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Phytoremediation Potential of Water Hyacinth for Removal of Chromium From Tannery Effluent

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ABSTRACT

Tannery effluent from chrome tanning carries chromium, mostly as trivalent chromium, together with salts, sulfide and a heavy load of organic matter, and its treatment is a persistent problem for small and medium tanneries. Water hyacinth (*Eichhornia crassipes*), a fast-growing floating plant that takes up metals through its roots, is often proposed as a low-cost way to strip chromium from such water. This narrative review asks what published work does and does not show about that proposal. It draws on literature on chromium chemistry and toxicity, on phytoremediation and rhizofiltration, on the biology and ecological risks of water hyacinth, and on studies of metal uptake by this plant, and it reports no new data. The evidence shows that water hyacinth can concentrate chromium, mainly in its roots, and that part of the removal is simple sorption rather than metabolic uptake. Most of it comes from short experiments with clean synthetic solutions, so it says little about real effluent, where salinity, organic load, competing ions and chemical form change both toxicity and uptake. Questions of mass balance, long-term plant health, safe disposal of metal-laden biomass and invasive-species risk are seldom answered together. The review concludes that water hyacinth is best regarded as a polishing or pre-treatment step to be tested on site, and it sets out what a credible pilot would need to measure.

Keywords: Water hyacinth; *Eichhornia crassipes*; Phytoremediation; Chromium; Tannery effluent; Rhizofiltration; Narrative review

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Article Class: Narrative Review

1. Introduction

Leather making is old, and so is its habit of leaving a mess behind. Most of the world's leather is tanned with chromium salts, and the spent liquors that leave the tannery

carry chromium along with salt, sulfide, fats, proteins and a great deal of oxidisable organic matter (1, 2). Chromium is the part that worries regulators and neighbours most, because its forms differ sharply in



mobility and toxicity (3, 4). Conventional treatment can deal with it, but the chemical and physical methods involved cost money that many small tanneries do not have (5, 6).

Against that background, plants look attractive. Phytoremediation uses living plants to take up, hold or transform pollutants (7, 8), and a variant called rhizofiltration relies on roots in flowing or standing water to strip metals out (9, 10). Among aquatic plants, water hyacinth (*Eichhornia crassipes*) has been the favourite for decades. It is a floating plant from South America that grows very quickly, builds a dense mat of feathery roots and has been tried on everything from nutrient-rich sewage to metal-bearing industrial water (11, 12).

This article asks a plain question: what do the published studies actually show about using water hyacinth to remove chromium from tannery effluent? It is a narrative review of the general literature, written without local data. We do not report measurements from any particular tannery, district or treatment plant, and nothing here should be read as a performance figure for a specific site. We try instead to separate three things that are often run together: what the plant is known to do, what has been shown to work on real effluent, and what remains an assumption. The aim is a fair account of what has been shown, as distinct from what has simply been repeated.

2. Literature Review

2.1 Chromium in Tannery Effluent

Chromium exists in several oxidation states, but only two matter in practice. Trivalent chromium is the form used in tanning; it binds readily to particles and to organic molecules and tends to precipitate near neutral pH (2, 13). Hexavalent chromium is more soluble and more

mobile, and it is recognised as the more hazardous form, with toxic and carcinogenic effects on people (3, 4, 14). The two forms can interconvert. Manganese oxides in soils and sediments can oxidise Cr(III) to Cr(VI), while organic matter and reduced iron can push the reaction the other way (13, 15). Table 1 summarises the forms that matter for a floating plant. Chromium is also only one of several metals of concern in industrial water, and general toxicology reviews place it alongside lead, cadmium, arsenic and mercury (14, 16).

In tannery water the picture is further complicated by organic ligands from protein and tanning agents, which can keep Cr(III) in solution at pH values where the free ion would otherwise settle (2). The same effluent also carries high salt concentrations and sulfide, and these affect plants independently of the metal (1). Any treatment that is judged only by the chromium number in the outflow will miss much of this. The chemistry is also not fixed, so one measurement at the inlet may not describe what the plants meet further along the pond.

Table 1. Chromium in tannery effluent and what each form means for a floating plant.

Form	Main source	Behaviour and relevance to the plant
Cr(III)	Spent chrome-tanning liquor (1, 2)	Binds to particles and organic ligands, precipitates near neutral pH (13); sorbs to roots and is less toxic (17)
Cr(VI)	Oxidation of Cr(III), some process chemicals (15)	Soluble and mobile (13, 18); taken up readily and damaging (19, 20)
Bound Cr	Complexes with tanning and protein residues (2)	Stays dissolved where free Cr(III) would settle; uptake by roots unclear

Note: Qualitative summary of the cited chemistry and toxicity literature; speciation in any real effluent must be measured.



2.2 Water Hyacinth as a Treatment Plant

Water hyacinth has several features that suit treatment work. It grows fast under warm, nutrient-rich conditions, and its population can expand explosively when little holds it back (21). Its roots are large and finely divided, offering a great deal of surface to the water. And the plant floats, so harvesting is a matter of lifting the mat rather than digging. Early experiments showed that it removed a range of metals from polluted water (22), and later work compared uptake of several metals in detail (23, 24).

The same traits that make it useful make it a nuisance. Water hyacinth is among the best-known invasive aquatic plants. Dense mats block light and flow, deplete oxygen below the surface, interfere with fishing and navigation and provide breeding sites for insects that carry disease (25, 26). A species that is being promoted for a treatment pond must therefore be contained, and a pond that overflows in a flood is not a hypothetical risk.

There is also a physiological ceiling. The plant tolerates fresh and mildly saline water but suffers as salinity rises (27). Tannery effluent is often salty, which means that raw effluent may be too harsh for the plant unless it is diluted or pre-treated, and this sits awkwardly with the idea of a simple, cheap pond. A plant that grows beautifully in a beaker has told us little about a tannery drain.

2.3 How Plants Handle Metals

Plants cope with metals in different ways. Some, the excluders, keep metals out of their shoots; a few hyperaccumulators take them up in large amounts; and most species fall somewhere between (28, 29). Water hyacinth is not a hyperaccumulator of chromium. It behaves instead as a root accumulator that holds much of what it takes up in the roots (23, 30).

The removal process itself has two parts that are easy to confuse. One is passive binding to cell walls and surfaces, which works even on dead tissue (31, 32); the other is active uptake into living cells, which depends on the plant staying healthy. Authors have argued that studies should distinguish the two, because they behave differently over time and imply different treatment designs (33). Reports that lump them together as 'removal' are hard to compare.

2.4 Chromium Toxicity to Plants

Chromium has no known essential role in plants, and in excess it damages them. Reviews describe reduced growth, chlorosis, disturbed nutrient balance and oxidative injury, with Cr(VI) generally the more damaging form (17, 19). Plants can take up Cr(III) and Cr(VI) by different routes, and some partly reduce Cr(VI) to the less toxic trivalent form in their tissues (34, 35). In vegetable crops, most of the chromium taken up stays in the roots, with little moving upward (36). The factors that control uptake in a given system include the chemical form, pH and the presence of other ions (20).

2.5 Constructed Wetlands and Practical Context

Floating-plant ponds sit within the broader family of treatment wetlands, whose performance depends on hydraulic design, loading and climate as much as on the plants (37). Reviews of phytoremediation of metals stress the importance of the whole system, and also its slowness compared with chemical methods (38, 39). A broader overview of bioremediation of metals adds that biological methods work best as part of a sequence (40). Nothing in this literature suggests that plants replace the chemical steps; the more modest claim is that they may reduce how much those



steps have to do.

3. Materials and Methods

3.1 Scope

The review asks whether water hyacinth can plausibly remove chromium from tannery effluent, how far published experiments support that, and what a convincing demonstration would contain. It covers chromium chemistry and toxicity, the biology and risks of the plant, uptake studies, and treatment-system context. It does not address organic load or sulfide treatment in detail, and the wider economics of tannery operation are left aside.

3.2 Literature Assembly

This is a narrative synthesis. No formal systematic search was made, no database list or search string is claimed, and no screening or scoring of studies was done. The authors chose sources for relevance, influence and clarity of methods, so the selection reflects judgement. Every work cited was published on or before the date of this issue. Studies on other metals and other plants are used for what they teach about mechanism and limits, not as evidence of chromium removal by water hyacinth.

3.3 Appraisal Framework

To judge how far a report can be trusted, we asked four questions of it. Was the water real effluent or a prepared solution? Was the chromium form identified? Was the experiment long enough to see the plant's health change? And was the fate of the removed metal accounted for? [Table 2](#) sets out the compartments in which chromium could end up, which is the basis for the last question. A report need not satisfy all four, but each gap narrows what can be concluded. None of this is hard to do, but each step is easy to skip.

Table 2. Where chromium may end up in a water hyacinth treatment system.

Compartment	What happens	Evidence
Root surface	Sorption and binding to cell walls (31 , 32)	Good for synthetic solutions
Root tissue	Uptake and storage; much stays in roots (23 , 41)	Moderate
Shoots and leaves	Limited upward movement (36 , 41)	Moderate
Water and sediment	Precipitation, settling, bound complexes (13 , 15)	Seldom measured
Harvested biomass	Concentrated metal that needs handling (42 , 43)	Rarely followed

Note: Compartments are those discussed in the cited work; the weight of evidence for each is the authors' qualitative reading.

4. Results

4.1 What the Uptake Studies Show

[Figure 1](#) shows a treatment line of the kind these studies have in mind. The experimental literature consistently reports that water hyacinth lowers the concentration of dissolved metals in the water it grows in ([22](#), [23](#), [30](#)). For chromium and zinc in aqueous solution, one study found that the plant accumulated both and that the roots held far more than the shoots ([41](#)). Work on cadmium and zinc found a similar pattern, with removal depending on concentration and exposure time ([24](#), [32](#)). Sorption studies on plant tissue show that part of this removal needs no living plant at all ([31](#)).

Two cautions follow. First, the numbers in these reports cannot be carried from one study to another, because plant size, solution volume, exposure time and metal form all differ. Second, the plant's behaviour towards chromium specifically has been studied far less than its behaviour towards cadmium, zinc or lead, and conclusions about chromium are often



borrowed from them. Such gaps are rarely dishonest; they are the ordinary result of studying what is easy to control.

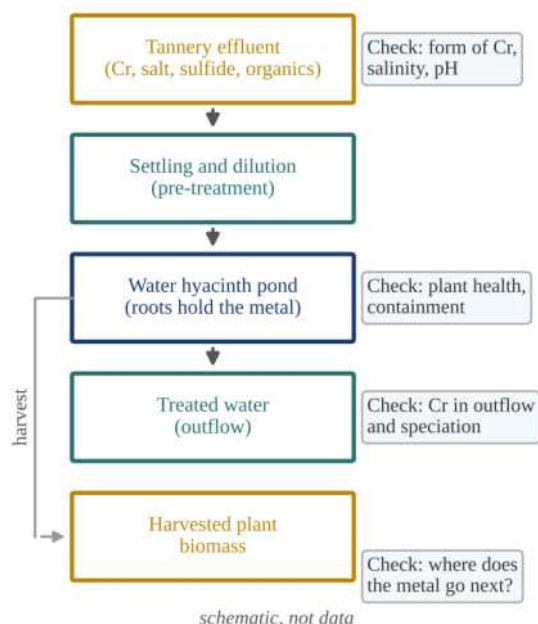


Figure 1. A water hyacinth treatment line for tannery effluent and the points that need checking (schematic, not data).

4.2 From Beaker to Tannery

Most uptake experiments use a clean solution of a single metal salt in tap or nutrient water, run for days or weeks in small containers. A tannery drain is something else. It carries salt, sulfide, suspended solids and organic matter, together with a mixture of chromium forms that change as the water ages (1, 2). High salinity limits the plant (27), organic ligands change what is available to roots (2), and competing ions may reduce metal uptake. Table 3 sets typical experimental conditions against the real situation.

Design details matter as well. In treatment wetlands generally, the time water spends in contact with plants, the depth of the pond, the loading rate and the climate all influence what comes out of the far end (37). A floating-plant pond is no different. If the flow is too fast, roots have little time to act; if the pond is too shallow or too hot,

the plants suffer; and if the water evaporates, the salt left behind becomes more concentrated, which works against a plant that already dislikes salt (27). Few experimental reports describe these features in enough detail to be repeated.

Table 3. Gaps between typical experiments and a working tannery treatment line.

Typical experiment	Real effluent	Consequence
Clean synthetic solution (24, 41)	Salts, sulfide, organics, many metals (1, 27)	Uptake and toxicity differ
Days to a few weeks	Continuous flow for seasons	Long-term health unknown
Chromium as a single added salt	Mixed forms that change over time (2)	Speciation not matched
Bench containers	Ponds with sun, rain, algae, mosquitoes	Scale-up untested (37)
Removal from water reported	Fate of the metal needed	No mass balance (33)

Note: Qualitative comparison; the experimental features listed are those commonly described in the cited studies, not attributed to any single one.

Studies of other metals in real or mixed wastewater suggest that plants often perform differently from their beaker behaviour (12, 39). That is why the same plant can look excellent in one report and unremarkable in the next. We found no basis in the literature we reviewed for expecting that chromium would be an exception. Figure 2 shows the main questions that a study might address and how well the typical report covers them. Outdoor ponds add their own complications: sunshine and warmth help the plant but can also favour algae that compete for nutrients, rain dilutes the water for a day or two, and evaporation concentrates the salts afterwards. None of these is a reason to doubt the plant, but each is a reason to doubt a result obtained without them. A treatment that works only



in the greenhouse is a finding about greenhouses.

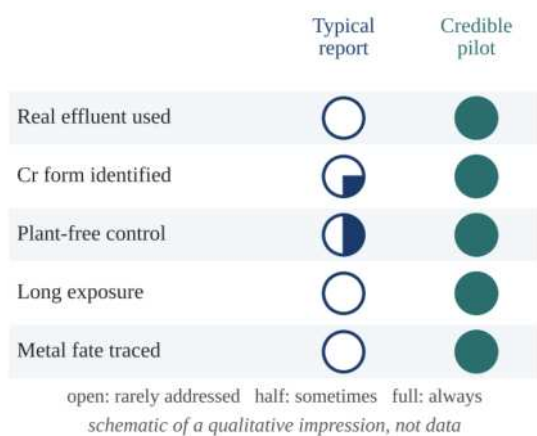


Figure 2. Qualitative matrix of what is addressed in typical studies (schematic, not data).

4.3 Where the Chromium Goes

Reporting that chromium has left the water is only half an answer. It may be bound to the roots, stored in tissue, precipitated and settled into sediment, or reduced to a less toxic form (15, 35). Each fate has a different consequence. Metal held in the plant must be harvested and handled; metal in the sediment accumulates in the pond; metal that is only sorbed can, in principle, be released again if conditions change (33). Removal from the water and removal from the problem are not the same thing.

The harvested plant is the heart of the matter. Water hyacinth is often suggested as a feedstock for biogas, ethanol or compost (42, 44), and biogas production from plants used to treat industrial effluent has been described (43). When the plant has been used to collect metal, however, those routes need care, because the digestate, ash or compost may then carry the metal on. Disposal is therefore not an afterthought but part of the design, and few studies follow the metal beyond the point of harvest. A cheap treatment that creates a second waste problem has only moved the cost.

Sediment deserves a mention too. Trivalent chromium tends to settle out as precipitates and bound complexes (2, 13), so a pond with a long residence time may remove much of the metal by simple settling whether or not plants are present. Without an unplanted control, that removal can be credited to the plant by mistake, and over many months the pond bed becomes a store of metal that will someday have to be dealt with.

4.4 Reading a Claim of Effectiveness

A reader meeting a claim that water hyacinth removes chromium from tannery effluent can ask a short sequence of questions. What was the water? Which chromium form was added or measured? Over how long, and what happened to the plants? Was a plant-free control run alongside, so that settling and adsorption to the container could be separated from plant effects? And where did the metal go? A report that answers all five is uncommon, and one that answers none should be read as an observation rather than as evidence of treatment capacity. This is a habit worth keeping even when the answer seems obvious.

Claims about cost need the same scrutiny. Plant-based treatment is often described as cheap, yet a working pond needs land, harvesting labour, pre-treatment for salinity, containment and a disposal route for the biomass. Whether the total compares well with conventional methods (5, 6) depends on all of these, and it is rarely costed in the experimental literature.

5. Discussion

5.1 Interpretation and Practical Reading

The main finding of this review is a conditional one. Water hyacinth can take chromium out of water, mostly into its roots, and there is good reason to expect it to do so for dilute, low-salinity, mainly



trivalent chromium solutions (23, 36, 41). There is much less reason to expect that it will cope unaided with raw tannery effluent. The most sensible role, on the present evidence, is as a polishing step after conventional treatment, or as one stage in a sequence that includes dilution or settling (38, 40). It is a modest claim, and it is the one the literature will currently bear.

The weight of the evidence also depends on what question is asked. If the question is whether the plant can accumulate chromium, the answer is a fairly confident yes. If it is whether a pond of it can bring a real tannery discharge within acceptable limits, the answer is that nobody has shown it convincingly in the work we reviewed. The distance between those two questions is where most of the uncertainty lives.

That view does not make the plant uninteresting. A floating mat adds shade and a large surface for microbes, and it is a visible, low-technology addition that a small operator can maintain. Those benefits are real but belong to a pilot to be demonstrated, not an outcome to be assumed. Figure 3 sketches the ladder from bench to working line, and most published work sits on its lowest rungs.

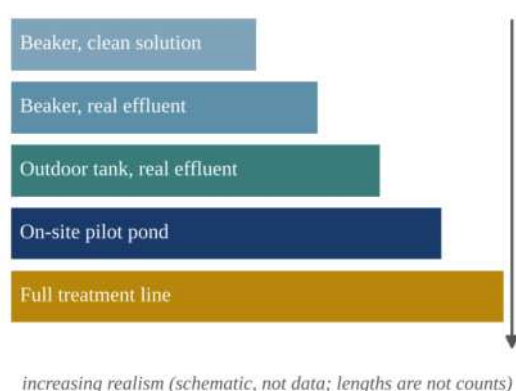


Figure 3. The scale-up ladder from bench to working treatment line (schematic, not data).

5.2 Limitations

This review has limits that readers should keep in mind. It is narrative, not systematic, so the selection of sources rests on our judgement and a different team might have chosen differently. We could not check every primary paper at the level of its raw data, and for that reason we have not quoted effect sizes or removal percentages from individual studies. Much of the mechanistic evidence comes from other metals or other plants, and non-chromium studies have been used to frame hypotheses, not to settle them. And because the review is general, it says nothing about any specific tannery, region or treatment plant. Reviews of this kind are more useful when they say where the evidence stops than when they smooth it over.

5.3 Directions for Future Work

Three needs stand out. First, pilot-scale studies on real, characterised effluent, with chromium speciation measured at inlet and outlet and with plant-free controls. Second, full mass balances that follow the metal into roots, shoots, sediment and harvested biomass, together with long runs that show whether the plants stay healthy. Third, work on the safe use or disposal of metal-laden biomass, and on containment so that the plant does not become a problem of its own (11, 25). Nothing here argues against trying the plant; it argues for measuring what happens when it is tried.

A credible pilot would also record the unglamorous details: salinity and pH, how the effluent was diluted or pre-treated, how often the mat was harvested, and what it cost in labour. Standardised reporting along these lines would let different studies be compared, which is at present almost impossible. These points apply to almost any biological treatment proposed for industrial water, not to water hyacinth



alone.

6. Conclusion

Water hyacinth is a plausible, low-technology component of chromium treatment, with a clear mechanism by which roots hold the metal. The evidence, as we can responsibly summarise it, does not yet show that it can treat raw tannery effluent, and it says little about the long-term fate of the chromium it collects. What the literature does show is where the proposal is strongest, which is dilute, mainly trivalent chromium in low-salinity water, and where it is weakest, which is salty, organic-rich effluent and biomass disposal. Between those poles lies most of the practical interest, and most of the missing evidence.

For the practitioner the message is practical rather than discouraging. The plant can be tried, provided the effluent is pre-treated, the pond is contained, the chromium is traced and the harvested biomass has somewhere safe to go. For the researcher, the opportunity is a set of pilots that are long enough, realistic enough and fully accounted to turn a plausible idea into a measured result. A shared reporting template, covering the water, the chromium form, the duration and the fate of the metal, would make results from different groups comparable for the first time, and it costs nothing to adopt. Patient, well-documented pilots will serve the field better than another round of short beaker tests.

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9. Conflict of Interest

The authors declare no conflict of interest.

10. Author Contributions

A.L. conceived the review and wrote the sections on chromium chemistry and tannery effluent. W.C. wrote the sections on plant biology and the experimental literature. N.Z. wrote the sections on treatment systems and future work. All authors revised the manuscript and approved the final version.

11. Ethics Statement

This is a review of published literature. No human participants or animals were involved and no ethical approval was required.

12. Data Availability

No new data were generated. All sources are cited in the reference list.

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