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Enhanced lead accumulation in cassia bark linked to lichen and algae: A case study from Northern Vietnam

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ABSTRACT

High lead (Pb) levels in cassia products pose a significant threat to both the global spice supply chain and public health. Addressing this critical issue, our study investigates Pb accumulation within the soil-cassia system in Northern Vietnam, a major cassia-producing region. Soil and cassia samples were collected from six key cassia-growing regions along the Red River, and their compositions and properties were systematically evaluated. Although soil Pb concentrations were low, significant enrichment of Pb was detected in the cassia bark skin (1.6–3.3 mg kg^{-1}). Notably, the enhanced accumulation of Pb in cassia bark shows a clear correlation with the presence of epiphytic lichen and algae. We observed that Pb concentrations in these lower plant species were approx. one order of magnitude higher than in the bark itself. Our findings strongly suggest that lichen and algae likely act as adhesion agents, significantly contributing to increased Pb accumulation on the bark. Despite low soil Pb concentrations indicating it is not the primary source, evidence points strongly towards airborne Pb deposition; therefore, the removal of epiphytic, surface-dwelling lower plants should be prioritized as a key mitigation strategy. We strongly recommend expanding research efforts to develop proactive and preventive measures.

1. Introduction

The global cinnamon/cassia market was valued at approx. USD 1 billion in 2024 and is projected to reach USD 1.5 billion by 2030 (Grand-View-Research, 2024). This growth is driven by increasing consumer awareness of cinnamon/cassia's health benefits and the rising demand for natural food products. However, the contamination of cinnamon and cassia products with toxic compounds, such as lead (Pb), has led to unexpected recalls by importing countries, posing significant challenges for the global cinnamon and cassia supply chain, particularly for key exporters in Asia. Subsequently, US Food and Drug Administration (FDA) cautioned that prolonged exposure to such products could pose health risks, including elevated blood lead levels and other adverse effects, particularly for young children. This highlights the urgency for the cinnamon/cassia industry to take action and underscores the need for stricter control measures.

There is minimal research on Pb contamination in cinnamon and cassia products, an issue that has only recently gained attention from regulatory bodies such as the FDA and was highlighted in a few recent studies conducted in Ecuador (Yánez-Jácome et al., 2024) and Europe (Ghidotti et al., 2025). This underscores a critical knowledge gap, particularly regarding the mechanisms of Pb accumulation and potential mitigation strategies. The contamination of heavy metals, such as Pb, in plants can generally occur through multiple pathways (as illustrated in Fig. 1), including atmospheric deposition, application of heavy metal-containing fertilizers, pesticides, and irrigation water, or absorption from contaminated soil during cultivation (Nagajyoti et al., 2010; Angon et al., 2024). Regions with less stringent environmental regulations may be particularly vulnerable to such contamination. Cinnamon/cassia trees can take up Pb from contaminated soil through their roots, contributing to contamination in the harvested product. Pb^{2+} ions in the soil solution can be absorbed by the root system along with

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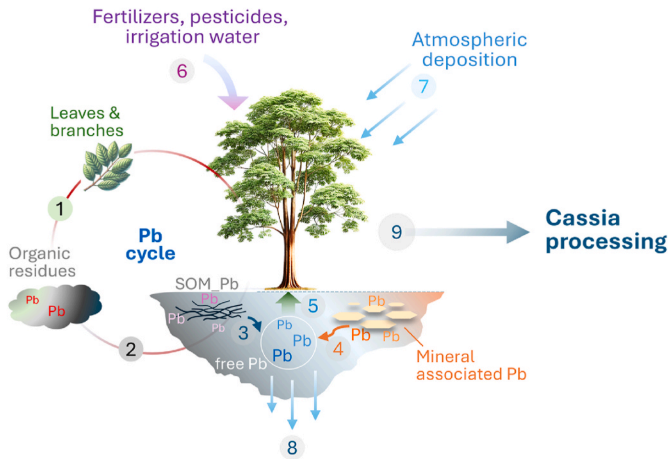

Fig. 1. Schematic illustration of lead (Pb) transfer pathways within the soil–cassia system: (**1**) Fallen branches and leaves accumulate in the soil; (**2**) Organic residues containing Pb are transformed into humus substances that retain Pb or decompose to release free Pb ions; (**3**) Decomposition of soil organic matter (SOM) releases Pb ions; (**4**) Weathering of soil minerals releases Pb ions; (**5**) Uptake of Pb ions by cassia; (**6**) Introduction of Pb through the use of Pb-contaminated fertilizers or pesticides; (**7**) Pb is deposited from the atmosphere through dust or rainfall; (**8**) vertical leaching of Pb; (**9**) losses of Pb through the harvesting of cassia products.

essential nutrients such as Ca^{2+}, as they are chemical analogs with similar ionic radii and chemical behavior (Pourrut et al., 2011). After entering the roots, most Pb becomes immobilized through various mechanisms, including binding to cell walls, complexation with organic ligands such as phytochelatins and metallothioneins, and sequestration within vacuoles (Pourrut et al., 2011). However, a small fraction of Pb may enter the xylem sap and be transported upward through the transpiration stream, potentially reaching the leaves, stems, and bark, especially in young or actively growing tissues. In cinnamon or cassia, where the bark is the primary harvested product, the accumulation of Pb in bark poses a direct risk to human health.

Airborne deposition is another notable pathway for Pb contamination in cinnamon/cassia. Vast contamination of soil and agricultural products by Pb emitted from vehicle's engines and machines that used gasoline with Pb additive (tetraethyllead) is an example for atmospheric Pb source (Lin et al., 2022); and its widespread human health risks subsequently led to a global ban of leaded gasoline at the end of the last century. Nowaday, sources of atmospheric Pb pollution are more diverse; however, coal combustion and lingering legacy of leaded gasoline remain major contributors (Pacyna et al., 2009; Kayee et al., 2021; Ray and Das, 2023; Guan et al., 2025). Airborne deposition of Pb may also be seen in different environments such as mining areas (Li and McDonald-Gillespie, 2020; Kasongo et al., 2024), urban and industrial areas (Widory et al., 2004; Lee et al., 2019; Tao et al., 2021; Ye et al., 2022); smelting and metal processing operations (Félix et al., 2015). Cinnamon/cassia grows near these sources can be potentially contaminated; and the common airborne pathways are either dry deposition (Pb-containing particles and gases settle directly from the air onto plant surfaces or soil) or wet deposition (rain or fog brings airborne Pb down to the surface).

The accumulation of Pb on cassia/cinnamon bark through airborne deposition may be amplified by the presence of surface microbiomes such as mosses and lichens (Ancora et al., 2021) given their induced microenvironments with high moisture and adhesion surfaces. A similar phenomenon has been reported in recent studies (Ng et al., 2006; Taurozzi et al., 2024) regarding the entrapment of microplastic particulates. Therefore, the presence of these surface-dwelling lower plants is likely to enhance the retention of Pb or Pb-associated dust on cinnamon and cassia bark. Since these species lack a root system, they absorb nutrients and pollutants directly from the air and surrounding environment rather than from the soil (Phaenark et al., 2024; Gómez-Ensastegui et al., 2025), becoming valuable bioindicators for assessing airborne deposition of Pb (Carignan et al., 2002; Wu et al., 2016).

This study provides a rapid assessment of Pb levels in the soil-cassia system in northern Vietnam, a key region that contributes significantly to the global cinnamon/cassia trade. To achieve this, soil and plant samples were collected and analyzed in parallel. The elucidation of Pb sources was based on an integrated analysis of Pb concentrations within the soil–cassia system and their geographical variation. As airborne deposition was hypothesized as a potential source of Pb, surface layers including cassia skin and surface lower plants (e.g., algae and lichen) were subjected to various instrumental analyses, such as microscopy, chemical speciation and X-ray diffraction. Since Si, Al and Fe are potential proxies for airborne contamination (Semenov et al., 2020), their concentrations and phases in barks and surface lower plants were also investigated. The findings are expected to provide valuable insights into the fate of Pb within the soil-cassia system, guiding future research, assisting local cassia producers in safeguarding their input materials and products, and promoting sustainable control measures in not only Vietnam but also other cassia growing regions worldwide.

2. Materials and methods

2.1. Sample preparation

A survey was conducted along a ~100 km transect across Northern Vietnam's key cassia-growing regions, characterized by hilly terrain with slopes of 15–30° and elevations around 200 m. To assess Pb accumulation, six sampling sites were selected within this transect, specifically choosing locations with cassia trees at least 10 years old (Fig. 2).

At each sampling site, cassia plant samples were collected by felling a mature tree (approx. 10 m in height and 20 cm in trunk diameter), along with corresponding soil samples from three distinct topographical positions: hilltop, mid-slope, and hillfoot. At each site, we created composite soil samples from four spots, each approx. 1 m from the tree base. These samples combined sub-samples from three depths: 0–5, 5–30, and >30 cm deep). This design aimed to capture the spatial distribution of Pb in the root zone, track potential discrepancies in Pb content between surface and subsoils, and ultimately help elucidate the pathway of Pb accumulation. The soil samples were air-dried at room temperature, homogenized, sieved through a 1 mm mesh and then used for further analysis. The cassia tree sample was cut close to the base and divided into different parts: Grade A (refering to the trunk section from the ground up to a height of 2.25 m), Grade B (refering to the trunk section from a height of 2.25 m to the branching point) and Grade C (the section from the branching point to the top and large branches) (Fig. 3a). Algae and lichens commonly occurred on the surface of cassia bark. They were carefully removed from the underlying bark. Following their removal, a layer-by-layer peeling process was conducted to isolate the skin, bark, and wood core (Fig. 3b). In the context of this study, "skin" refers to the thin outermost layer (~1 mm thick) that covers the exposed surface of cassia bark after algae and lichens have been removed. All collected samples were air-dried and used for further analyses.

2.2. Analyses

Each 1 g of sample of soil and plant was mixed with 10 mL of 65 % HNO_3 and 1 mL of 30 % H_2O_2 and left to stand overnight. The samples were then digested using a microwave digestion system (Mar6, CEM Corporation), where the temperature was gradually raised to 180 °C and maintained for 2 h. After cooling to room temperature, the digestate was accurately diluted to 50 mL with double-distilled water. Finally, the samples were analyzed for total Pb, Al, Si and Fe content using

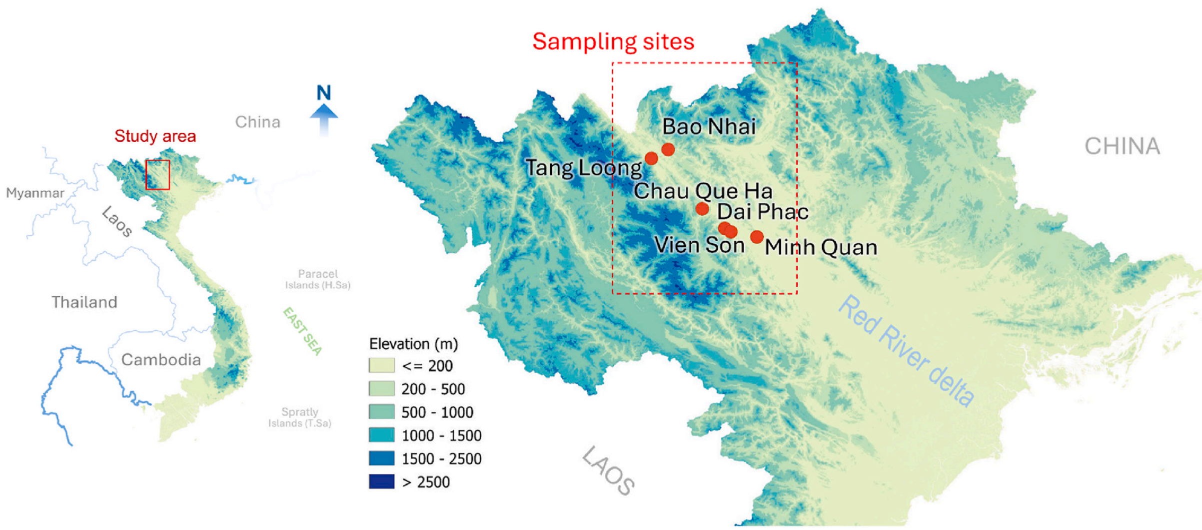

Fig. 2. A topographic map presenting six sampling sites across a major cassia-growing region in Northern Vietnam.

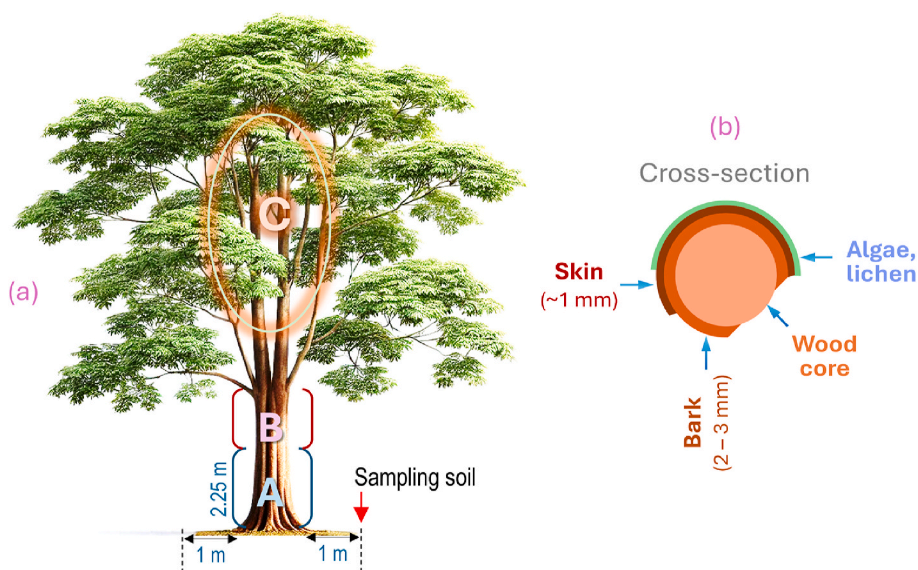

Fig. 3. Illustration of: (a) the different grades (A, B, C) of cassia biomass sampled; (b) cross-section illustrating the segmentation of cassia samples into distinct components (wood core, bark, skin and algae/lichen) prior to analysis.

inductively coupled plasma-mass spectrometry (Aglient Technologies 7900 ICP-MS). All analyses were carried out by Eurofins Vietnam. Algae and lichen samples were further examined under a microscope (Kruss MBL2000-T-PL-30W) for identification and taxonomic classification. Since Si, Al and Fe might be proxies of airborne deposition, their concentrations in algae and lichen were also examined. Silicates (dust particles) were also examined using Scanning electron microscopy (SEM, JSM IT800) coupled with energy-dispersive X-ray spectrometry (EDS, Oxford ISIS 300); and their mineral phases were determined by Xray diffraction (Bruker AXS D5005). The dataset was assessed for normality using the Shapiro-Wilk test, and potential statistically significant differences were analyzed using the Kruskal-Wallis one-way ANOVA.

3. Results

3.1. Lead in the soil in the cassia growing areas

Fig. 4a illustrates the geographic variation in Pb levels across soil layers and cassia-growing regions. Differences among soil layers were relatively minor (Fig. 4b), whereas Pb concentrations varied substantially between sampling sites (Fig. 4c). Along the Red River's Northwest-Southeast transect, surface soil Pb concentrations slightly increased from upstream to downstream, consistent with the increasing mining activities observed in the downstream areas. This trend was more pronounced at four downstream sites, specifically from, from Chau Que Ha (11.9 mg kg^{-1}) to Minh Quan (35.1 mg kg^{-1}). Chau Que Ha was the only site where soil Pb concentration was comparable to the average Pb threshold in the Earth's crust (14.8 mg kg^{-1}), as reported by (Heinrichs et al., 1980). In contrast, the remaining five sampling areas exhibited Pb concentrations approx. 1.4 to 2.4 times higher than this average crustal threshold. Notably, all the sampling areas have Pb concentrations significantly lower than the maximum allowable threshold (50 mg kg^{-1}) according to FAO regulations. The consistently low Pb levels in soils across all growing regions indicate that soil is likely not the major contributor of Pb to cassia trees.

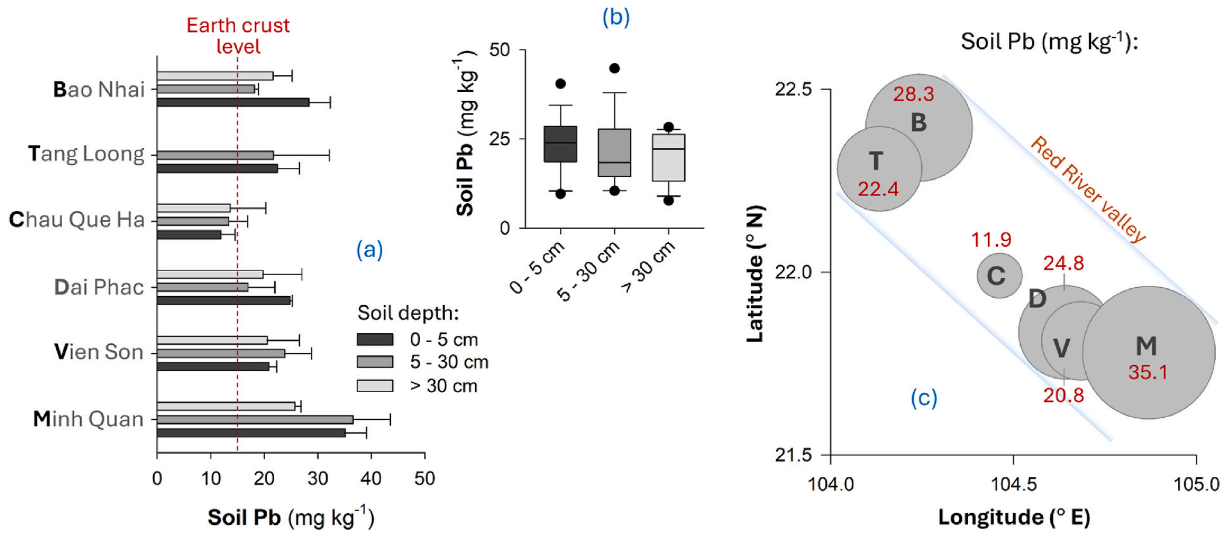

Fig. 4. Lead (Pb) distribution in soils from the primary cassia-growing region along the Red River in northern Vietnam: (a) Variation in soil Pb concentrations across sampling sites; (b) Differences in Pb concentrations among soil layers; (c) Bubble diagram showing the spatial distribution of Pb concentrations in surface soils (0–5 cm). Sampling locations are denoted by letters: B – Bao Nhai, T – Tang Loong, V – Vien Son, C – Chau Que Ha, D – Dai Phac, and M – Minh Quan. The values represent the average Pb concentrations at each site. Noting that only two layers (i.e., 0–5 cm and 5–30 cm) were collected, as the soil at Tang Loong is relatively shallow.

3.2. Distribution of lead in cassia trees

The distribution of Pb in different parts/grades of cassia trees is illustrated in Fig. 5a. Accumulation of Pb in the wood core and bark was negligible, with concentrations consistently below 0.5 mg kg^{-1}. In contrast, accumulation of Pb in the skin was significantly higher than in both the bark and wood core. Skin Pb concentrations ranged from 0.5 to 6.5 mg kg^{-1} and tended to increase in the following order: grade A (median, $\tilde{x} = 1.6$ mg kg^{-1}) < grade B ($\tilde{x} = 2.2$ mg kg^{-1}) < grade C ($\tilde{x} = 3.3$ mg kg^{-1}). The variability in Pb concentrations increased progressively from grade A to grades B and C. In general, Pb concentration in cassia trees tends to increase along two gradients simultaneously: (1) from wood core to bark/skin and (2) from the older parts (trunk) to the younger parts (top) of the tree. The wood core and bark appeared relatively pristine, with Pb concentrations below New York's threshold of 1 mg kg^{-1}. In contrast, most skin samples exhibited Pb levels exceeding this threshold. The geographic distribution of Pb in the skin samples is presented in Fig. 5b, though no clear spatial trend was observed. Notably, there was no significant correlation between Pb concentrations in any cassia grade and those in the corresponding soils,

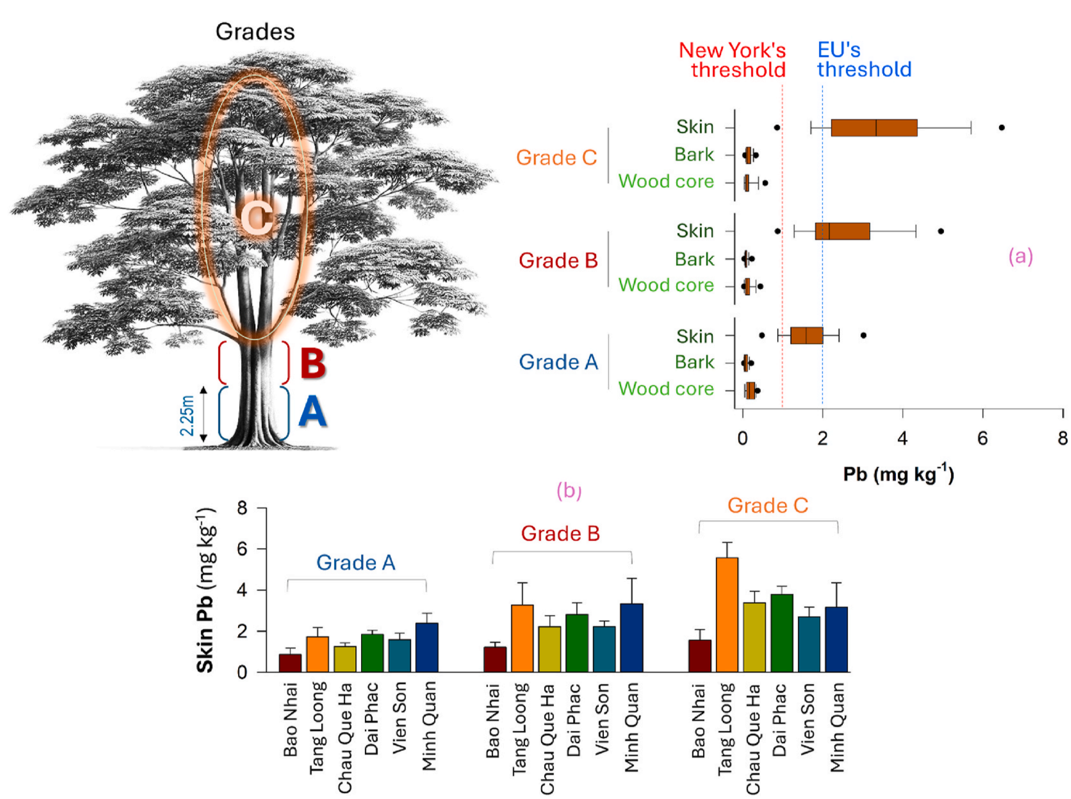

Fig. 5. Boxplots and barcharts showing Pb levels in: (a) different parts/grades of cassia (n = 18); and (b) bark skin in different sampling sites (n = 3).

suggesting that soil Pb budget may not be the primary contributor to Pb accumulation in cassia trees. Since algae and lichen are also present on the skin surface in patch-like formations, they may contribute to the Pb levels detected in the skin. Further insights into Pb accumulation in algae and lichen are provided in Section 3.3.

3.3. Lead in algae and lichen on cassia bark

Lichens were found to be more widespread than algae across the study regions. The algae sample in Tang Loong was identified as *Trentepohlia* sp. 2 (Fig. 6a). In contrast, detailed classification of lichens from other sites was not possible due to their desiccated state, a condition developed to withstand the cold and dry environment (Fig. 6b). Comparative Pb concentrations in algae and lichen are presented in Fig. 6c. Pb concentration in algae was found to be 17.3 ± 9.0 mg kg^{-1} (mean ± standard deviation, averaged across hilltop, mid-slope, and hillfoot locations). In contrast, Pb concentrations in lichen varied significantly across sampling sites, with the lowest level recorded in Bao Nhai (10.3 ± 1.5 mg kg^{-1}) and the highest in Minh Quan (50.8 ± 21.7 mg kg^{-1}). A gradient of increasing Pb concentration in lichens was observed from upstream (Bao Nhai) to downstream (Minh Quan) (Fig. 6c), closely aligning with the pattern found in the bark (as described in Section 3.1 and Fig. 5b). A significant correlation between Pb levels in algae/lichens and skin (Fig. 6d) suggests that both were exposed to the same contamination source. However, algae and lichens retained more Pb due to their higher adhesibility. Another significant gradient ($p < 0.05$) is the increasing Pb concentration in algae and lichens from hillfoot to hilltop (Fig. 6e), with median Pb values of 15.0, 19.5 and 26.7 mg kg^{-1} at the hillfoot, mid-slope and hilltop, respectively. These two gradients suggest a potential influence of airborne deposition, where the activiy of wind may play a role in Pb accumulation in lichen and algae.

Both lichens and algae demonstrated a remarkably high capacity for dust retention, as evidenced by their elevated Al and Fe contents (Fig. 7a–b). The median concentrations of Al and Fe were 952 and 1160 mg kg^{-1} in algae and 911 and 1115 mg kg^{-1} in lichen. These Al and Fe concentration ranges were at least 10 times higher than those in skin, bark and wood core. It should be noted that the measured Al contents do not represent the total amounts of dust, as the HNO_3/H_2O_2 digestion used is only capable of partially dissolving dust particles. In addition to chemical analysis, we also tracked dust particle contamination in algae by using electron microscopy (Fig. 7c). Dust particles were indicated by the co-enrichment of Al and Si, appearing as similarly shaped cloud-like formations (Fig. 7d). These particles mostly have microsizes (up to 20 μm) and consist of various mineral phases, including quartz, kaolinite, and amphiboles (Fig. 7e). Herein, Fe was not enriched, or its fine particulates were beyond the present resolution of the SEM-EDS image. These findings suggest that lichens and algae on cassia bark may function as 'micro-traps' for dust and Pb. However, the mechanism of Pb sorption onto cassia-associated lichens and algae remains unclear. No significant correlation between Pb and Al or Fe in the algae/lichen samples was observed. Consequently, it is uncertain whether Pb (ions) are directly retained on the lichen/algae surfaces or primarily associated with dust particles, such as silicates and iron oxides, deposited on them. This highlights the need for further investigation into the fractionation and binding forms of airborne Pb.

4. Discussion

It is important to first highlight that Pb concentrations in the surface soil were generally low, ranging from 11.9 to 35.1 mg kg^{-1} (Fig. 4a). The subsoils showed relatively consistent patterns of Pb concentration (Fig. 4b). Some study sites exhibited Pb levels close to the average concentration in the Earth's crust (approx. 14.8 mg kg^{-1}) (Heinrichs et al., 1980), while others showed slightly higher values. However, all sites had Pb concentrations below the FAO threshold of 50 mg kg^{-1} applied for agricultural soils. No clear geographic pattern of Pb distribution was observed in cassia; however, two internal gradients in Pb

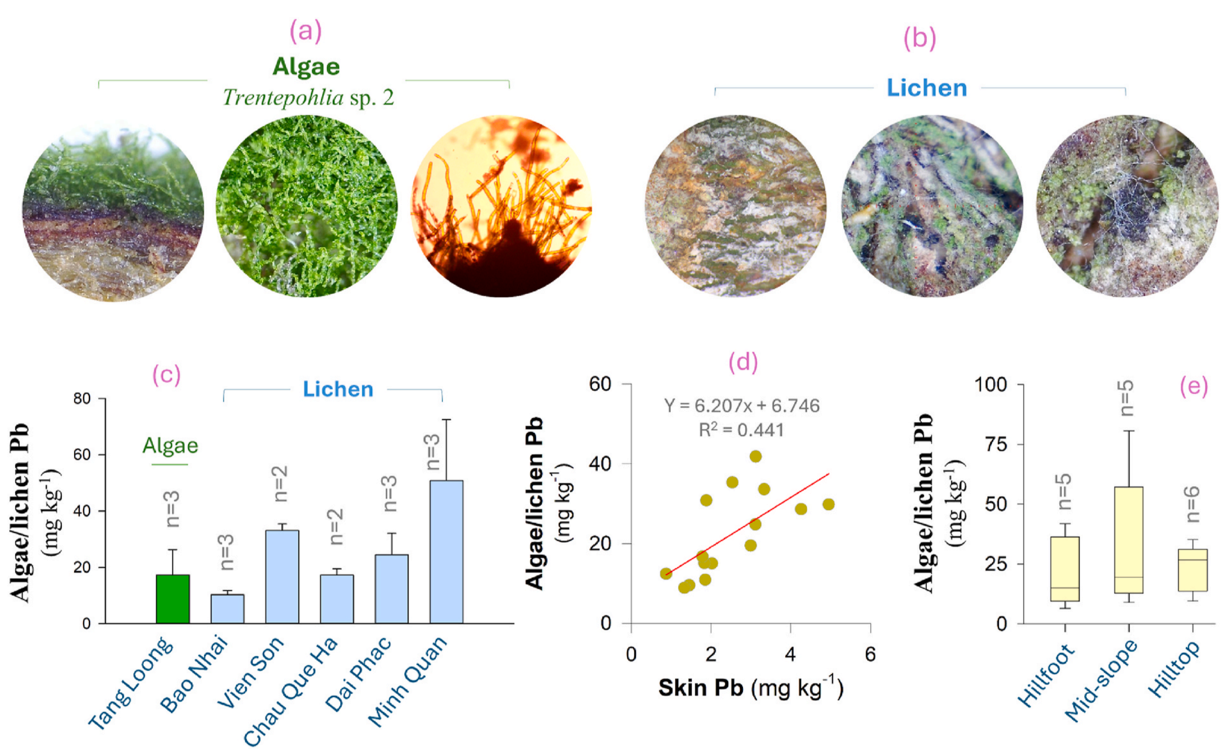

Fig. 6. Lead in algae and lichen on cassia bark: (a–b) Microscopic images of green algae and lichen on cassia bark; (c) A barchart comparing lead concentrations in algae and lichen across different sampling sites; (d) A scatter diagram presenting a strong correlation between Pb in algae/lichen and bark skin; (e) A boxplot diagram illustrating lead concentration variations among hilltop, mid-slope, and hillfoot locations. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

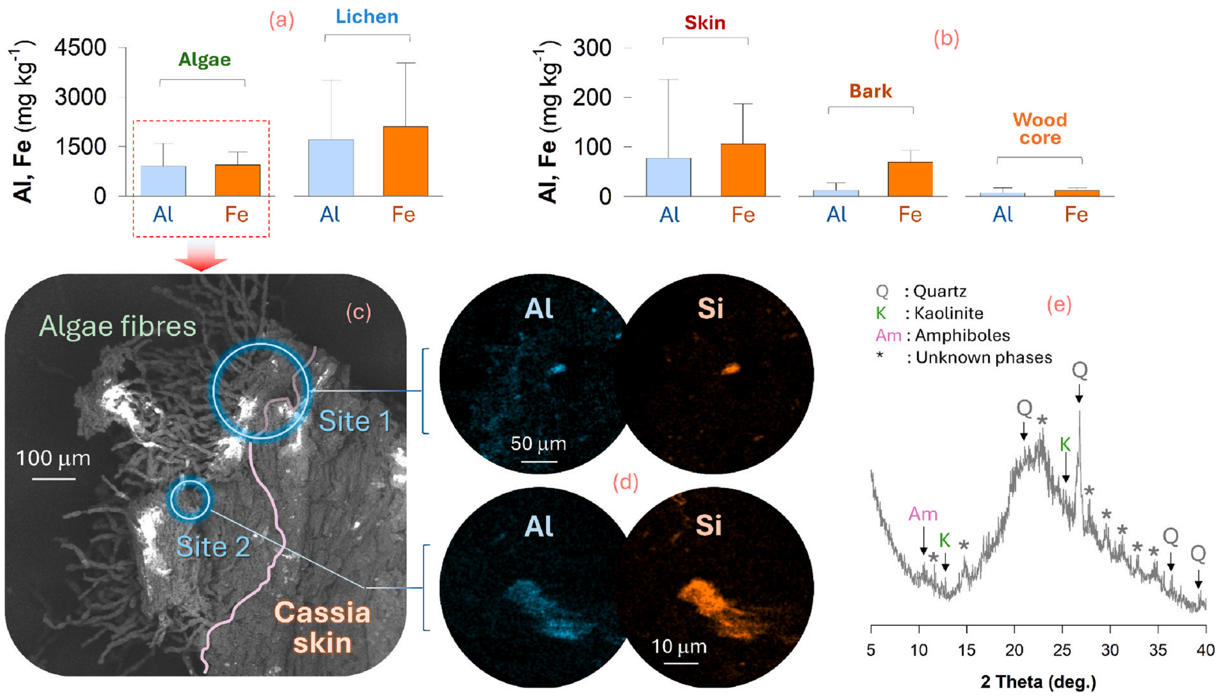

Fig. 7. Tracking silicate dust in algae/cassia skin: (a) concentrations of Al and Fe in algae and lichen; (b) concentrations of Al and Fe in skin, bark and wood core; (c) SEM image of a cross-section of cassia bark, highlighting distinguishable algae fibers and cassia skin; (d) elemental maps showing two regions containing Al/Si-rich particles; and (e) corresponding XRD pattern confirming the presence of silicate minerals (dust particles).

accumulation are noteworthy: (i) Pb concentrations tend to increase from grade A (older parts) to grade C (younger parts), and (ii) Pb also increases from the wood core toward the bark skin. The elevated levels of Pb in the bark skin (ranging from 1.6 to 3.3 mg kg^{-1}) are of particular concern, as they exceed the regulatory thresholds set by New York State (1 mg kg^{-1}) and EU (2 mg kg^{-1}). Although internal translocation may contribute to Pb accumulation in cassia, it is unlikely to be the primary pathway in this study. Conversely, airborne deposition emerges as a potential significant source of Pb contamination for cassia.

Observations of algae and lichen, non-vascular plant species growing on cassia bark with minimal connectivity for nutrient and pollutant exchange with the host plant, suggest a potential airborne source of Pb contamination. Pb concentrations in algae and lichen ranged from 10.3 to 50.8 mg kg^{-1}, approx. one order of magnitude higher than those detected in the cassia bark skin. These findings suggest that airborne Pb contaminated both the algae/lichen and the cassia bark skin. A strong correlation between Pb accumulated in algae/lichen and in bark skin is shown in Fig. 6d. Algae and lichen exhibited substantial Pb retention (Fig. 6c), as they colonized the exposed surface of the bark skin and possess high surface areas with dense microporous structures (Fig. 6a and b), which consequently facilitate the adhesion of Pb and dust particles. The ability of lichens to capture particulate matter has also been documented in recent studies (Ng et al., 2006; Taurozzi et al., 2024; Thakur et al., 2024). The hypothesis of an airborne Pb source is further supported by the accumulation patterns of Pb in cassia bark skin along a toposequence (hillfoot, mid-slope, and hilltop) (Fig. 6e). Contrary to previous studies that reported greater airborne contamination at lower elevations, attributed to limited air circulation (Wallace et al., 2010; Liao et al., 2025), our findings reveal higher Pb concentrations in cassia skin at hilltops. This suggests that higher elevations in this region may have experienced greater exposure to atmospheric Pb deposition, potentially from external or even long-range sources. A similar trend was observed in cassia trees, with the upper parts (e.g., treetops) exhibiting higher Pb levels than the lower sections (Fig. 5a–b). This pattern is likely due to greater exposure of the upper parts to airborne Pb deposition. Overall, our data support the presence of airborne Pb contamination in cassia; however, this phenomenon warrants further investigation, particularly considering the potential influence of algae/lichen-induced microenvironments as well as field cares (e.g., pruning, proper plant spacing, improved drainage). Additionally, chronological, topographical, and climatic factors should be considered.

Fig. 8 presents a schematic illustration of Pb accumulation in cassia, emphasizing areas with elevated risk, and simultaneously, surface-dwelling lower plants, such as algae and lichens, play an enhancing role by trapping Pb and dust particles. Our findings also indicate that while soil Pb may contribute to cassia's Pb uptake, it is unlikely to be the dominant pathway. Therefore, a comprehensive mitigation strategy should address not only airborne sources but also other potential pathways simultaneously. The observed upward gradient of Pb concentration from the core to the bark presents a significant challenge for the cassia industry, as the bark is the primary commercial product. Peeling is a straightforward approach, but its effectiveness seems inconsistent, as bark areas lacking algae and lichens generally contain less Pb. Therefore, continued exploration of alternative peeling methods is warranted. Particularly, lichen and algae attached to the bark were found to accumulate Pb at levels approx. 10 times higher than those in the bark skin, underscoring the importance of their thorough removal during processing. In another context, high Pb accumulation capacity of algae and lichen suggests their potential uses as bioindicators for early detection of Pb contamination (Loppi et al., 2006; Çobanoğlu and Kaan, 2024; Thakur et al., 2024), enabling timely interventions to prevent widespread contamination in the cassia ecosystem. During raw material processing, steps such as open-air drying and transportation, can inadvertently introduce Pb and other contaminants. For example, airborne dust may serve as additional sources of Pb, highlighting the need for effective control measures. Although direct evidence of airborne Pb sources remains limited, common contributors, such as transportation routes, waste treatment sites and industrial activities (Nguyen Viet et al., 2010; Nguyen et al., 2022, 2023), should be more strictly regulated. Proactive efforts are essential to re-evaluate and potentially relocate cultivation areas to regions with lower soil Pb levels, away from mines and high-traffic zones. Additionally, integrating advanced technologies

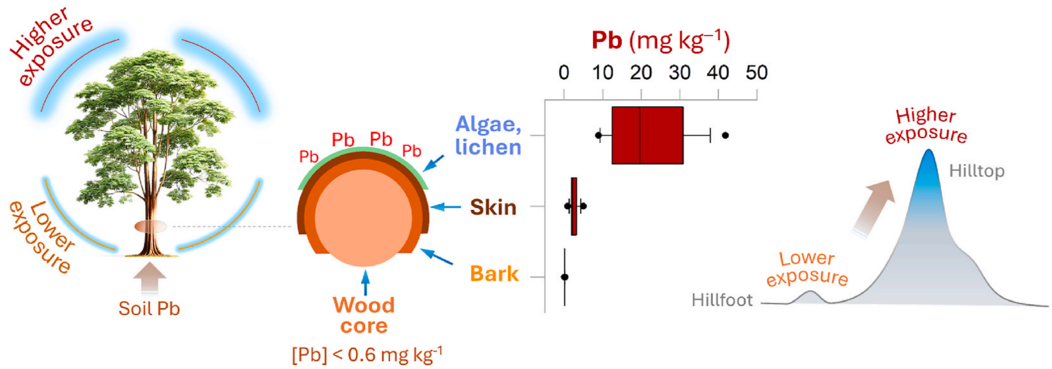

Fig. 8. Schematic illustration of lead (Pb) exposure within the cassia ecosystem in which treetops and hilltops are identified as areas with elevated risk.

into production processes is critical to reducing or eliminating exposure to external contaminants. The adoption of precision farming practices, supported by IoT, AI, and Big Data, offers a promising pathway for modernizing cassia cultivation. Finally, exploring innovative products and cascading applications for the safe and effective utilization of Pb-contaminated cassia materials and by-products is also vital.

5. Conclusion

This study highlights algae and lichens as the primary bioagents driving Pb accumulation in cassia bark across Northwest Vietnam's primary growing region. Their presence, coupled with Pb levels approx. one order of magnitude higher than the bark itself, significantly contributes to Pb enrichment in both cassia bark and its derived products. Despite low soil Pb concentrations, significant enrichment was detected on the outer bark. Our findings, based on spatial variations of Pb in soils, cassia trees, and surface lower plants, suggest that airborne deposition, rather than soil uptake, is the dominant pathway for Pb accumulation in cassia bark. Airborne particles likely introduce Pb into the cassia ecosystem, with algae and lichens acting as adhesion agents, facilitating Pb retention on cassia surfaces. However, direct empirical investigation and quantification of local airborne Pb deposition are still necessary to elucidate the mechanisms underlying Pb uptake and retention by algae and lichens at the molecular level. Simultaneously, managing the growth of algae and lichens in conjunction with the development of advanced harvesting and pre-processing techniques should be central to future proactive strategies for mitigating contamination.

CRediT authorship contribution statement

Tien M. Tran: Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Dung D. Nguyen:** Resources, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Anh T. La:** Investigation, Formal analysis, Data curation. **Hoan T. Dao:** Methodology, Investigation, Formal analysis, Data curation. **Anh T.Q. Nguyen:** Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Trang T. Vu:** Formal analysis, Data curation, Conceptualization. **Van M. Dinh:** Formal analysis, Data curation, Conceptualization. **Minh N. Nguyen:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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