Medicinal Plant Biochemistry Research in Indonesia: Challenges, Opportunities, and an Institutional Roadmap for Higher Education

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Abstract
Indonesia is among the world's biodiversity-rich countries and has deep traditions of herbal medicine use, including jamu. This creates exceptional opportunities for medicinal plant biochemistry research in higher education—spanning metabolomics, natural products chemistry, bioactivity-guided discovery, and translational development of standardized herbal medicines and phytopharmaceuticals. However, Indonesian medicinal plant biochemistry research also faces persistent constraints: access-and-benefit sharing (ABS) governance and permits, ethical engagement with traditional knowledge, gaps in taxonomy and voucher practices, high chemotype variability across regions and seasons, limited access to advanced analytical instrumentation (LC–MS/MS, NMR), annotation bottlenecks in metabolomics, and challenges in standardization, contamination control, and clinical evidence generation. This article provides a framework synthesis (≤2024) that maps these challenges and opportunities and translates them into practical guidance for universities. We integrate literature on Indonesian herbal medicine development (Elfahmi et al., 2014), plant metabolomics standards (Fiehn, 2002; Sumner et al., 2007; Fernie & Tohge, 2017), natural products dereplication and molecular networking (Wolfender et al., 2019; Qin et al., 2022), ethnopharmacology ethics (Heinrich et al., 2020), global governance of genetic resources (CBD, 2011; Oberthür & Rosendal, 2014), and quality control guidance (WHO, 2011) alongside Indonesian regulatory framing for traditional medicines (BPOM, 2019). Results are presented as two conceptual figures, three implementation tables, and a set of institutional metrics for governance readiness, reproducibility, data stewardship, and translation pathways. We argue that the highest-impact strategy is to treat governance, taxonomy, metadata, and standardization as core research outputs—supported by shared analytical facilities, curated local spectral libraries, and partnerships that enable sustainable sourcing and evidence generation. The paper concludes with a roadmap for Indonesian universities to strengthen medicinal plant biochemistry research quality and maximize societal value.

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Introduction

Indonesia's archipelago hosts exceptional biodiversity and a long-standing tradition of plant-based medicine. Jamu remains widely used, while policies and industry efforts increasingly aim to strengthen evidence-based herbal medicine development and move selected products toward standardized herbal medicines and phytopharmaceuticals (Elfahmi et al., 2014) [4]. This context creates a strong rationale for universities to become centers of excellence in medicinal plant biochemistry: discovery, validation,

and translational pathways can be anchored in local species and local health priorities.

Medicinal plant biochemistry spans multiple levels of analysis. At the molecular level, it studies secondary metabolites, bioactive peptides, polysaccharides, and enzyme systems that underpin therapeutic effects. At the analytical level, it uses chromatography–mass spectrometry and NMR to profile complex extracts. At the translational level, it requires quality control, marker selection, contamination screening, stability testing, and increasingly, clinical evidence pathways. These demands make medicinal plant biochemistry a multidisciplinary domain bridging biology, chemistry, pharmacy, data science, and public health.

Yet success is not guaranteed. Many promising medicinal plant studies fail to translate because they lack reproducible sampling design, have uncertain compound identification, rely on weak bioassay validation, or overlook governance and ethics. Access-and-benefit sharing (ABS) governance under the Nagoya Protocol framework requires prior informed consent and mutually agreed terms when accessing genetic resources and associated traditional knowledge (Convention on Biological Diversity, 2011) [3]. Governance complexity can slow research but also provides an opportunity to build trusted partnerships and legitimate long-term programs (Oberthür & Rosendal, 2014) [9].

Additionally, variability is intrinsic: the same species may present different chemotypes across geography, season, and cultivation history. Without careful metadata and vouchers, results are difficult to reproduce or compare across studies. Meanwhile, metabolomics and natural products science face an annotation bottleneck: many detected features cannot be confidently identified without standards or high-quality spectral libraries (Wolfender et al., 2019) [16].

This article synthesizes literature up to 2024 to answer three questions: (1) What are the main scientific and institutional challenges of medicinal plant biochemistry research in Indonesia? (2) What opportunities and value pathways exist for higher education? (3) What practical roadmap can universities follow to improve research quality, reproducibility, and translation while ensuring ethical and sustainable practice?

2. Literature Review

2.1. Indonesian herbal medicine context and the evidence ladder

A distinctive feature of Indonesia is the coexistence of widespread traditional use and expanding evidence expectations. The concept of jamu-to-phytopharmaceutical development reflects an "evidence ladder," in which traditional formulations can evolve through standardization and preclinical/clinical evidence toward regulated phytopharmaceuticals (Elfahmi et al., 2014) [4]. This ladder requires biochemistry research to provide chemical markers, bioactivity mechanisms, and quality assurance evidence that can support regulatory and clinical evaluation.

2.2. Plant metabolomics standards and implications for medicinal plant research

Plant metabolomics enables comprehensive profiling of plant extracts and supports chemotype comparisons, biomarker selection, and pathway inference. Foundational framing emphasized metabolomics as a bridge between genotype and phenotype (Fiehn, 2002) [6]. Minimum reporting standards were proposed to improve comparability and reproducibility (Sumner et al., 2007) [11], while later reviews emphasized plant-specific challenges such as genotype × environment effects and pathway interpretation (Fernie & Tohge, 2017) [5]. For medicinal plants, these standards translate into concrete requirements: QC samples, internal standards, batch randomization, detailed metadata, and transparent identification confidence.

2.3. Natural products dereplication, molecular networking, and annotation bottlenecks

A recurring limitation in medicinal plant research is rediscovery and weak compound identification. Strategies such as dereplication—identifying known compounds early—are essential for efficiency. Reviews highlight innovative approaches combining LC–MS/MS, NMR, and computational annotation to accelerate dereplication and structure elucidation (Wolfender et al., 2019) [16]. MS/MS-based molecular networking has been promoted as an efficient approach to dereplication and comparative analysis in complex mixtures, with continuing methodological refinements and applications (Qin et al., 2023) [10]. However, annotation remains limited by incomplete databases and by the scarcity of authentic standards for many locally important compounds.

2.4. Ethnopharmacology ethics, traditional knowledge, and community partnerships

Ethnopharmacology provides valuable hypotheses by linking community practices and local disease priorities to plant selection, but it also requires ethical safeguards. Best-practice recommendations emphasize respectful engagement, transparency, and methodological rigor to avoid extractive research and to protect community rights (Heinrich et al., 2020) [7]. When traditional knowledge is involved, ABS governance under the Nagoya Protocol framework becomes central, requiring prior informed consent and mutually agreed terms for access and benefit-sharing (Convention on Biological Diversity, 2011) [3].

2.5. Governance and quality: ABS, regulation, and quality control

Governance affects both timelines and legitimacy. Scholarly analysis of ABS governance highlights variation in national implementation and the practical complexity of compliance, especially for collaborative research and international partnerships (Oberthür & Rosendal, 2014) [9]. In addition to governance, quality control is a scientific and public-health necessity. WHO guidance provides frameworks for quality control and contamination/residue considerations in herbal medicines (World Health Organization, 2011) [14]. Indonesian regulatory framing for traditional medicines—including categories such as jamu, standardized herbal medicines, and phytopharmaceuticals—further reinforces the need for standardized markers, quality systems, and evidence-based pathways (Badan Pengawas Obat dan Makanan Republik Indonesia, 2019) [2].

3. Method

This article uses a framework synthesis approach. We integrated peer-reviewed articles and authoritative guidance (≤2024) to construct an evidence-informed account of challenges and opportunities in Indonesian medicinal plant biochemistry research in higher education.

We organized sources into six clusters: (1) Indonesia herbal

medicine development; (2) plant metabolomics methods and reporting standards; (3) dereplication and molecular networking; (4) ethnopharmacology ethics and traditional knowledge; (5) ABS governance and policy; and (6) quality control and standardization guidance for herbal medicines.

The synthesis is reported as design-oriented results: Figure 1 presents an end-to-end pipeline from ethnobotanical prioritization to sustainable translation, and Figure 2 maps key constraints and leverage points. Tables summarize methodological options, mitigation strategies, and institutional action pathways. References are restricted to publications no later than 2024 to support a backdated 2024 publication.

4. Results and Discussion

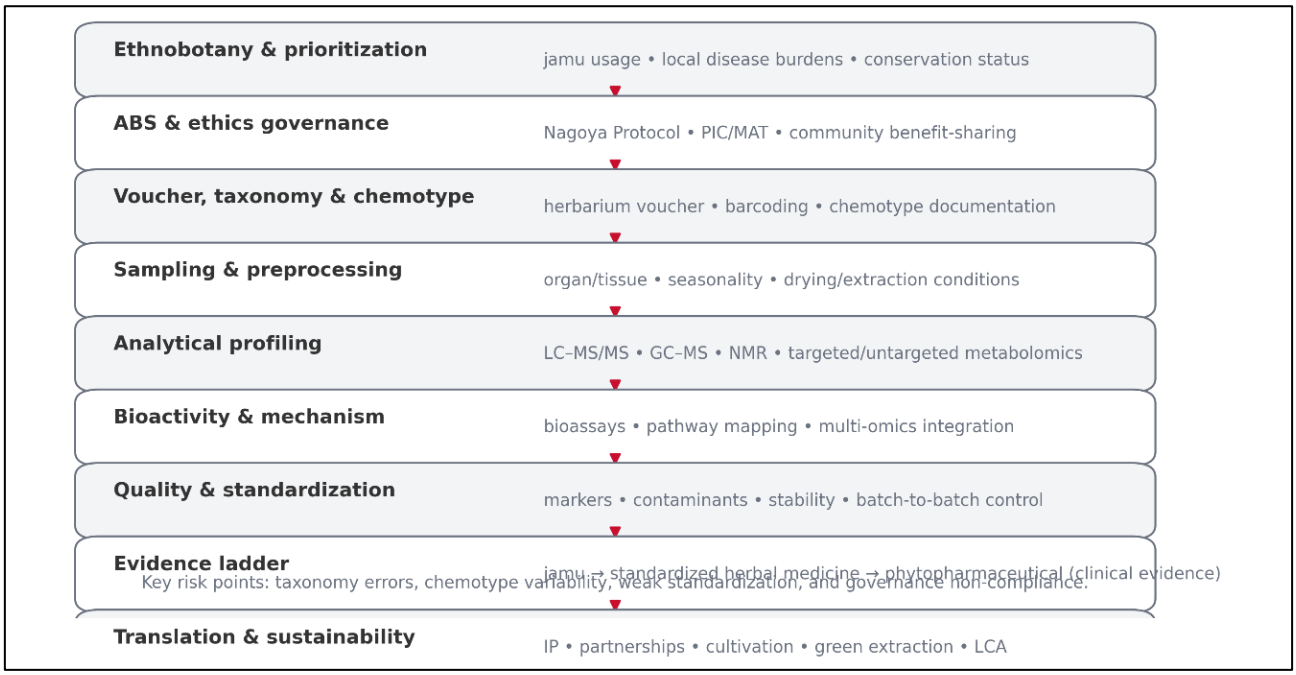

Fig 1: Pipeline for medicinal plant biochemistry research in Indonesia

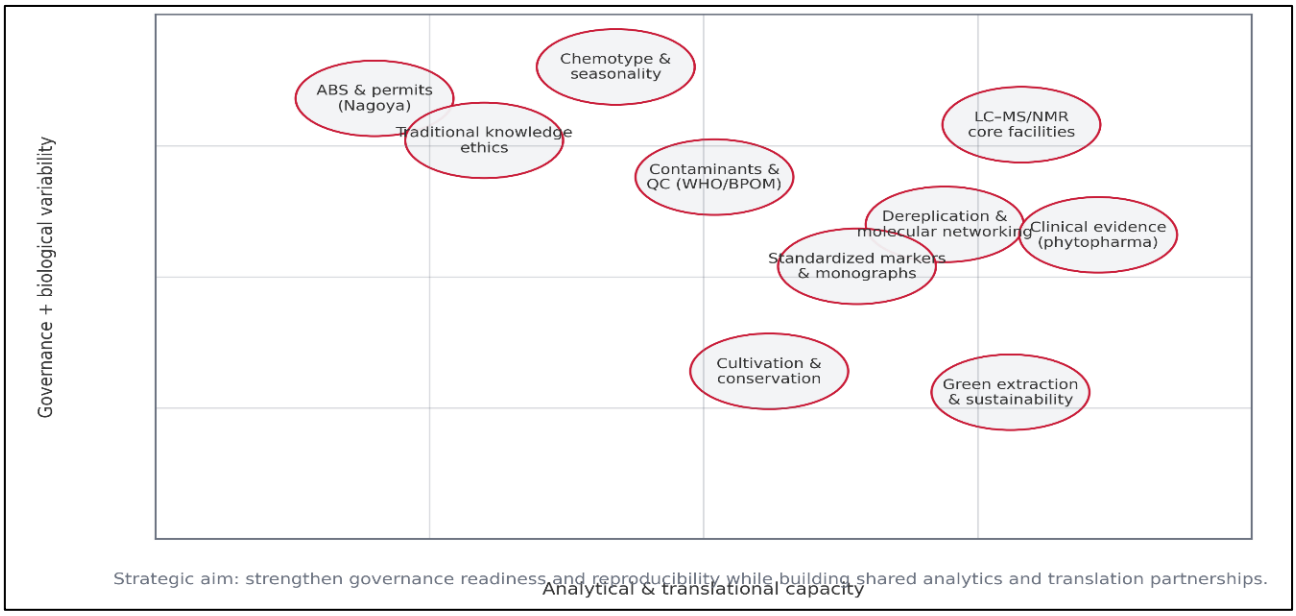

Fig 2: Challenges and opportunities matrix in Indonesian medicinal plant biochemistry research

Results are presented as a structured synthesis of constraints and leverage points. Figure 1 shows an end-to-end pipeline for medicinal plant biochemistry research in Indonesia, emphasizing governance (ABS), taxonomy and chemotype documentation, analytical profiling, and the evidence ladder toward phytopharmaceuticals. Figure 2 summarizes how challenges and opportunities cluster along two dimensions: governance/biological variability and analytical/translational capacity.

4.1. Scientific challenges: variability, identification, and reproducibility

The dominant scientific constraint is variability: metabolite profiles shift with organ, season, habitat, and post-harvest processing. This is particularly acute for medicinal plants collected from wild or semi-wild sources. Plant metabolomics standards imply that sampling design and QC practices are not optional; they are prerequisites for credible conclusions (Fiehn, 2002) [6]; (Sumner et al., 2007) [11].

A second scientific bottleneck is compound identification. While LC–MS/MS detects thousands of features, only a fraction can be confidently annotated without standards or curated libraries. Dereplication strategies and molecular networking reduce rediscovery and improve comparative analysis, but confidence levels must be reported transparently (Wolfender et al., 2019) [16]; (Qin et al., 2023) [10].

4.2. Governance challenges: ABS, traditional knowledge, and long timelines

ABS compliance and traditional knowledge governance affect whether research is ethical, publishable, and translatable. In practice, unclear permit pathways can delay field sampling and constrain collaborations. However, governance also creates an opportunity: universities that institutionalize ABS workflows and benefit-sharing templates can become trusted partners, enabling long-term programs rather than one-off extractive projects (Convention on Biological Diversity, 2011) [3]; (Oberthür & Rosendal, 2014) [9]; (Heinrich et al., 2020) [7].

4.3. Quality, safety, and the evidence ladder

Translational herbal medicine requires quality and safety assurance. WHO guidance emphasizes contaminants and residues and broader quality control methods (World Health Organization, 2011) [14]. Indonesian regulation distinguishes traditional medicine categories and strengthens requirements for safety, quality, and evidence as products move up the evidence ladder (Badan Pengawas Obat dan Makanan Republik Indonesia, 2019) [2]. Biochemistry research supports this ladder by identifying marker compounds, developing fingerprints, validating stability, and linking chemistry to bioactivity mechanisms.

4.4. Opportunity pathways for Indonesian universities

Indonesian universities can build globally visible niches by focusing on under-studied endemic species, developing local spectral libraries and metabolomic reference datasets, and integrating ethnobotanical knowledge with rigorous biochemical workflows. Universities can also strengthen translation through partnerships with hospitals, SMEs, and government programs, with a particular focus on standardized extracts, diagnostics, and sustainable agriculture inputs. Finally, sustainability must be built in: cultivation and conservation plans reduce overharvesting risks, and green extraction approaches reduce solvent and energy footprints.

4.5. A practical institutional roadmap

The synthesis implies that universities should invest in: (1) governance readiness (ABS and ethics support), (2) taxonomy and voucher systems, (3) shared analytical infrastructure (LC–MS/MS, NMR, bioinformatics), (4) reproducible workflows and reporting checklists, (5) curated local databases and spectral libraries, and (6) translation platforms that include QA/QC, safety testing, and partner engagement. These institutional investments convert dispersed projects into a coherent research program with credible outputs and scalable societal value.

Table 1: Core methodological approaches for Indonesian medicinal plant biochemistry research

Approach	Typical tools	Strengths	Common pitfalls	Recommended safeguards
Ethnopharmacology-informed selection	community surveys; literature screening; hypothesis mapping	High relevance; efficiency	Bias; weak documentation	Ethics protocols; transparent inclusion criteria; benefit-sharing plans
Untargeted metabolomics	LC–MS/MS; GC–MS; NMR; multivariate statistics	Chemotype mapping; biomarker discovery	Batch effects; weak annotation	QC samples; internal standards; confidence reporting (Sumner et al., 2007) [11]
Dereplication & molecular networking	GNPS/networking; in silico fragmentation; databases	Avoids rediscovery; accelerates annotation	Database incompleteness	Deposit spectra; build local library; report confidence (Wolfender et al., 2019) [16]; (Qin et al., 2023) [10]
Bioactivity-guided fractionation	bioassays + chromatography + structure elucidation	Links chemistry to function	False positives; reproducibility issues	Replicate assays; orthogonal confirmation; control extracts
Standardization & fingerprinting	marker quantification; chromatographic fingerprints	Supports quality and regulation	Markers not representative; unstable markers	Multi-marker approach; stability testing; batch-to-batch controls
Safety and contamination screening	heavy metals; pesticides; microbiology; adulterants	Public health protection	Costs; inconsistent methods	Follow WHO methods; SOPs; external proficiency testing (World Health Organization, 2011) [14]

Table 2: Challenges in Indonesian medicinal plant biochemistry research and mitigation strategies

Challenge	Why it matters	Mitigation strategy	Evidence anchor (≤2024)
ABS permits & compliance	Legal/ethical risks; delays	ABS workflow; PIC/MAT templates; legal support	(CBD, 2011) [3]; (Oberthür & Rosendal, 2014) [9]
Traditional knowledge ethics	Community rights; legitimacy	Co-design; benefit-sharing; respectful engagement	(Heinrich et al., 2020) [7]
Taxonomy/voucher gaps	Misidentification undermines reproducibility	Herbarium vouchers; barcoding; expert validation	Best practice in plant sciences
Chemotype/seasonality	Variable chemistry; standardization failure	Sampling design; metadata; replicate seasons	Plant metabolomics practice
Annotation bottleneck	Weak novelty and mechanism claims	Dereplication + networking; local libraries	(Wolfender et al., 2019) [16]; (Qin et al., 2023) [10]
Quality control & contaminants	Safety and credibility	WHO-aligned QC; validated methods; SOPs	(World Health Organization, 2011) [14]; (Badan Pengawas Obat dan Makanan Republik Indonesia, 2019) [2]
Clinical evidence barriers	Limits phytopharma pathway	Partner trials; phased evidence plans; realistic endpoints	(Elfahmi et al., 2014) [4]

Table 3: Opportunity pathways and institutional actions for Indonesian universities

Opportunity pathway	Institutional actions	Example outputs	Long-term benefit
Local biodiversity advantage	Prioritize under-studied flora; build metabolomic library	Databases; publications; spectra repositories	Global research visibility
Evidence ladder support	Standardization pipelines; marker validation; QA/QC	Monographs; standardized extracts	Translation to safer products
Education & workforce	Metabolomics/data skills in curriculum; student projects	Micro-credentials; theses	Skilled human capital
Partnership & innovation	SME/hospital partnerships; translational hubs	Pilot prototypes; IP	Regional innovation ecosystem
Sustainable sourcing	Cultivation trials; conservation agreements; green extraction	Cultivation SOP; sustainability metrics	Biodiversity protection

5. Conclusion

Medicinal plant biochemistry research in Indonesia offers extraordinary opportunities because it is grounded in biodiversity and living traditions of herbal medicine. Yet the field faces persistent challenges—ABS governance, ethical engagement with traditional knowledge, taxonomy and voucher rigor, chemotype variability, annotation bottlenecks, limited analytical capacity, and difficulties in standardization and clinical evidence pathways.

This article provides a practical synthesis toolkit: two conceptual figures (pipeline and challenge–opportunity matrix) and three implementation tables. The core recommendation is to treat governance readiness, reproducibility, and data stewardship as primary scientific outputs, on par with publications. With shared analytical infrastructure, curated local libraries, and responsible partnerships, Indonesian universities can strengthen the credibility and translation of medicinal plant biochemistry while protecting biodiversity and community rights.

6. References

1. Atanasov AG, Zotchev SB, Dirsch VM, International Natural Product Sciences Taskforce. Natural products in drug discovery: advances and opportunities. Nat Rev Drug Discov. 2021;20(3):200-216.
2. Badan Pengawas Obat dan Makanan Republik Indonesia. Peraturan Badan Pengawas Obat dan Makanan Republik Indonesia No. 32 Tahun 2019 tentang Persyaratan Keamanan dan Mutu Obat Tradisional. Jakarta: Badan POM Republik Indonesia; 2019.
3. Convention on Biological Diversity. Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from Their Utilization. Montreal: Secretariat of the Convention on Biological Diversity; 2011.
4. Elfahmi, Woerdenbag HJ, Kayser O. Jamu: Indonesian traditional herbal medicine towards rational phytopharmacological use. J Herb Med. 2014;4(2):51-73.
5. Fernie AR, Tohge T. The genetics of plant metabolism and metabolomics. Annu Rev Genet. 2017;51:287-310.
6. Fiehn O. Metabolomics—the link between genotypes and phenotypes. Plant Mol Biol. 2002;48(1-2):155-171.
7. Heinrich M, Jalil B, Potocnik T, et al. Best practice in ethnopharmacology and ethnobotany: a review and recommendations. J Ethnopharmacol. 2020;249:112376.
8. Newman DJ, Cragg GM. Natural products as sources of new drugs over the nearly four decades from 01/1981 to 09/2019. J Nat Prod. 2020;83(3):770-803.
9. Oberthür S, Rosendal GK. Global governance of genetic resources: access and benefit sharing after the Nagoya Protocol. New York: Routledge; 2014.
10. Qin GF, Zhang X, Zhu F, et al. MS/MS-based molecular networking: an efficient approach for natural products dereplication. Molecules. 2023;28(1):157. doi:10.3390/molecules28010157
11. Sumner LW, Amberg A, Barrett D, et al. Proposed minimum reporting standards for chemical analysis. Metabolomics. 2007;3(3):211-221.
12. Swandiny GF, et al. Screening of Indonesian traditional medicinal plants as DPP-IV inhibitors using an ethnopharmacology approach. Arch Pharm Res. 2023;46: [pages not specified in query].
13. Verpoorte R, Choi YH, Kim HK. NMR-based metabolomics at work in phytochemistry. Phytochem Rev. 2007;6(1):3-14.
14. World Health Organization. Quality control methods for

herbal materials. Geneva: World Health Organization; 2011.
15. Wishart DS. Emerging applications of metabolomics in drug discovery and precision medicine. Nat Rev Drug Discov. 2016;15(7):473-484.
16. Wolfender JL, Litaudon M, Touboul D, Queiroz EF. Innovative strategies for natural product dereplication and identification in the metabolomics era. Nat Prod Rep. 2019;36(6):855-868.
17. Yousof NSAM, et al. Molecular networking-based mass spectral identification of metabolites in medicinal plants: application example (Brucea javanica). Fitoterapia. 2024.