

Original Research

Received 23 May 2026

Revised 18 July 2026

Accepted 01 Aug 2026

Natural Resources for Human Health 2026, Vol. 6 (13s): 954–965

KEYWORDS:

Plant poisons, forensic toxicology, toxicokinetics, biomarkers, LC-MS/MS, high-resolution mass spectrometry, medico-legal interpretation, phytotoxins, sustainable justice, analytical toxicology.

Plant-Derived Poisons in Forensic Toxicology: Toxicokinetic, Biomarkers, Analytical Detection, and Medicolegal Interpretation for Sustainable Justice

Bishant Solath^{1*}, Pratishttha Singh², Abhay Agarwal³, Kajal Sharma⁴, Thakur Shruti Singh⁵, Sinduja Gupta⁶, Roopal Sharma⁷, Ayushi Sharma⁸, Harman poonia⁹, Gurvir Singh¹⁰

¹Department of Forensic Science, Institute of Allied Health Sciences (UIAHS), Chandigarh University, Chandigarh, India.

Email- bishantchaudhary1999@gmail.com

²Emergency Department, AIIMS Jai Prakash Narayan Apex Trauma Center, Delhi, India.

Email- pratishttha799@gmail.com

³Assistant Professor, Faculty of Basic, Life and Applied Sciences, Apex University, Jaipur, Rajasthan, India

Email - abhayagarwal116@gmail.com

⁴Assistant Professor, Department of Forensic Science, University Institute of Allied Health Sciences (UIAHS), Chandigarh University, Chandigarh, India.

Email- sharmakajal03271@gmail.com

⁵Assistant Professor, Department of Forensic Science, Assam Downtown University, Guwahati, Assam, India.

Email- tssingh044@gmail.com

⁶Assistant Professor, Department of Forensic Science, RIMT University, Mandi Gobindgarh, Punjab, India.

Email- sindujagupta29@gmail.com

⁷Assistant Professor, Department of Forensic Science, RIMT University, Mandi Gobindgarh, Punjab, India.

Email- roopalsharma1306@gmail.com

⁸Assistant Professor, Institute of Applied Science, Department of Forensic Science, Mangalayatan University, Aligarh, Uttar Pradesh, India.

Email- ayushi.sharma@mangalayatan.edu.in

⁹Assistant Professor, Department of Forensic Science, RIMT University, Mandi Gobindgarh, Punjab, India.

Email- manpoonia8764@gmail.com

¹⁰Student, Department of pharmacy, Swami Vivekanand College of Pharmacy, Banur, India.

Email- singhgurvur775@gmail.com

*Corresponding Author:

Bishant Solath (bishantchaudhary1999@gmail.com)

ABSTRACT: Toxic plants continue to be significant in forensic toxicology because they are both readily available and toxic plants and are diverse in their chemical makeup and potential to cause clinical and pathological effects that can be very non-specific. Some

phytochemicals can cause cardiovascular, neurological, gastrointestinal, hepatic or multisystem toxicity, which can be lethal. Some of the phytochemicals can result in cardiovascular, neurological, gastrointestinal, hepatic or multisystem toxicity, which can be fatal. The integration of botanical evidence, toxicokinetic data, biomarkers, biological matrices, analytical confirmation, autopsy findings, and circumstances of death are required to make the forensic interpretation of these cases. The current review is a synthesis of plant-poison toxicology and a focus on those poisons that are known to be specific to plants: aconitine, oleandrin, taxines, colchicine, atropine/scopolamine, strychnine, ricin, abrin, and pyrrolizidine alkaloids. Targeted screening can still be done by the traditional chromatographic methods, while sensitive and selective confirmations are becoming common with liquid chromatography-tandem mass spectrometry (LC-MS/MS) and high-resolution mass spectrometry (HRMS). The presence of biomarkers like ricinine, 3,5-dimethoxyphenol, oleandrin and characteristic alkaloid profiles may assist in toxicological attribution, but these considerations should be taken into account when interpreting the results: absorption, metabolism, matrix distribution and degradation, and post mortem redistribution. The review also discusses medico-legal interpretation, chain of custody, analytical uncertainty and the fact that it is important to distinguish between exposure and toxicologically significant contribution to death. A sustainable-justice perspective is added by taking a resource-efficient approach to screening, in responsibility to preserve evidence, by using standardized analytical workflows, or by providing access to advanced instrumentation in an equitable manner, and by practicing responsible laboratory practices for the environment. The review highlights several areas of current quantitative toxicokinetics, validated biomarkers, reference materials, interlaboratory harmonization, and interpretation of low-level findings, which remain problematic. Investigating plant poisoning, particularly with plants that are popular in the kitchen, requires analytical accuracy and sustainable working practices that are accessible, resource efficient and harmonised and can be carried out in various laboratory environments.

I. INTRODUCTION

Plant-derived poisons have a unique place in forensic toxicology since the origin can be a common ornamental, medicinal, agricultural or natural plant that is not normally regulated. Human poisoning can occur after accidental ingestion, when these plants are mistaken for food to be eaten, after exposure to traditional medicine, by intent to self-poison or by deliberate administration to another person. Alkaloids, cardiac glycosides, toxalbumins, taxines and other biologically active compounds have been reported as present in some of the plants mentioned in the historical and contemporary forensic literature. A wide survey of fatal plant poisoning revealed many of the toxic plants, and confirmed the multianalyte, chromatographic detection of plant toxins in biological samples [1]. Modern forensic investigations still stress the fact that there are many non-specific clinical symptoms and signs, and autopsy findings that can be explained by plant toxins.

Chemical diversity makes for a more toxicological challenge. Aconitine causes an acute cardiovascular and neurological toxicity while oleandrin and cerberin have a more prominent effect on the electrophysiology of the cardiovascular system. Tropane alkaloids found in *Datura* cause anticholinergic effects, and *Taxus* has taxines that have potentially lethal cardiac effects. Protein toxins such as ricin and abrin have much different requirements for analysis than do small-molecule alkaloids.

The identification of analytes, on the other hand, is not enough for forensic identification. Complementary evidence may be provided by botanical material, gastrointestinal contents, blood, urine, bile and others. The selection and interpretation of the post mortem specimens should take into account the degradation, redistribution and matrix effect and the fact that the concentration detected is not necessarily the concentration existing at the time of death [2], [3].

The analytical technology has evolved from TLC and traditional immunoassays to LC-MS/MS, high resolution mass spectrometry (HRMS), targeted multianalyte screening and proteomic technologies. A validated UHPLC-MS/MS method has been used to identify many naturally occurring toxic compounds in blood simultaneously, providing a good example of the

potential of broad forensic screening of blood [4]. More modern HRMS workflow is able to generate accurate mass and fragmentation data for targeted and untargeted toxicological investigations.

Thus, this review addresses to the forensic aspect of plant-derived poisons, linking toxicokinetics, biomarkers, analytical detection, sample selection, medico-legal interpretation with sustainable justice. **For the purposes of this review, sustainable justice in forensic toxicology will be viewed as the ability to obtain accurate, reproducible, and defensible analytical results in ways that are environmentally responsible, uses resources efficiently, and is accessible to all laboratories – regardless of geographic or economic limitations.**

II. REVIEW METHODOLOGY AND SCOPE

A **structured review technique** known as **SANRA (Scale for the Assessment of Narrative Review Articles)** was used to make the review process transparent and to incorporate the evidence pertinent to the field of forensic plant-poison investigation. Literature from PubMed-indexed publications, forensic-science journals, toxicology journals, analytical-chemistry literature, and recent, peer-reviewed reviews were reviewed. Publications regarding human poisoning, postmortem toxicology, toxicokinetics, biomarkers, analytical validation, mass spectrometric detection and medico-legal interpretation were chosen.

The review will highlight nine representative toxin groups that include the aconitines, cardiac glycosides of Nerium and related plants, taxines of Taxus, tropane alkaloids of Datura, colchicine, strychnine, ricin, abrin and pyrrolizidine alkaloids. These groups were chosen as being of diverse chemical structure, to represent plant poisons and because they pose varying analytical and interpretative problems.

There is much variation in the evidence base. Certain toxins have established analytical biomarkers and LC-MS/MS methods while others are challenging due to instability, low levels, complex matrices, and/or lack of certified reference materials. Forensic literature has recently grown to provide increased knowledge of aconitine fatalities, detection of abrin, analysis of oleandrin, ricinine as an exposure marker and screening for multiple analytes in plants [5]–[10].

The review highlights the four interrelated forensic questions: What is the toxic constituent? How does it toxicokinetically behave? What is the biomarker or analytical target for the result of exposure? How is the result of exposure to be medically and legally interpreted? They are all important to make because the mere fact that something can be detected analytically does not imply that it caused the death. The results of the toxicology analysis need to be incorporated with the scene findings, clinical history, autopsy observations, specimen quality, analytical limitations and other possible explanations for the findings [11], [12].

The main gap in the research is the lack of a standardized approach to link the plant identification, toxin-specific biomarkers, toxicokinetic, analytical confirmation and medico-legal interpretation. Another key component of sustainable justice is analytical approaches that are efficient but also cost-effective, repeatable, transferable from lab to lab and reduce waste of samples.

III. CLASSIFICATION AND TOXICOKINETICS OF PLANT-DERIVED POISONS

A. Phytochemical Classification

There are two main methods by which plant poisons can be classified: on the basis of chemical structure and on the basis of their toxicological mechanism. Examples of alkaloids are aconitine, strychnine, atropine, scopolamine and colchicine. The glycosides found in a cardio-tonics are oleandrin, neriifolin, thevetin and cerberin. Ricin and Abrin are examples of protein toxins. Taxines are complex diterpenoid alkaloids found in the species of Taxus. Another important group of compounds are pyrrolizidine alkaloids which can be metabolically activated to cause hepatotoxic and genotoxic effects [13], [14].

TABLE I: REPRESENTATIVE PLANT-DERIVED POISONS

Plant/source	Principal toxin	Chemical class	Major toxic effect	Representative forensic target
Aconitum spp.	Aconitine	Diterpenoid alkaloid	Cardiotoxic/neurotoxic	Aconitine, mesaconitine
Nerium oleander	Oleandrin	Cardiac glycoside	Cardiotoxic	Oleandrin

Thevetia peruviana	Thevetin/neriifolin	Cardiac glycoside	Cardiotoxic	Thevetin, neriifolin
Cerbera odollam	Cerberin	Cardiac glycoside	Cardiotoxic	Cerberin
Taxus baccata	Taxines	Diterpenoid alkaloids	Cardiotoxic	Taxine B, 3,5-DMP
Datura spp.	Atropine/scopolamine	Tropane alkaloids	Anticholinergic	Atropine, scopolamine
Strychnos nux-vomica	Strychnine	Indole alkaloid	Neurotoxic	Strychnine
Ricinus communis	Ricin	Protein toxin	Ribosomal inhibition	Ricin/ricinine
Abrus precatorius	Abrin	Protein toxin	Ribosomal inhibition	Abrin peptides
Pyrrolizidine-containing plants	PAs	Alkaloids	Hepatotoxic/genotoxic	Parent PAs/metabolites

Table 1. The toxins of plants are chemically diverse and therefore need to be analyzed in a toxin specific manner. Molecular structure is directly related to the diversity of absorption, metabolism, matrix distribution, stability and detection.

B. Aconitine Toxicokinetics

Aconitine and other Aconitum alkaloids are potent, fast-acting, voltage-gated sodium channel persistent activators which prolong the depolarisation and cause the channel to become more excitable. They are responsible for toxicities such as paresthesias, gastrointestinal symptoms, hypotension, and disturbances of the nervous system and/or cardiovascular system (ventricular arrhythmias). Extensive distribution and complex metabolic activity have been reported, but the relationship of the administered dose, circulating concentration and fatal outcome has yet to be fully delineated [15], [16].

The toxic principles of aconite have been identified in peripheral blood, cardiac blood, urine, liver, kidney, bile, stomach contents, and vitreous humor, by forensic studies. A possible advantage of using LC-MS/MS is that concentrations can be low, and the compound may undergo decomposition which can make the interpretation difficult [17]–[19]. A recent study of 25 cases of aconitine-related deaths provides further proof that LC-MS/MS analysis can be a valuable tool in the analysis of postmortem samples.

C. Cardiac Glycosides

Cardenolides (and sometimes bufadienolides) which inhibit Na^+/K^+ -ATPase are found in oleander, yellow oleander and Cerbera species. The toxicological effects include gastrointestinal effects, hyperkalemia, conduction abnormalities, dysrhythmia and cardiovascular collapse [20], [21].

When using LC-MS/MS with the appropriate extraction and storage procedures, oleandrin is sufficiently stable. Blood, urine, liver, bile, stomach contents and tissues are all sources in which it can be detected [22], [23]. The present reviews stress the importance of immunoassays of digoxin in screening due to the crossreactivity although chromatographic mass spectrometry would give more specific evidence.

There's a related, but different, challenge with Cerberin. However, Cerbera odollam poisoning is of special consideration in South Asia where intentional poisoning using the seed has been reported for a long time in Kerala [24]. The development of LC-MS/MS detection for cardiac-glycoside species-specific confirmation, such as for cerberin, neriifolin and tanghinin in human serum, has been recently developed.

D. Taxines and Colchicine

A feeling of uneasiness, drowsiness, and lethargy may be the only signs of taxus poisoning if the plant material can't be identified. Taxine B and related alkaloids have significant cardiac toxicity and **3,5-dimethoxyphenol is a degradation**

product/aglycone marker of Taxines that can be used as an analytical marker of *Taxus* exposure [25], [26]. Post mortem investigations have proved that evidence from plants combined with LC-MS/MS or GC-MS analysis is also very important.

Toxicity from *Colchicum* poisonings may occur after ingestion of *Colchicum autumnale*, which may be due to the plant being confused with an edible species. Clinical deterioration is delayed and gastrointestinal injury and multiorgan toxicity make interpretation difficult. There has been forensic and pathological correlation for the fatal cases reported [27] and [28].

TABLE II: Toxicokinetic And Forensic Characteristics

Toxin	Primary target	Important matrix	Useful biomarker	Major interpretive issue
Aconitine	Voltage-gated Na^+ channels	Blood, urine, liver	Aconitine/related alkaloids	Low concentration
Oleandrin	Na^+/K^+ -ATPase	Blood, liver, urine	Oleandrin	Redistribution/cross-reactivity
Taxines	Cardiac ion channels	Blood, urine, stomach	Taxine B, 3,5-DMP	Plant absence
Atropine/scopolamine	Muscarinic receptors	Blood, urine, stomach	Parent alkaloids	Rapid kinetics
Strychnine	Glycine receptors	Blood, urine, tissues	Strychnine	Distribution
Ricin	Ribosome	Blood, urine, tissues	Ricin/ricinine	Protein detection
Abrin	Ribosome	Blood/tissues	Abrin/peptides	Limited validated assays
Colchicine	Microtubules	Blood, urine, tissues	Colchicine	Delayed toxicity
PAs	Hepatic metabolism	Blood/urine	Parent/metabolites	Metabolic activation

Table 2. There is a wide variation in toxicokinetic behavior of plant toxins and sample selection and biomarker selection must be based on the chemical and biological characteristics of the suspected poison.

IV. BIOMARKERS AND ANALYTICAL DETECTION

A. Conventional Analytical Methods

Botanical inspection, microscopy, thin-layer chromatography, color reactions, immunoassays and traditional HPLC have been the methods traditionally used to investigate plant poisons. These techniques are still applicable in the initial investigation, especially when sophisticated instruments are not available. However, many plant toxins are present at low levels or are associated with similar toxins in the same plant making them less specific [29].

Multianalyte UHPLC-MS/MS has greatly enhanced screening ability. A few methods have been validated that measure dozens of toxic principles of plant origin in blood, such as aconitine, atropine, colchicine, oleandrin, ricinine, scopolamine, strychnine, and some cardiac glycosides [4].

B. LC-MS/MS and HRMS

LC-MS/MS is especially well suited for the analysis of nonvolatile, thermally labile and structurally complex plant toxins. High sensitivity and selectivity is achieved by multiple-reaction monitoring. This method has been used on aconitine, oleandrin [22] and *Datura* alkaloids [29] as well as for the yew toxins.

HRMS can further this capability by giving us accurate-mass data, isotopic patterns and retrospective data analysis. These properties are useful if a toxic substance is suspected and not represented in the reference suite and/or the range of known reference properties is limited. But there are requirements for the HRMS workflow – first, there must be validated identification criteria, then there must be suitable spectral libraries, and assessment of measurement uncertainty, and a significant amount of computational resources.

TABLE III: Analytical Methods for Plant Poisons

Method	Main application	Strength	Limitation
TLC	Preliminary screening	Low cost	Low sensitivity
HPLC-UV/DAD	Targeted analysis	Accessible	Limited structural specificity
GC-MS	Volatile/derivatized compounds	Established libraries	Derivatization may be required
LC-MS/MS	Targeted confirmation	High sensitivity/selectivity	Reference standards required
UHPLC-MS/MS	Multianalyte screening	High throughput	Matrix effects
HRMS	Broad/untargeted screening	Accurate mass	Cost and data complexity
Immunoassay	Rapid screening	Simple and fast	Cross-reactivity
Proteomic MS	Protein toxins	High specificity	Complex sample preparation
DNA barcoding	Botanical identification	Species information	Does not prove absorbed toxin

Table 3. There is no analytical platform that can be used for all investigations of plant poisons. A tiered approach of screening, confirmatory chemistry, and botanical evidence enhances the supportive value of the evidence.

C. Ricin and Abrin Biomarkers

Analytical methods are required to be different for protein toxins. The ricin is found in the *Ricinus communis* and ricinine is an alkaloid that can be used as useful exposure biomarker. LC-MS/MS is used for the measurement of ricinine in urine, but background levels due to consumer **products containing ricin (castor beans) should be taken into account. Ricinine is not itself toxic, but is a stable marker of the presence of ricin in castor bean material excreted by the kidney.**

Peptide detection by LC-MS/MS, MALDI-MS, immunological methods and functional assays are all methods available for direct ricin confirmation. The use of proteomic can distinguish ricin and related proteins of castor by identification of the peptides specific to the ricin.

Abrin has similar difficulties. An *Abrus precatorius* protein that inactivates its ribosome. There is a lack of universal standardisation of biological-sample detection methods and immunological and mass-spectrometric methods remain significant [6].

D. Tropane Alkaloids

The main targets forensically in *Datura* poisoning are atropine, scopolamine and hyoscyamine. **LC-MS/MS is now the standard method** for the detection of tropane alkaloids as it is more sensitive and selective, however, HPLC-MS and GC-MS have also been used to demonstrate detection of tropane alkaloids in stomach contents, blood, urine and plant material [29]. The combined chemical analysis and botanical identification, as is evident from the case investigations, is extremely useful in *datura*. DNA barcoding can be used as an additional tool to LC-MS/MS in cases of degraded and/or ambiguous plant morphology.

E. Biomarker Selection

Ideally, a forensic biomarker should be analytically specific, be relevant to the temporal exposure, have a sufficient stability and should have a defensible association to the exposure. In the case of parent toxins, if they are sufficiently stable and measurable,

they are often used. Under certain conditions metabolites could be useful because the parent compound has a short half-life. When the toxin is not easily measured, source-specific markers can also be used to help determine the presence of the toxin.



Fig. 1. Integrated analytical pathway for plant-poison investigation.

The pathway in Fig. 1 starts with a scene and plant evidence, moves on to the selection of specimens, preliminary screening, instrumental analysis (specific or general), confirmation of the biomarkers and integrated medico-legal interpretation. **Pathway is iterative – evidence found at any point in the pathway may lead to revisiting previous evidence.**

V. FORENSIC SPECIMEN SELECTION AND MEDICO-LEGAL INTERPRETATION

A. Specimen Selection

However, quantitative interpretation of postmortems is usually performed in peripheral blood which is less subjected to redistribution than central blood. Urine may be useful for detecting previous exposures, but has little value for detecting toxic levels at the time of death. The relative protection from its breakdown of the vitreous humor may create an additional matrix and it may be less affected by the redistribution that occurs after death. When ingestion of a plant poison is suspected, liver, bile, stomach contents and tissue samples may be especially helpful.

While the principles of specimen selection are generally followed in forensic toxicology, some additional aspects have to be taken into account when dealing with plant toxins. Botanic matter may be detected in the stomach contents, while only small amounts of the active toxin can be found in blood and urine. On the other hand, there are plant toxins that may decompose quickly and it is hard to interpret the negative results.

B. Postmortem Redistribution and Stability

Concentrations are difficult to interpret due to postmortem redistribution. The concentration of a compound in a tissue or in the blood may change following death due to transfer between tissues and blood. Analytical results may also be influenced by various factors such as temperature, decomposition, specimen storage, specimen site and chemical stability.

For instance, **benzoylaconine and aconine** can be produced by hydrolysis of aconitine during improper storage conditions which emphasizes the need for validated storage conditions and **for immediate and proper freezing of samples**. It may therefore be necessary to measure the concentration in peripheral blood, urine, bile, liver, stomach contents and vitreous humor together and not individually.

C. Toxicological Interpretation

If a plant toxin is detected, this does not necessarily mean that the plant toxin is responsible for the death. Interpretation should consider:

- confirmation; and
- concentration and distribution;
- known toxicological effects;
- timing of exposure;
- specimen quality;
- postmortem redistribution;
- decomposition;
- exposure to both drugs and poisons;
- autopsy findings;
- botanical evidence; and
- circumstances surrounding death.

In modern forensic toxicology, the importance of combining results from the laboratory with the information from the scene, investigations into the subject's medical history, pathological evaluation, and the limitations of specimens became evident.

TABLE IV: Medico-Legal Evidence Framework

Evidence domain	Key question	Forensic contribution
Scene evidence	Is a toxic plant present?	Exposure hypothesis
Botanical evidence	What species is involved?	Source identification
Gastric contents	Is plant material present?	Ingestion evidence
Blood	Is toxin systemically present?	Exposure confirmation
Urine	Is toxin/metabolite excreted?	Exposure support
Vitreous humor	Is toxin present in protected matrix?	Complementary evidence
Tissue	Is toxin distributed to organs?	Toxicokinetic support
Autopsy	Are compatible findings present?	Pathological correlation
Analytical validation	Is the result reliable?	Evidentiary strength
Circumstances	Does exposure fit the case history?	Causal interpretation

Table 4. The medico-legal interpretation must be done by combining different kinds of evidence, not solely concentrating on any one analytical aspect.

D. Chain of Custody and Quality Assurance

Investigations involving plant-poisoning are especially susceptible to contamination and/or loss of context as the botanical material may be removed from the laboratory. As basic as it sounds, it is vital that these be properly labelled and sealed, and that transfers are properly documented, that analytical procedures are properly validated, that reference standards are used, that records are kept, and that quality-control samples are included. Within the international forensic setting, accreditation of the laboratory, chain of custody, method validation and measurement uncertainty are key.

The analytical method should be reported, as well as the type of specimen, what it can be detected in, the analytical confirmation method, the confirmation criteria and the limitations. When quantitative interpretation is not scientifically sound, then conclusions should not be translated into quantitative, unsupported statements.



Fig. 2. Medico-legal interpretation framework for plant-derived poisoning.

The framework of this figure (2), brings together: Scene evidence, botanical identification, analytical toxicology, Pathology, Toxicokinetics, and contextual information leading to a cause-of-death interpretation. **Convergence of independent, but mutually concordant evidence lines increases causal inference**

VI. SUSTAINABLE JUSTICE AND FUTURE FORENSIC PRACTICE

Sustainable justice goes beyond analytical accuracy to reaching people and using resources efficiently, and being environmentally responsible and treating the scientific systems fairly. **Sustainable justice in forensic toxicology is achieved here by obtaining accurate, reproducible and defensible analytical results, while using environmentally responsible, resource efficient, and equitable methods and practices in all laboratories without regard for geographical or economic considerations.** The advanced LC-MS/MS and HRMS are expensive and specialized analytical techniques with high analytical capability. Practical forensic system should therefore employ a graduated approach with inexpensive screening first, followed by a confirmatory test of the selected samples.

A. Resource-Efficient Analytical Workflow

Investing in a sustainable workflow can help to reduce unnecessary sample usage, such as by focusing on evidence-rich samples and employing multiplex techniques. Multiple toxins from plants can be targeted at once with multianalyte LC-MS/MS, rather than having to conduct individual assays for each toxin. These can minimize the number of times the extraction needs to be repeated, the amount of solvents used, the time of the instruments used, and the amount of specimens used [4].



Fig. 3. Tiered analytical workflow for plant-poison investigation.

In the sustainable way shown in Fig 3, low-cost screening is conducted at Tier 1, and above that more advanced confirmatory testing is done when necessary – saving resources and sample – and avoiding the unnecessary, high cost testing of Tier 2.

B. Responsible Laboratory Practice

The principles of green analytical chemistry can be integrated by using miniaturised extraction, reduced volume of solvent used, shorter chromatographic runs, reusable consumables (where appropriate) and digital documentation instead of paper documentation. These measures should not affect the sensitivity, specificity or chain-of-custody requirements.

C. Equitable Access

Reliable toxicological testing, beyond highly specialized laboratories is also essential for sustainable forensic justice. There may be limited HRMS, certified reference materials, and special expertise available in the regional forensic laboratories. To limit geographical disparities, the use of standardized LC-MS/MS panels, validated reference library, common quality control materials, and interlaboratory proficiency testing are useful.

TABLE V: Sustainability Dimensions

Dimension	Current challenge	Sustainable direction
Analytical	High instrument cost	Tiered screening
Sample use	Large specimen requirements	Miniaturized extraction
Solvents	High organic-solvent consumption	Reduced-volume methods
Expertise	Specialist dependence	Standardized workflows
Data	Fragmented reporting	Digital evidence systems
Access	Unequal instrumentation	Regional reference networks
Quality	Method variability	Harmonized validation
Justice	Unequal analytical capability	Accessible confirmatory testing

Table 5. There is a need to simultaneously consider the reliability of the results of toxicology analyses, laboratory resources, environmental impacts, standardization and equitable access to expert toxicology evidence in order to achieve sustainable forensic toxicology.

D. Future Analytical Direction

It is likely that future investigations of plants as a source of poisons will include combination of targeted LC-MS/MS, HRMS-based retrospective screening, molecular plant-based identification, proteomics, metabolomics and machine-assisted spectral interpretation. These systems would enhance the identification of less common plant toxins, and decrease the reliance on preselected lists of analytes. Computational prediction should, however, not be a substitute for conclusions based on evidence but should be an evidentiary support. The importance of confirmatory analytical criteria, validated reference materials, measurement uncertainty and expert interpretation have not been compromised.

VII. RESEARCH GAPS AND FUTURE SCOPE

There are some key areas of research that are still unmet. Toxins that are specific to a particular plant, that is, pesticides, are only available for a few, and even in humans, and especially postmortem, are limited by toxicokinetic data sets. Second, there are validated biomarkers for some toxins and are sparsely developed for others. Third, all of the uncommon phytotoxins do not always have reference materials and certified standards. Fourthly, direct comparison between laboratories is possible to be prevented by matrix effects and post mortem degradation. **Fifth, standardized reference intervals for most plant toxins are not available for post mortems. Most of the concentrations of plant toxins are from single case reports, and there is a lack of population pharmacokinetic data, which would be useful to help interpret the concentrations of these toxins. Another gap deals with the concentration to effect relationships. Published concentrations are available for**

many plant poisons, but do not easily permit the determination of universal fatal or nonfatal concentrations. This is particularly the case for cardiac glycosides, aconitine, taxines and protein toxins. Thus, it is important to consider the numerical concentrations in the broader evidentiary context, and not use it as a universal decision boundary. There is need for future studies to focus on the development of multicenter case databases, harmonised analytical protocols, isotope labelled internal standard, metabolite panels validated for use, interlaboratory proficiency testing, and reporting frameworks. More sensitive and comprehensive forensic investigation is possible with the recent developments in HRMS, multianalyte LC-MS/MS, detection of proteins in forensic analysis and other matrices.

VIII. CONCLUSION

Plant-derived poisons are an important forensic problem due to their chemical diversity, the variability of their toxicokinetics and the nonspecific pathological manifestations make a determination of cause of death difficult. Toxin-specific analytical and interpretative strategies are needed, such as with aconitine, oleandrin, taxines, tropane alkaloids, colchicine, strychnine, ricin, abrin, and pyrrolizidine alkaloids. Confirmatory toxicology has been significantly enhanced by the use of LC-MS/MS and HRMS and can be aided by the use of biomarkers like oleandrin, ricinine, 3,5-dimethoxyphenol and characteristic alkaloid profiles. However, botanical, pathological, toxicokinetic and circumstantial evidence must be combined with the analytical detection. A sustainable justice must include accurate and yet accessible, resource efficient, standardized, and environmentally-friendly forensic toxicology. The exercise of advanced analytical chemistry and harmonized interpretation frameworks together with equitable forensic infrastructure should be used in the future to achieve progress. In plant-poison deaths, the combination of botanical information, toxicological data, and contextual information continue to be the foundation for a defensible medicolegal conclusion.

REFERENCES

- [1] Barbosa-Filho, B., Soto-Blanco, B., & Melo, M. M. (2019). A review of cardiac glycosides: Structure, toxicokinetics, clinical signs, diagnosis and antineoplastic potential. *Toxicon*, 158, 63–68. <https://doi.org/10.1016/j.toxicon.2018.11.001>
- [2] Bandara, V., Weinstein, S. A., White, J., & Eddleston, M. (2010). A review of the natural history, toxinology, diagnosis and clinical management of *Nerium oleander* (common oleander) and *Thevetia peruviana* (yellow oleander) poisoning. *Toxicon*, 56(3), 273–281. <https://doi.org/10.1016/j.toxicon.2010.03.026>
- [3] Barnhart, F. E., Bonnell, H. J., & Rossum, K. M. (2001). Postmortem drug redistribution. *Forensic Science Review*, 13(2), 101–129.
- [4] Bévalot, F., Cartiser, N., Bottinelli, C., Fanton, L., & Guitton, J. (2016). Vitreous humor analysis for the detection of xenobiotics in forensic toxicology: A review. *Forensic Toxicology*, 34, 12–40. <https://doi.org/10.1007/s11419-015-0294-5>
- [5] Darby, S. M., Miller, M. L., & Allen, R. O. (2001). Forensic determination of ricin and the alkaloid marker ricinine from castor bean extracts. *Journal of Forensic Sciences*, 46(5), 1033–1042.d-nb+6
- [6] Dinis-Oliveira, M. A., Remião, F., & Carvalho, F. (2012). Principles and procedures in forensic toxicology. *Clinics in Laboratory Medicine*, 32(4), 493–507. <https://doi.org/10.1016/j.cl.2012.06.005>
- [7] Flanagan, R. J., & Connally, G. (2005). Interpretation of analytical toxicology results in life and at postmortem. *Toxicological Reviews*, 24(1), 51–62. <https://doi.org/10.2165/00139709-200524010-00004>
- [8] Gaillard, Y., et al. (2004). *Cerbera odollam*: A “suicide tree” and cause of death in the state of Kerala, India. *Journal of Ethnopharmacology*, 95(2–3), 259–265. <https://doi.org/10.1016/j.jep.2004.08.016>
- [9] Gao, Y., Fan, H., Nie, A., Yang, K., Xing, H., Gao, Z., Yang, L., Wang, Z., & Zhang, L. (2022). Aconitine: A review of its pharmacokinetics, pharmacology, toxicology and detoxification. *Journal of Ethnopharmacology*, 293, 115270. <https://doi.org/10.1016/j.jep.2022.115270>
- [10] Li, L., Zhang, L., Liao, T., Zhang, C., Chen, K., & Huang, Q. (2022). Advances on pharmacology and toxicology of aconitine. *Fundamental & Clinical Pharmacology*, 36(4), 601–611. <https://doi.org/10.1111/fcp.12761>
- [11] Li, N., et al. (2024). Mass spectrometric analysis strategies for pyrrolizidine alkaloids. *Food Chemistry*, 434, 137438. <https://doi.org/10.1016/j.foodchem.2023.137438>
- [12] McIntyre, J. W., et al. (2020). Research progress of aconitine toxicity and forensic analysis of aconitine poisoning. *Forensic Science International*, 315, 110421. <https://doi.org/10.1016/j.forsciint.2020.110421>

- [13] Musshoff, A. M., et al. (2013). Quantification of aconitine in post-mortem specimens by validated liquid chromatography–tandem mass spectrometry. *Journal of Analytical Toxicology*, 37(5), 289–295. <https://doi.org/10.1093/jat/bkt020>
- [14] Nie, A., et al. (2022). An insight into current advances on pharmacology, pharmacokinetics, toxicity and detoxification of aconitine. *Biomedicine & Pharmacotherapy*, 151, 113115. <https://doi.org/10.1016/j.biopha.2022.113115>
- [15] Niitsu, H., Fujita, Y., Fujita, S., Kumagai, R., Takamiya, M., Aoki, Y., & Dewa, K. (2013). Distribution of Aconitum alkaloids in autopsy cases of aconite poisoning. *Forensic Science International*, 227(1–3), 111–117. <https://doi.org/10.1016/j.forsciint.2012.10.021>
- [16] Pietsch, M. J., et al. (2017). Post-mortem findings in 22 fatal *Taxus baccata* intoxications and a possible solution to its detection. *Journal of Forensic and Legal Medicine*, 52, 56–61. <https://doi.org/10.1016/j.jflm.2017.08.016>
- [17] Pittman, C. T., et al. (2013). Analysis of a ricin biomarker, ricinine, in 989 individual human urine samples. *Journal of Analytical Toxicology*, 37(4), 237–240. <https://doi.org/10.1093/jat/bkt012>
- [18] Schieltz, D. M., et al. (2011). Analysis of active ricin and castor bean proteins in a ricin preparation, castor bean extract, and surface swabs from a public health investigation. *Forensic Science International*, 209(1–3), 70–79. <https://doi.org/10.1016/j.forsciint.2011.03.012>
- [19] Sharma, S., et al. (2023). Trends in the analysis of abrin poisoning for forensic purposes. *Journal of Forensic and Legal Medicine*, 98, 102564. <https://doi.org/10.1016/j.jflm.2023.102564>
- [20] Steenkamp, P. A., et al. (2004). Fatal *Datura* poisoning: Identification of atropine and scopolamine by high performance liquid chromatography/photodiode array/mass spectrometry. *Forensic Science International*, 145(1), 31–39. <https://doi.org/10.1016/j.forsciint.2004.04.077>
- [21] Sundov, Z., Ninčević, Ž., Definis-Gojanović, M., Glavina-Durdov, M., Jukić, I., Hulina, N., & Tonkić, A. (2005). Fatal colchicine poisoning by accidental ingestion of meadow saffron—Case report. *Forensic Science International*, 149(2–3), 253–256. <https://doi.org/10.1016/j.forsciint.2004.06.034>
- [22] Tracqui, A., Kintz, P., Branche, F., & Ludes, B. (1998). Confirmation of oleander poisoning by HPLC/MS. *International Journal of Legal Medicine*, 111(1), 32–34. <https://doi.org/10.1007/s004140050107>
- [23] Tracqui, M. L., et al. (2014). Screening approach by ultra-high performance liquid chromatography–tandem mass spectrometry for the blood quantification of thirty-four toxic principles of plant origin. *Journal of Chromatography B*, 976, 71–81. <https://doi.org/10.1016/j.jchromb.2014.10.028>
- [24] Zhai, J. X., Yan, H., Shen, M., Shen, B. H., & Liu, W. (2018). Determination of oleandrin in blood and liver samples by LC–MS/MS. *Fa Yi Xue Za Zhi*, 34(6), 585–589. <https://doi.org/10.12116/j.issn.1004-5619.2018.06.002>
- [25] M. R. Khanna, R. Sarkar, A. Saxena, S. Loganayagi, A. H. Dheidan and O. Muhsin, "The Impactful Analysis of ML Based Technology in Forecasting the Specific Disorders in a Community," 2024 4th International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE), Greater Noida, India, 2024, pp. 263-265, doi: 10.1109/ICACITE60783.2024.10616989.
- [26] Zheng, F., Zhang, J., Wang, B., & Yan, J. (2025). Forensic and toxicological insights into aconite poisoning: A retrospective analysis of clinical and postmortem findings. *Forensic Science International*, 371, 112478. <https://doi.org/10.1016/j.forsciint.2025.112478>
- [27] R. Sivapriyan, R. Sarkar, Y. P. K. Reddy, S. Loganayagi, D. S. Kareem and A. -H. Meassar, "The Framework for Training and Validation of Healthcare System using Accurate Classifier Model," 2024 4th International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE), Greater Noida, India, 2024, pp. 12-15, doi: 10.1109/ICACITE60783.2024.10616861.
- [28] Suryapratap Ray; Tejasvi Bhatia, "Digital Investigative Model in IoT: Forensic View," in *Digital Forensics and Internet of Things: Impact and Challenges*, Wiley, 2022, pp.59-71, doi: 10.1002/9781119769057.ch5.
- [29] J. R. C., H. Brahmini and S. Manimaran, "A Decentralized Framework for Verifying the Integrity of DNA and Toxicology Reports Using Blockchain," 2025 IEEE 4th International Conference on Technology, Engineering, Management for Societal impact using Marketing, Entrepreneurship and Talent (TEMSMET), New Delhi, India, 2025, pp. 1-6, doi: 10.1109/TEMSMET65536.2025.11467438.
- [30] X. Lin, K. Xu, C. Lin and W. Wu, "SynTrust-FL: Forensic-Aware Robust Federated Learning for Edge-Intelligent IoT," in *IEEE Internet of Things Journal*, doi: 10.1109/JIOT.2026.3732855