (*Tamarindus indica* and *Ficus religiosa*) in ensuring the transformation of Pb to PbO (lower oxidation state of Pb) has also been elucidated.

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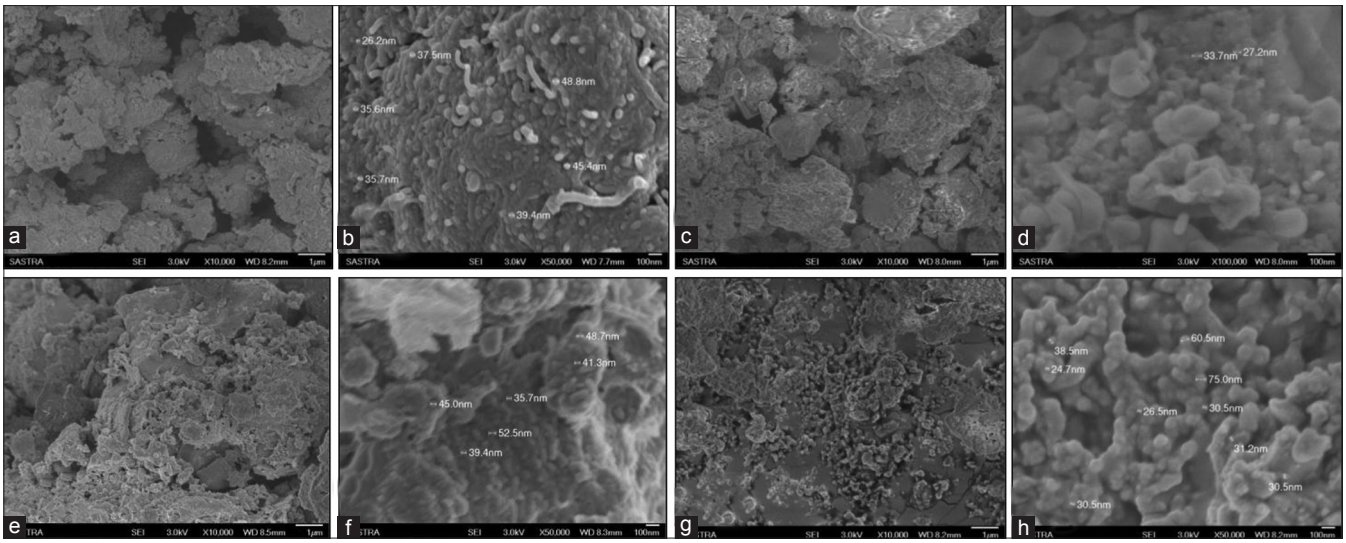

Fig. 9: Scanning electron micrographs of intermediates obtained after different arddha gajaputa cycles.
Monodispersity of the nanoparticles are observed with increase in puta cycle. (a) 1st *puta* cycle (lower magnification), (b) 1st *puta* cycle (higher magnification), (c) 5th *puta* cycle (lower magnification), (d) 5th *puta* cycle (higher magnification) and (e) 15th *puta* cycle (lower magnification), (f) 15th *puta* cycle (higher magnification) (g) 50th *puta* cycle (lower magnification), (h) 50th *puta* cycle (higher magnification).

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