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RESEARCH ARTICLE

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Nutrient composition and heavy metal accumulation in water hyacinth [*Eichhornia crassipes* (*Mart.*) *Solms*] and water lettuce (*Pistia stratiotes* L.) from the Dande River, Nepal: Implications for use as alternative feed resources

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Abstract

Background: The proliferation of invasive aquatic macrophytes poses a significant ecological challenge globally, while many tropical regions face chronic shortages of affordable livestock feed. This study addresses this dual problem by assessing two invasive species, water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*), from the Dande River in Nepal. The objective was to evaluate their potential as a sustainable feed resource by comparing their nutritional and mineral profiles against their heavy metal and mycotoxin contamination. Thirty-five samples of each species were subjected to a comprehensive analysis.

Results: The analysis revealed promising nutritional compositions on a dry matter basis. *P. stratiotes* had a higher mean crude protein (CP) of 19.89%, while *E. crassipes* contained 17.17% CP. Both species were rich sources of essential macrominerals, especially potassium (K). Mycotoxin screening showed Aflatoxin B1 and B2 levels were below the detection limit of 1.0 µg/kg. However, a critical toxicological barrier was identified. While arsenic and lead levels were within permissible limits, cadmium (Cd) was dangerously elevated. The mean Cd concentration was 0.15 µg/g in *E. crassipes* (7.5 times the World Health Organization [WHO] limit) and 0.98 µg/g in *P. stratiotes* (49 times the WHO limit).

Conclusion: Despite their nutritional merits, the biomass of both species from the Dande River is unequivocally unsafe for direct use as animal feed due to the severe risk of cadmium poisoning and food chain contamination. This study underscores the need for site-specific safety assessments and recommends that this invasive biomass be redirected towards non-food valorization pathways, such as biogas production.

KEYWORDS
heavy metals, invasive aquatic plants, proximate composition, unconventional feed, water hyacinth, water lettuce

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INTRODUCTION

Freshwater ecosystems worldwide face increasing pressure from invasive aquatic plants. The two free-floating species in particular—water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*)—have become especially problematic. Though they are native to South America, these species have spread across tropical and subtropical regions on almost every continent, largely because of their rapid vegetative growth.[1,2] This may be due to the high reproductive potential and rapid growth rate of the species. For instance, water hyacinth can double its biomass within about a week, enabling the formation of dense surface mats that expand quickly across water bodies.[3]

The proliferation of these invasive macrophytes suppresses native aquatic ecosystems by blocking light penetration and inducing hypoxic conditions upon decomposition.[4] Furthermore, the dense vegetative mats create stagnant microhabitats that favor disease vectors.[5,6] These infestations also impose significant socioeconomic burdens by disrupting inland navigation, fisheries, and local water supplies.[7,8]

In Nepal, the issue has emerged as a pressing local concern. The Dande River in Rupandehi District provides a clear case: a watercourse that historically served as an important freshwater resource is now heavily infested by both water hyacinth and water lettuce. Simultaneously, farmers in the region often face shortages of affordable livestock feed, particularly during the dry season when natural forage is scarce.[9] These intersecting challenges have prompted consideration of an alternative approach rather than pursuing eradication alone.[10] Additionally, stakeholders are also exploring the potential for converting abundant aquatic biomass into low-cost livestock feed.[11]

Many aquatic weeds contain appreciable levels of protein and essential minerals, and therefore they could function as supplementary feedstuffs.[12,13] However, this opportunity also entails substantial risks. Both *E. crassipes* and *P. stratiotes* are efficient accumulators of dissolved and particulate substances, including heavy metals and other contaminants.[14] Previous studies extensively document the phytoremediation capacity of *P. stratiotes* in removing heavy metals and organic pollutants from industrial, glass, and paper mill effluents.[15–17] While this characteristic underlies their utility in phytoremediation, it also raises food-safety concerns. The Dande River receives effluents from urban and healthcare waste streams, which increases the likelihood that harvested plants may contain toxic residues. If contaminated biomass is fed to livestock, contaminants may bioaccumulate in animal tissues or products and ultimately pose hazards to human consumers.[18]

This study provides the first comparative site-specific safety assessment of these invasive species in the Dande River, addressing a critical gap in local feed safety data. We hypothesized that while both *E. crassipes* and *P. stratiotes* possess adequate macronutrients for livestock, their capacity for bioaccumulation results in heavy metal concentrations exceeding safe feed limits. By juxtaposing nutritional promise against toxicological risk, this work seeks to inform evidence-based management strategies, clarifying whether invasive weeds can be safely incorporated into feed systems or should instead be directed towards alternative valorization pathways.

MATERIALS AND METHODS

Study area and sample collection

The study was conducted on the Dande River in the Rupendehi District of Lumbini Province, Nepal (approx. 27°28′50.3″ N, 83°26′39.9″ E), as shown in Figure 1. A total of 35 ($n = 35$) distinct samples of *E. crassipes* and 35 ($n = 35$) samples of *P. stratiotes* were collected from randomly selected sites along the river between May and July 2023. This specific window captures peak vegetative growth prior to major monsoon flushing, representing the maximum available biomass. This period corresponds to the late spring/early monsoon season, and for consistency, mature plants in the vegetative (pre-flowering) stage were selected. For each sample, 1 kg of the fresh plant material was gathered. For *E. crassipes*, roots were detached on-site, while for *P. stratiotes*, the whole plant was used.

Ethical approval

Institutional ethical approval was not required for this study. The research solely involved environmental plant sampling and did not utilize human participants or live animal subjects.

Sample processing and preparation

Samples were transported to the Animal Nutrition Laboratory at the Institute of Agriculture and Animal Science (IAAS), Paklihawa Campus. The plant material was washed thoroughly with tap water to remove debris, chopped into small pieces, and dried in a hot air oven at 55°C for 24–36 h until a constant weight was achieved. The dried material was then ground into a fine, homogeneous powder and stored in airtight, labeled containers pending analysis.

Analytical procedures

The proximate composition of the samples was determined in accordance with the standard methodologies of the Association of Official Analytical Chemists (AOAC).[19] Crude protein (CP) was quantified via the Kjeldahl method (AOAC 2001.11), ether extract (EE) by Soxhlet extraction, crude fibre (CF) through sequential acid–alkali digestion, and total ash by incineration. The nitrogen-free extract (NFE) content was subsequently calculated by difference.

For elemental analysis, samples first underwent microwave-assisted acid digestion. The concentrations of essential minerals and toxic heavy metals were then quantified using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) at the National Animal Feed and Livestock Quality Management Laboratory, Hariharbhawan, Lalitpur. The system was calibrated using multi-element standard solutions. Procedural blanks were included for quality control, and the analysis was conducted in strict accordance with the laboratory's established

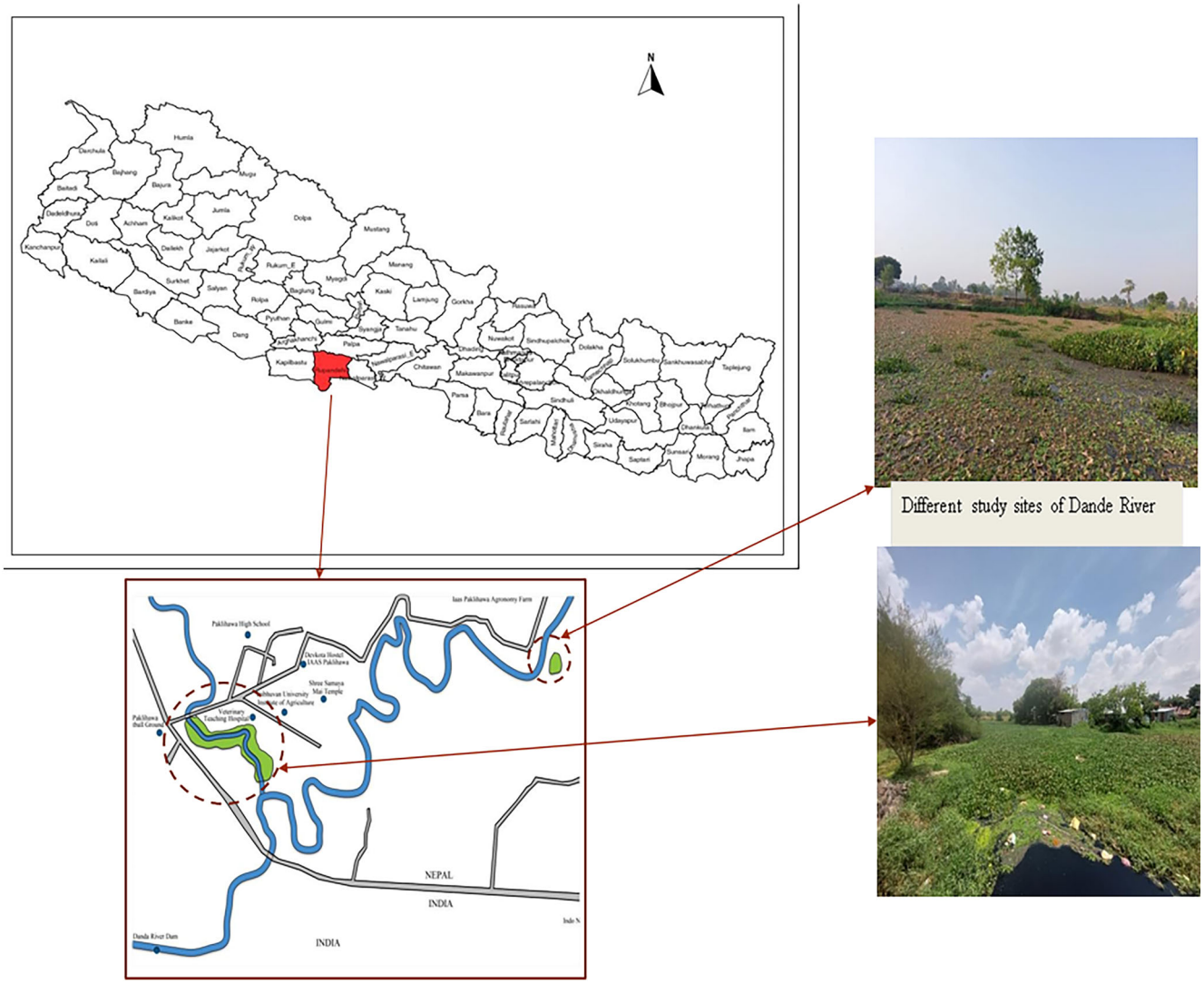


FIGURE 1 Study area showing sample collection points for *Eichhornia crassipes* and *Pistia stratiotes* along the Dande River, Rupandehi, Nepal.

and validated internal protocols. All results were reported on a dry weight (DW) basis in micrograms per gram (μg/g).

Aflatoxins B1 and B2 were quantified using High-Performance Liquid Chromatography with fluorescence detection. This analysis was preceded by sample purification using an immunoaffinity column. The established limit of quantification (LOQ) for this method was 1.0 μg/kg.

Data analysis

Data were compiled in Microsoft Excel 2021 and analyzed using R software (version 4.2.2). Descriptive statistics were calculated, and all results are presented as the mean ± standard deviation (SD). An independent sample *t*-test was utilized to evaluate statistically significant differences in nutrient and heavy metal concentrations between *E. crassipes* and *P. stratiotes*. The threshold for statistical significance was established at $p < 0.05$.

RESULTS

Proximate composition

The nutritional profiles of both species, on a dry matter basis, are summarized in Table 1. Both plants demonstrated substantial levels of key macronutrients. *P. stratiotes* exhibited a higher mean crude protein content (19.89% ± 3.71%) compared to *E. crassipes* (17.17% ± 6.38%). The total ash content was also considerably higher in *P. stratiotes* (17.85% ± 4.94%) than in *E. crassipes* (11.04% ± 1.42%).

Heavy metal and mineral concentrations

The analysis of heavy metals and essential minerals revealed significant accumulation of various elements (Table 2). Both plants were exceptionally rich in macrominerals, particularly potassium (K) and calcium (Ca). Regarding toxic heavy metals, arsenic (As) and lead

(Pb) concentrations remained within World Health Organization [WHO] permissible limits for both species. However, cadmium (Cd) levels were exceptionally high in both species, far exceeding the WHO limit of 0.02 μg/g. *P. stratiotes* demonstrated a significantly greater capacity for Cd accumulation (0.98 ± 0.22 μg/g) compared to *E. crassipes* (0.15 ± 0.03 μg/g).

Mycotoxin analysis

The screening for Aflatoxin B1 and B2 showed that levels for all samples of both species were below the established detection limit of 1.0 μg/kg (Table 3).

DISCUSSION

The compositional data from the Dande River samples indicate that both *E. crassipes* and *P. stratiotes* have genuine nutritive attributes that merit attention in a region where feed scarcity is a persistent constraint.[11,20] The observed crude protein levels in both species place these aquatic weeds within the protein range of respected forage crops such as alfalfa and well above the minimal maintenance requirements for ruminants (commonly cited near 7%–8% CP).[21,22] In practical terms, if these values are maintained after reasonable drying and handling, limited incorporation of processed aquatic biomass into rations could raise the protein content of ubiquitous low-grade feeds such as rice straw and other crop residues, thereby supporting better maintenance and production performance in smallholder herds.

Beyond protein, the plants' mineral profiles strengthen the argument for their potential as supplements. High potassium content together with appreciable calcium, phosphorus, magnesium, and trace elements such as zinc and manganese address several micronutrient deficits that commonly limit livestock productivity in subsistence systems.[12] Energy proxies—the nitrogen-free extract value around 47%—combined with moderate crude fiber (15%–18%) suggest an acceptable balance between fermentable carbohydrate and structural fiber, particularly if harvesting is timed for younger, more tender growth and if biomass is processed to enhance palatability and uniformity. These compositional characteristics imply applicability across a range of production systems: direct supplementation for ruminants at modest inclusion rates, formulation into processed ingredients for monogastrics, or incorporation into low-cost aquafeeds where nutrient profiles are matched to species-specific needs.[23,24]

The socio-economic logic that leads farmers to consider river biomass is straightforward and compelling. During dry seasons, when

TABLE 1 Comparative proximate composition of *Eichhornia crassipes* and *Pistia stratiotes* (on a dry matter basis).

Nutrient parameter	*E. crassipes* (mean ± SD)	*P. stratiotes* (mean ± SD)
Crude protein (%)	17.17 ± 6.38	19.89 ± 3.71
Crude fiber (%)	17.78 ± 1.11	15.90 ± 2.81
Ash (%)	11.04 ± 1.42	17.85 ± 4.94
Ether extract (%)	1.34 ± 0.55	3.18 ± 0.79
Nitrogen-free extract (%)	47.34 ± 7.26	47.67 ± 7.30

TABLE 3 Mycotoxin contamination in *Eichhornia crassipes* and *Pistia stratiotes*.

Mycotoxin	*E. crassipes* (μg/kg)	*P. stratiotes* (μg/kg)
AflatoxinB1	<1.0 (BDL)	<1.0 (BDL)
AflatoxinB2	<1.0 (BDL)	<1.0 (BDL)

Abbreviation: BDL, below detection limit.

TABLE 2 Comparative heavy metal and mineral concentrations (μg/g dry weight) in *Eichhornia crassipes* and *Pistia stratiotes*.

Element	Category	*E. crassipes* (mean)	*P. stratiotes* (mean)	WHO permissible limit (μg/g)
Arsenic (As)	Toxic metal	0.14	0.15	0.2
Lead (Pb)	Toxic metal	1.07	0.29	2.0
Cadmium (Cd)	Toxic metal	**0.15**	**0.98**	**0.02**
Copper (Cu)	Micro-mineral	22	18	-
Zinc (Zn)	Micro-mineral	95	80	-
Manganese (Mn)	Micro-mineral	550	480	-
Calcium (Ca)	Macro-mineral	15,000	2300	-
Phosphorus (P)	Macro-mineral	7000	3360	-
Potassium (K)	Macro-mineral	30,000	32,830	-
Magnesium (Mg)	Macro-mineral	4500	3700	-
Sodium (Na)	Macro-mineral	2500	3730	-

Note: Toxic heavy metals were analyzed individually to assess safety variance. Macro- and micro-minerals were quantified using pooled composite samples to establish mean nutritional baselines; standard deviations are therefore not applicable. Values exceeding the World Health Organization [WHO] limit are highlighted in bold.

natural forage availability collapses and commercial concentrates are unaffordable, a free and abundant local resource appears to offer immediate relief. Using locally available biomass could reduce cash outflows, improve feed security, and support resilience against seasonal feed shortages.[25,26] Moreover, locally driven utilization strategies can create employment opportunities in harvesting, processing, and small-scale value chains if managed and regulated properly.

Toxicological constraints, broader implications, and management pathways

Notwithstanding the nutritional promise, the toxicological profile measured in the present study alters the risk–benefit calculus decisively. Cadmium concentrations recorded in the biomass—mean values of 0.15 μg/g for *E. crassipes* and 0.98 μg/g for *P. stratiotes*—exceed the WHO guideline of 0.02 μg/g by large margins (approximately 7.5-fold and 49-fold, respectively).[27] These are not minor exceedances; they indicate active and significant uptake of cadmium from the Dande River environment and identify these plants as effective accumulators of this particular heavy metal.[28] Mycotoxin screening returned Aflatoxin B1 and B2 below the detection limit used (1.0 μg/kg), which reduces immediate concern for fungal toxin exposure in fresh biomass. However, cadmium's persistence, tendency to bioaccumulate, and capacity for trophic transfer make it the dominant hazard.[29] Cadmium does not metabolize or clear rapidly; it concentrates in renal and hepatic tissues and transfers to animal products, meaning that chronic exposure through contaminated feed can lead to insidious animal health problems like kidney and liver dysfunction, reproductive impairment, and reduced productivity through dietary exposure.[18]

While interspecies differences were clear, spatial variation across the Dande River was modest, suggesting that contamination is widespread along the river rather than localized. This pattern likely reflects diffuse pollution from multiple sources, including agricultural runoff, urban discharge, and informal waste disposal. The sources of cadmium contamination in this watershed are likely multifactorial and linked to regional land use and waste management practices specific to the Rupandehi District. The proximity of the river to industrial zones and urban centers results in the continuous influx of untreated municipal effluents and industrial discharges. Furthermore, agricultural inputs used in adjacent farmlands, particularly phosphate fertilizers, which are known to contain trace cadmium, are plausible non-point contributors.[30] The very process that makes these species useful in phytoremediation thus converts biomass into a concentrated hazardous material.[31] In other words, the river is being cleansed at the cost of producing contaminated plant material that cannot safely enter the food chain without robust decontamination.

Before dismissing the biomass entirely, the feasibility of post-harvest decontamination must be evaluated. Physical methods, such as extensive washing, are insufficient because cadmium is intracellularly bound rather than merely present as surface dust. Chemical treatments, including acid washing (e.g., using dilute hydrochloric acid or EDTA), can solubilize and remove heavy metals from plant tissues. Similarly, certain solid-state fermentation techniques utilizing specific microbial strains have shown potential in reducing heavy metal bioavailability in feedstuffs. However, these detoxification protocols are highly technical, require costly chemical inputs, and generate secondary toxic effluents that must be managed. Given the socio-economic reality of smallholder farming in Nepal, implementing such complex, capital-intensive decontamination steps is currently impractical and economically unviable.

Given this situation, the immediate policy and management implication is clear. Direct feeding of untreated river-harvested biomass to livestock is not acceptable under current contamination levels. Yet declaring the biomass unusable would be a missed opportunity unless safe alternative pathways are developed. Several non-food valorization options can capture economic and energetic value while preventing mobilization of heavy metals into the food supply.[32] Centralized anaerobic digestion for biogas production offers a viable route to local renewable energy; biogas systems can convert large volumes of wet biomass into methane-rich gas suitable for cooking or small-scale electricity generation while concentrating metals in the digestate that must be handled under controlled conditions.[33] Industrial uses like pulping for paper or fiberboard manufacture can sequester contaminants in non-food commodities. Thermal conversion processes, including pyrolysis to produce biochar and syngas, present additional industrial valorization pathways,[34] although the fate of metals in thermal residues needs careful evaluation and regulatory oversight. Controlled composting may produce a stabilized organic amendment, but compost made from contaminated feedstock should be restricted to non-food applications such as land reclamation or forestry to avoid transfer into food webs.[35,36]

An effective management program therefore requires integration of technical, institutional, and social measures. On the technical side, centralized processing facilities with appropriate containment and treatment for contaminated residuals are essential. Institutionally, community advisories, local ordinances banning direct feeding, and monitoring programs for livestock products are immediate priorities. Socially, engaging farmers and local stakeholders in co-designing feasible collection and processing arrangements increases compliance and economic uptake. In parallel, upstream interventions to reduce contaminant inputs and promotion of safer agricultural chemical practices are necessary to lower environmental Cd loads over time and to make any future consideration of biomass feeding possible.[37]

This study has several limitations that inform key directions for future research. First, its cross-sectional design and constrained spatial–temporal coverage underscore the need for comprehensive, long-term monitoring, including seasonal and spatial mapping of contamination. Second, the absence of controlled animal transfer trials highlights a critical gap. Therefore, future work should include controlled feeding trials to quantify tissue transfer rates. It should also incorporate speciation and bioavailability analyses for a more nuanced risk assessment. Finally, moving beyond characterization, subsequent studies should evaluate practical solutions through pilot-scale trials of non-food valorization technologies, supported by rigorous lifecycle and socio-economic assessments.

CONCLUSION

This study provides the first integrated evaluation of the nutritional and toxicological profiles of *E. crassipes* and *P. stratiotes* from the Dande River, Nepal. While both species demonstrated significant nutritional potential—notably high crude protein contents reaching 19.89% in *P. stratiotes*—this utility is completely overshadowed by extreme cadmium contamination. Cadmium concentrations reached 0.98 µg/g in *P. stratiotes*, which is approximately 49 times the WHO safety limit. This toxicological risk renders the biomass unequivocally unsafe for livestock feed, as it would introduce cadmium into the food chain. Therefore, we strongly recommend against its use as feed and advocate for redirecting this biomass towards non-food valorization pathways like biogas production. To advance this field, future research must prioritize controlled in vivo feeding trials to quantify cadmium trophic transfer rates and rigorously evaluate pilot-scale non-food valorization technologies.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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