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Tapyo and Iodine Deficiency Disorders: Preliminary SEM-EDS Characterization of a Traditional Apatani Salt and its Implications for Thyroid Health

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ABSTRACT: Tapyo, a traditional alkaline salt substitute prepared from plant ash by the Apatani tribe of Ziro Valley, Arunachal Pradesh, India, is widely credited in community narratives with protecting the Apatani from goiter despite historically limited access to iodized salt, an observation we term the “Apatani goiter paradox.” No elemental characterization of tapyo has previously been published. We collected four independently prepared tapyo batches from households in Hari, Hong, and Hiija villages, Ziro Valley, in 2013, and analyzed them by scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDS) and standard iodometric titration. All four batches were dominated by potassium (28.56-58.10 wt%) and chlorine (4.81-39.83 wt%), with variable sodium (0.94-4.38 wt%); two batches also showed a substantial oxygen/carbon fraction (59.0-62.8 wt% O), consistent with a residual alkaline ash/carbonate component. An unidentified minor constituent, labeled “I” by the EDS software but quantified against an uncalibrated standard, appeared in two of the four batches; this signal should not be read as confirmed iodine, and most likely reflects an unidentified trace impurity. Iodometric titration, the appropriate method for bulk iodine assessment, detected no iodine in any of the four batches. Tapyo is, compositionally, a potassium/chloride-dominant, non-iodized plant-ash salt substitute, with no reliable evidence of nutritionally relevant iodine by either method. If it is consumed as a substitute for iodized salt rather than alongside it, this may make tapyo an overlooked contributor to iodine deficiency disorder (IDD) risk in Apatani communities, rather than the protective factor community narrative describes. Larger, more rigorous follow-up studies are needed to properly test the Apatani goiter paradox.

1. INTRODUCTION

Iodine deficiency disorders (IDD) are a preventable cause of goiter, hypothyroidism, and impaired neurodevelopment, and universal salt iodization (USI) programmes remain the main global response [1]. India's USI programme has done well by this measure, reaching 94% national coverage of adequately iodized household salt by 2019-2021, with the North-Eastern states, including Arunachal Pradesh, performing comparatively well against this benchmark [2,3]. Even so, traditional or non-iodized salt use persists in some remote and tribal areas, and district-level surveys in North-East India still find goiter rates above the World Health Organization's 5% public-health threshold, for example a total goiter rate of 7.22% among schoolchildren in East Khasi Hills, Meghalaya [4]. Interventions such as "Jeevan Bindi", an iodine-releasing patch developed for tribal women in Maharashtra who do not routinely use iodized salt, reflect an ongoing recognition that reliance on traditional salt sources remains an IDD risk factor in Indian tribal communities [3].

The Apatani, an indigenous tribal community of Ziro Valley in the Lower Subansiri district of Arunachal Pradesh, are reportedly the only community in the region with the traditional knowledge to prepare tapyo, an alkaline salt substitute made by leaching the ash of locally available plants [5,6]. It is prepared from one or more of an estimated fifteen locally used plant species, including Phragmites karka ("pepu"), Eleusine coracana ("sarshe"), and Ambrosia artemisiifolia ("gonde unio"), among others [5,6]. Community accounts describe tapyo as a dietary staple that predates reliable access to industrially iodized salt in this remote Himalayan-foothill region, and elders have reportedly not observed the visible goiter or cognitive impairment usually attributed to iodine deficiency [7]. A similar belief appears in the recent ethnobotanical literature on Pila, the alkaline plant-ash filtrate from which tapyo is made by dehydration: that long-standing tapyo consumption has protected the Apatani from goiter [8]. To our knowledge, this "Apatani goiter paradox", an apparent absence of endemic goiter in an inland, high-altitude population with no marine iodine sources and inconsistent access to iodized salt, has never actually been tested, whether against the elemental composition of tapyo itself or against systematic goiter-prevalence data specific to the Apatani; neither has previously been published.

Similar plant-ash salts have been characterized elsewhere. Vegetable salts made from maize, sorghum, pawpaw, and Hygrophila ash in Chad, and from Hygrophila schulli ash in Ethiopia, are consistently potassium-rich and sodium-poor relative to industrial sodium chloride, with no iodine fortification reported [9,10]. Elemental studies of the closely related Northeast Indian food additive Pila (also called Khaar), of which tapyo is a dehydrated form, similarly list aluminium, sodium, potassium, calcium, magnesium, chlorine, and trace metals among its constituents, again with no iodine [8]. Whether tapyo shares this profile, and in particular whether it contains any meaningful amount of iodine, has not previously been investigated. Here we report a preliminary elemental characterization of four archival tapyo batches, collected and analyzed in 2013 but never published, using SEM-EDS and iodometric titration, to evaluate what basis, if any, the community's protective narrative has, and what this means for IDD risk.

2. MATERIALS AND METHODS

2.1 Study Material

Tapyo is a traditional alkaline salt substitute that the Apatani tribe of Ziro Valley, Arunachal Pradesh, prepares from the ash of locally available plants. It is used as an everyday condiment and salt substitute, either instead of or alongside commercially iodized salt. The material studied here was solid tapyo as prepared and consumed by Apatani households, not any single isolated chemical constituent.

2.2 Sample Collection

Four batches of tapyo, each independently prepared by a different household, were collected in 2013 from Hari, Hong, and Hiija villages in Ziro Valley, Lower Subansiri district, Arunachal Pradesh. Apatani tapyo is traditionally made from the ash of one or more of roughly fifteen locally used plant species, but the specific plant source(s) for these four archival batches were not recorded at the time of collection and could not be determined retrospectively.

2.3 Extraction Procedure

No extraction or purification step was applied: whole tapyo samples were analyzed directly. For iodometric titration, an aliquot of each batch was dissolved in distilled water to make the test solution. For SEM-EDS, a fragment of each batch was mounted directly for imaging and microanalysis.

2.4 Analytical Methods

Elemental composition of each batch was determined from a single energy-dispersive X-ray spectroscopy (EDS) spot acquisition coupled to scanning electron microscopy, using Oxford Instruments INCA microanalysis software. Data were processed with the instrument's standard normalized, all-elements-analyzed quantification routine, against the following standards: carbon as $CaCO3$, oxygen as $SiO2$, sodium as albite, chlorine as KCl, and potassium as MAD-10 feldspar; iodine was quantified against an uncalibrated ("not defined") standard. Bulk iodine content was assessed separately by iodometric titration, using ascorbic acid as the titration standard, following the method of Silva et al. (1999) [11].

2.5 Statistical Analysis

Because only four batches were available, with no technical replicates, we report descriptive statistics (means and ranges) only; no formal hypothesis testing was performed.

3. RESULTS AND DISCUSSION

3.1 Preliminary Analysis

Table 1 summarises the SEM-EDS elemental composition of the four batches. Batches 1 and 2 were dominated by oxygen (62.80% and 59.02% by weight) and potassium (28.60% and 28.56%), with smaller contributions from carbon (batch 1 only), sodium, and chlorine, consistent with a residual alkaline ash/carbonate-rich fraction. Batches 3 and 4 were instead dominated by potassium (58.10% and 55.42%) and chlorine (37.20% and 39.83%), with higher sodium (3.32% and 4.38%) than batches 1-2, consistent with a chloride-salt-rich fraction. Potassium was the single most abundant cation in every batch, well ahead of sodium.

Table 1. SEM-EDS Elemental Composition of Four Tapyo Batches (Wt%, At%)

Element	Batch 1	Batch 2	Batch 3	Batch 4
C	2.08 (3.44)	ND	ND	ND
O	62.80 (77.88)	59.02 (77.11)	ND	ND
Na	1.71 (1.47)	0.94 (0.86)	3.32 (5.36)	4.38 (6.98)
Cl	4.81 (2.69)	11.48 (6.77)	37.20 (39.00)	39.83 (41.09)
K	28.60 (14.51)	28.56 (15.27)	58.10 (55.23)	55.42 (51.83)
I*	ND	ND	1.38 (0.41)	0.37 (0.11)
Total	100.00	100.00	100.00	100.00

** Labeled "I" by the EDS software and quantified against an uncalibrated ("not defined") standard; not confirmed to be iodine and most likely an unidentified trace impurity (see Discussion, Section 3.4).*

This split shows that tapyo batches are not chemically uniform: both an alkaline ash/carbonate-rich form and a chloride-salt-rich form can occur among independently prepared household batches.

3.2 Instrumental Analysis (SEM Imaging)

Representative scanning electron micrographs are shown in Figure 1. Batch 1 (Figure 1A) has a finer, more compacted granular texture, consistent with its oxide/carbonate-rich composition, while batches 2 to 4 (Figure 1B, C) show larger, more distinct crystalline fragments, consistent with their higher chloride-salt content. The archived micrograph for the Batch 2 and Batch 3

EDS acquisitions is in fact the same image, since the two point spectra were collected from the same imaged field at different times; we state this explicitly rather than present them as two independent images.

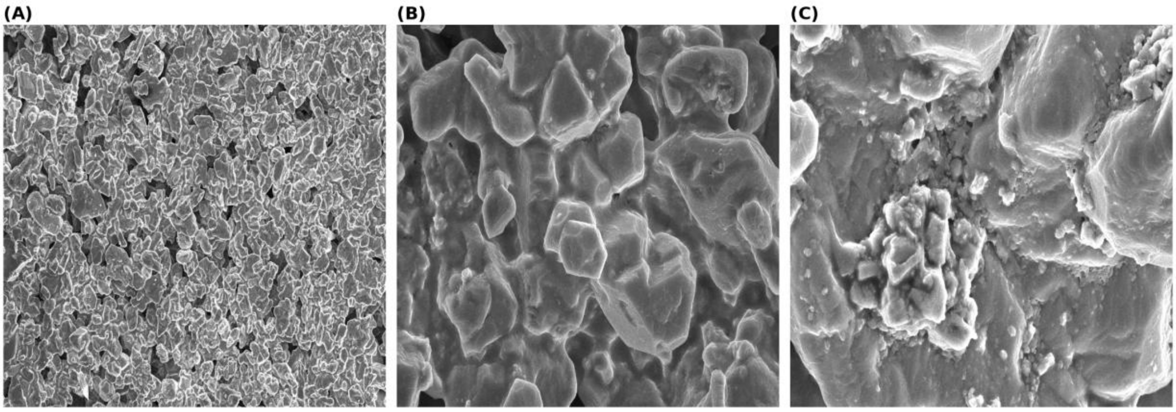

Figure 1. Representative scanning electron micrographs of the tapyo batches analyzed. (A) Batch 1. (B) Field of view shared by the Batch 2 and Batch 3 EDS point acquisitions (see Results, Section 3.1). (C) Batch 4. Scale bar (1 mm) as recorded in the source instrument reports; exact accelerating voltage and working distance were not retained.

An unidentified constituent, labeled "I" by the EDS software, was recorded only in batches 3 and 4, at 1.38 wt% (0.41 at%) and 0.37 wt% (0.11 at%) respectively, and was absent from batches 1 and 2 (Table 1). Because this signal was quantified against an uncalibrated ("not defined") standard, it cannot be confirmed as iodine (see Discussion, Section 3.4).

3.3 Iodine Titration Analysis

Iodometric titration for bulk iodine content was negative in all four batches, falling below the method's detection limit (Table 2). Neither analytical method identified a genuine iodine signal; the unidentified EDS "I" peak recorded in batches 3 and 4 (Section 3.2) is discussed further below.

Table 2. Unidentified EDS 'I' Signal (Unconfirmed) versus Iodometric Titration for Iodine

Batch	Unidentified EDS 'I' Signal, wt%	Iodine by Titration
Batch 1	ND	Not detected
Batch 2	ND	Not detected
Batch 3	1.38	Not detected
Batch 4	0.37	Not detected

The unidentified "I" peak recorded by EDS in batches 3 and 4 was quantified at 0.37-1.38 wt% (roughly 3,700-13,800 mg/kg, if it were iodine), two to three orders of magnitude above the WHO-recommended range of 15-40 mg/kg (ppm) for adequately iodized table salt [1,12]. No plausible natural or fortification process would produce iodine at this concentration in an unfortified plant-ash product. Taken together with the lack of a calibrated standard for this peak and its absence on iodometric titration, this points away from genuine iodine and toward an unidentified trace impurity or instrumental artifact.

3.4 Discussion

Across all four batches, the consistent finding is that tapyo is a potassium/chloride-rich, sodium-poor product, structurally similar to other plant-ash salts characterized elsewhere: maize-, sorghum-, and Hygrophila-derived vegetable salts in Chad and Ethiopia, which are likewise potassium-rich and sodium-poor relative to industrial sodium chloride [9,10], and the closely related Northeast Indian food additive Pila/Khaar, of which tapyo is a dehydrated form [8]. Like those salts, tapyo appears to derive its composition from the mineral content of burned plant material rather than from any deliberate fortification, and none of the plant-ash salts characterized so far, including Pila/Khaar, have been reported to contain iodine [8,9,10]. The unidentified

"I" peak in batches 3 and 4 was quantified against an uncalibrated ("not defined") standard, and the raw spectra for these batches carried an instrument-flagged "peak possibly omitted" warning. Given this, together with the implausible concentration discussed above and the negative titration result, we do not consider the peak confirmed iodine; we attribute it instead to an unidentified trace impurity or spectral artifact. We treat the negative iodometric titration, the appropriate assay for bulk iodine, as the definitive result for these batches.

On the face of it, our data do not support tapyo's elemental composition as an explanation for any historical absence of goiter in the Apatani community. Whether tapyo was consumed as a substitute for iodized salt or only as an occasional condiment alongside it is a distinction the ethnographic literature does not resolve; but if it was used as a substitute, our findings suggest that tapyo provides no meaningful dietary iodine, and could plausibly have contributed to iodine deficiency in households that relied on it, rather than protecting against it. The community's protective narrative may instead reflect factors we did not evaluate here: the growing reach of iodized salt across North-East India in recent decades, other unmeasured dietary iodine sources, or simply under-ascertainment of subclinical goiter in historical community observation, in the absence of any systematic, published goiter-prevalence survey specific to the Apatani.

It is worth stating plainly why we treat the two analytical methods so differently. SEM-EDS is not well suited to precise trace-halogen quantification in the first place: iodine's characteristic X-ray lines sit close in energy to lines from other elements commonly present in ash, and the reported concentration depends heavily on the reference standard used. When that standard is uncalibrated, as it was here, the number the software outputs cannot be trusted regardless of how large or small it looks. In a strict sense, the "I" signal in batches 3 and 4 was never a measurement of iodine at all, only a label the instrument's software assigned to an X-ray energy window. Iodometric titration, by contrast, is a wet-chemical method built specifically to quantify iodine in bulk. It is not simply a second opinion alongside EDS; it is the only one of the two methods actually validated for this purpose, which is why we treat its negative result, rather than the ambiguous EDS signal, as the definitive finding of this study.

It is also worth questioning the premise of the paradox itself. The claim that the Apatani have historically been free of goiter rests on community recollection, not on any documented survey, clinical record, or systematic screening. An absence of visible goiter in oral history is not the same as a documented absence of iodine deficiency, particularly for milder or subclinical presentations that would not necessarily draw attention in a remote community with limited healthcare access. It is equally possible that goiter was present but under-recognized or attributed to other causes, and that the protective narrative around tapyo consolidated only after iodized salt became available and any pre-existing deficiency resolved, retrospectively crediting a traditional practice for an unrelated public-health intervention. Without baseline prevalence data from the pre-iodization period, our findings cannot distinguish "tapyo genuinely made no difference to a real deficiency" from "the deficiency, and the need for protection, may never have been as severe as the narrative implies." A systematic goiter-prevalence survey, historical or contemporary, could help resolve this, and its absence is arguably a more fundamental gap in the literature than the elemental composition of tapyo itself.

A more speculative possibility is that tapyo's potassium/chloride-rich, sodium-poor profile has downstream physiological effects unrelated to iodine that are nonetheless relevant to thyroid health, for example through interactions between dietary potassium, sodium intake, and renal iodine handling. We are not aware of direct evidence for such a pathway in this population, and our data are not sufficient to support it; we raise it only to note that ruling out iodine as the active ingredient in the tapyo narrative does not rule out every plausible physiological mechanism. Testing that would require dedicated clinical and dietary investigation, not inference from elemental composition alone.

4. CONCLUSION

This preliminary characterization shows that tapyo, a traditional Apatani plant-ash salt substitute, is compositionally dominated by potassium and chloride, with variable sodium and an alkaline ash/carbonate fraction in some batches. Iodometric titration, the appropriate bulk assay, found no evidence of iodine in any of the four batches, and an unidentified minor constituent recorded by EDS in two batches, labeled "I" by the software but quantified against an uncalibrated standard, should not be read as confirmed iodine. The study has real limitations: the data were collected in 2013 and are reported here for the first time, so some original methodological details (SEM instrument make/model, accelerating voltage, sample-coating method, exact titration detection limit) were not retained; the sample size is small, just four batches with no technical replicates; the plant source of each batch is unknown; the unidentified EDS "I" signal could not be identified with the archival data available; and there is no paired clinical or biochemical iodine-status data, nor any published goiter-prevalence survey specific to the Apatani. These findings do not support tapyo's elemental composition as an explanation for the community's protective narrative around goiter, and instead raise the possibility that relying on tapyo as a salt substitute could be an overlooked risk factor for iodine deficiency rather than a protective one. Larger, more rigorous follow-up work, combining bulk elemental assay (e.g., ICP-MS) with documented dietary patterns of tapyo versus iodized salt use and clinical/biochemical thyroid and iodine status, is needed to properly test the Apatani goiter paradox.

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AUTHOR CONTRIBUTIONS

Hage Nobin: Conceptualization; provision of specimens; review and editing of the manuscript.

Mariam Shadan: Supervision; iodometric titration analysis; contribution to data analysis; drafting and critical revision of the manuscript.

Mohd. Afzal: Technical/instrumental analysis (SEM-EDS); contribution to data analysis; drafting and critical revision of the manuscript.

Abuzar Hamza: Coordination of the research collaboration; funding acquisition; contribution to data analysis; drafting and critical revision of the manuscript.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ETHICS STATEMENT

This study involved laboratory analysis of a food/salt product only. No human or animal subjects were sampled directly, and no individually identifiable data were collected or analyzed.

DATA AVAILABILITY STATEMENT

The SEM-EDS instrument reports and titration records generated in 2013 are available from the corresponding author on reasonable request.

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