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Biochemistry Research on Endemic and Regionally Unique Asian Plants for Anti-Ageing: Challenges, Opportunities, and a Translational Roadmap

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Article Info

Abstract

Asia contains exceptional botanical diversity and long-established traditions of medicinal plant use. This creates substantial opportunities for biochemistry research on endemic and regionally unique plants as sources of anti-ageing actives for skin and healthy ageing applications. Anti-ageing research, however, requires more than antioxidant screening: credible pathways must connect plant chemistry to mechanisms of ageing biology (oxidative stress, inflammation, extracellular matrix degradation, glycation, barrier dysfunction, and cellular senescence), followed by standardization, safety evaluation, and human evidence. This article provides a framework synthesis (≤2024) of endemic/regionally unique Asian plant biochemistry research for anti-ageing, focusing on the coupled challenges and opportunities that determine scientific credibility and translation readiness. We integrate literature on skin ageing mechanisms and biomarkers (Fisher *et al*., 2002; Rittié & Fisher, 2015; Kammeyer & Luiten, 2015), natural products and bioactive polyphenols (Atanasov *et al*., 2021; Newman & Cragg, 2020), metabolomics standards and annotation bottlenecks (Fiehn, 2002; Sumner *et al*., 2007; Wolfender *et al*., 2019), and governance considerations under the Nagoya Protocol (CBD, 2011; Oberthür & Rosendal, 2014). Results are presented as two conceptual figures (a biochemical mechanism map and an evidence–translation matrix) and three implementation tables mapping biochemical targets, assay and evidence ladders, and institutional strategies for higher education. We argue that the most impactful university programs pair rigorous taxonomy and metadata with multi-omics chemical profiling, mechanism-linked assays (e.g., MMP inhibition, anti-glycation, senescence modulation), reproducible standardization, and staged human studies, while ensuring ethical access and benefit-sharing for local communities. The synthesis concludes with a practical roadmap to move endemic plant leads from discovery to responsible anti-ageing innovation in Asia.

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Introduction

Population ageing and the growth of preventative health and skincare markets have expanded interest in anti-ageing research across Asia. Anti-ageing, in the context of skin and visible ageing, is shaped by chronological processes (intrinsic ageing) and external exposures (photoageing from ultraviolet radiation, pollution, and lifestyle factors). Biochemistry is central to this field because many ageing phenotypes emerge from molecular damage and signaling dysregulation: reactive oxygen species (ROS), inflammatory cascades, matrix metalloproteinase (MMP) activation, advanced glycation end-products (AGEs), and cellular senescence.

Asian countries also host exceptionally diverse flora, including many endemic and regionally unique species that are under-characterized in global metabolite databases. These plants can contain distinctive secondary metabolites (polyphenols, terpenoids, alkaloids, saponins) that may modulate ageing pathways. However, the anti-ageing potential of endemic plants is often reported using narrow assays (e.g., single antioxidant tests) without mechanistic depth, standardization, or translation readiness. As a result, promising biochemical signals often fail to progress into credible products or clinical evidence.

A second constraint is governance and ethics. Access to genetic resources and associated traditional knowledge is governed internationally by the Nagoya Protocol framework requiring prior informed consent and mutually agreed terms (Convention on Biological Diversity, 2011) [2]. University research on endemic plants must therefore ensure access-and-benefit sharing (ABS) compliance, community engagement, and responsible communication to avoid extractive bioprospecting practices.

This paper synthesizes literature up to 2024 to map challenges and opportunities for endemic/regionally unique Asian plant biochemistry research for anti-ageing. We focus on higher education contexts because universities combine discovery research, training, core analytical facilities, and partnerships necessary for translation. The paper asks: (1) What biochemical mechanisms and assay targets are most relevant to anti-ageing? (2) What challenges constrain endemic plant biochemistry research in Asia? (3) What institutional roadmap can universities adopt to produce credible evidence and responsible translation?

2. Literature Review

2.1. Biochemistry of skin ageing: from ROS to extracellular matrix remodeling

Photoageing research has clarified key molecular pathways. Ultraviolet exposure generates ROS, activates inflammatory signaling, and increases MMP expression, accelerating collagen degradation and wrinkle formation. Fisher *et al.* (2002) [6] provided foundational evidence linking UV exposure to collagen degradation mechanisms in human skin. Subsequent syntheses describe intrinsic vs extrinsic ageing and highlight roles of inflammation, DNA damage, and impaired repair (Rittié & Fisher, 2015) [13]; (Kammeyer & Luiten, 2015) [8]. These mechanisms define measurable biochemical targets for plant-derived interventions: antioxidants, anti-inflammatory compounds, MMP inhibitors, anti-glycation agents, and modulators of senescence-associated secretory phenotype (SASP).

2.2. Natural Products as Anti-Ageing Sources: Opportunities and Limits

Natural products remain a major source of drug and bioactive discovery and also inform cosmeceutical development. Reviews show that natural products contribute substantially to new therapeutics and provide diverse chemical scaffolds (Newman & Cragg, 2020) [10]; (Atanasov *et al.*, 2021) [1]. For anti-ageing applications, plant polyphenols (e.g., catechins, resveratrol-like stilbenes), triterpenoids, and saponins are commonly implicated in antioxidant and signaling modulation. However, translation requires standardization and safety assessment, because extracts are complex mixtures and bioactivity can shift with chemotype, processing, and formulation.

2.3. Metabolomics and dereplication in endemic plant biochemistry

Endemic plant leads often begin with chemical profiling. Metabolomics provides a comprehensive view of metabolites and supports chemotype mapping and biomarker discovery. Foundational framing emphasized metabolomics as the bridge between genotype and phenotype (Fiehn, 2002) [5]. Minimum reporting standards were proposed to increase transparency and reproducibility (Sumner *et al.*, 2007) [14]. For natural products, dereplication is critical to avoid rediscovery. Wolfender *et al.* (2019) [16] review strategies combining LC–MS/MS, NMR, and computational tools to accelerate dereplication and annotation, though identification remains a bottleneck due to incomplete libraries and lack of authentic standards.

2.4. Evidence ladder for anti-ageing claims and common evaluation pitfalls

Anti-ageing claims range from antioxidant activity to clinically observed improvements in wrinkles and elasticity. Evidence strength increases across stages: chemical characterization → *in vitro* mechanistic assays → ex vivo skin models → *in vivo* animal studies → human safety and efficacy trials. A recurring pitfall is over-reliance on generic antioxidant assays without mechanism linkage or skin-relevant models. Another is failure to control for confounders such as cytotoxicity, solvent effects, and batch variability. Robust anti-ageing evaluation therefore requires a panel of assays aligned to biological targets (MMP inhibition, collagen synthesis markers, anti-glycation, anti-inflammatory signaling) and transparent reporting of concentrations and controls.

2.5. Governance and ethics in endemic plant research in Asia

Research on endemic plants intersects with sovereignty over genetic resources and protection of traditional knowledge. The Nagoya Protocol provides a framework requiring prior informed consent and mutually agreed terms for access and benefit-sharing (Convention on Biological Diversity, 2011) [2]. Scholarly work on ABS governance highlights the practical complexity of implementation and cross-border research (Oberthür & Rosendal, 2014) [11]. Ethical best practice also emphasizes respectful engagement with communities and avoidance of extractive research when traditional knowledge guides plant selection (Heinrich *et al.*, 2020) [7].

3. Method

This article uses a framework synthesis approach. We integrated peer-reviewed journal articles and authoritative governance and standards sources published up to 2024 to construct a design-oriented synthesis of endemic/regionally unique Asian plant biochemistry research for anti-ageing.

Sources were grouped into five clusters: (1) skin ageing mechanisms and biomarkers; (2) natural products and anti-ageing bioactives; (3) metabolomics standards and dereplication workflows; (4) ethical and governance guidance (ABS and traditional knowledge); and (5) translation practices (standardization, formulation stability, safety and efficacy evidence).

We organized outputs into two conceptual figures and three tables. Figure 1 maps biochemical ageing mechanisms and intervention points for plant actives. Figure 2 maps evidence

strength versus translation readiness for representative Asian plant actives and for under-studied endemic leads. Table 1 lists key biochemical targets and recommended assays; Table 2 describes the evidence ladder and minimum reporting elements; and Table 3 summarizes challenges and

institutional mitigation strategies relevant to higher education.

Because this is a synthesis paper, results are presented as structured insights and actionable guidance rather than effect sizes from new experiments.
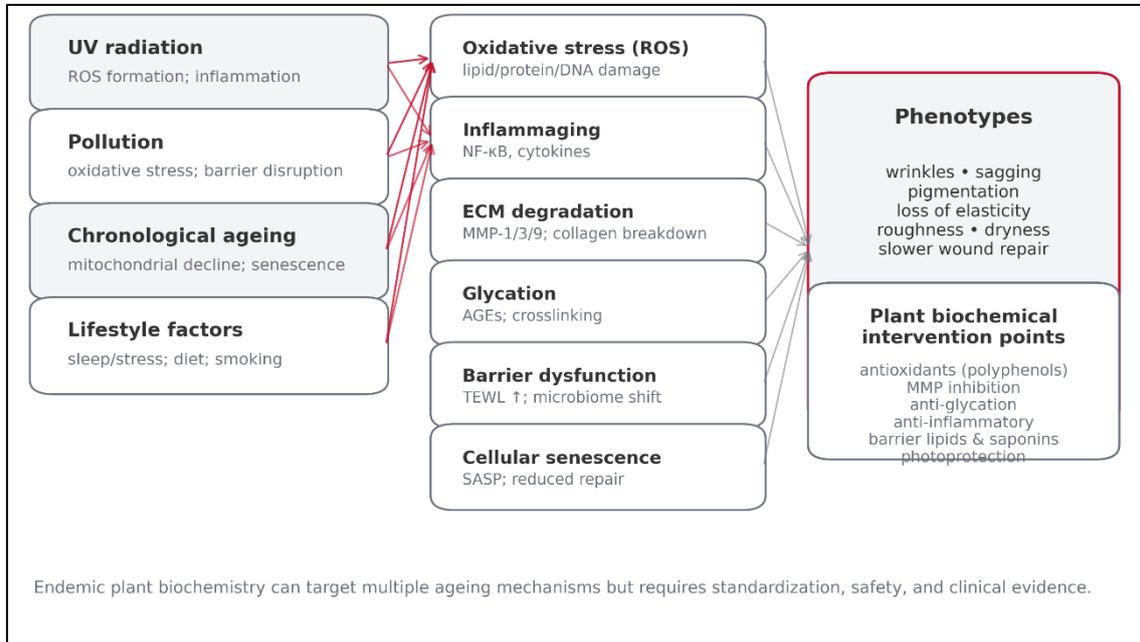
4. Results and Discussion

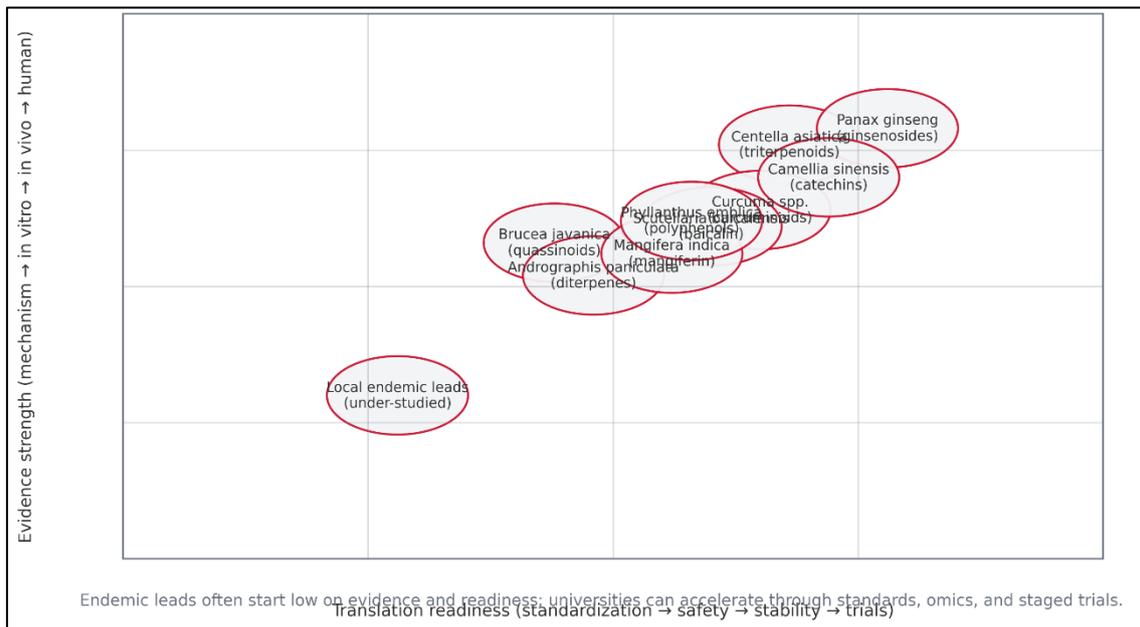**Fig 1:** Biochemical targets of skin ageing and plant intervention points

Fig 2: Evidence strength vs. translation readiness for Asian plant anti-ageing research

Results are presented as a synthesis of (1) biochemical targets, (2) research design and evidence standards, and (3) institutional strategies for translation. Figure 1 summarizes the major biochemical pathways of skin ageing and where plant-derived molecules can intervene. Figure 2 illustrates how research programs can move from low-evidence, low-readiness endemic leads toward higher levels of evidence and translation readiness.

4.1. Biochemical targets that matter for anti-ageing claims

Figure 1 indicates that oxidative stress and inflammation are upstream drivers that amplify downstream changes such as ECM degradation and barrier dysfunction. Consequently, "antioxidant-only" screening is insufficient; a credible anti-ageing program should include target-aligned assays: MMP inhibition and collagen/elastin markers, anti-glycation assays for AGEs, anti-inflammatory signaling markers (e.g.,

NF-κB pathway surrogates), and senescence-related readouts. This target alignment strengthens causal inference and reduces the risk of marketing-driven overclaims.

4.2. Variability and chemotype risks in endemic plant studies

Endemic and regionally unique plants can show extreme chemical variability across environments and seasons. Without chemotype mapping, results may not reproduce and standardization may fail. Metabolomics standards and QC practices (pooled QC samples, internal standards, batch randomization) are therefore essential (Fiehn, 2002) [5]; (Sumner *et al*., 2007) [14]. A practical strategy is to integrate untargeted metabolomics early to map chemotypes and identify marker panels that correlate with target bioactivity, followed by targeted quantification for standardization.

4.3. Annotation bottlenecks and dereplication-first workflows

Anti-ageing claims depend on chemical identity and dose. Wolfender *et al*. (2019) [16] emphasize dereplication strategies that combine MS/MS and NMR with computational tools. For endemic plants, gaps in global libraries are expected; therefore, universities should invest in building local spectral libraries and depositing spectra in open repositories, while clearly reporting identification confidence levels. Molecular networking approaches can accelerate discovery and comparison, but must be paired with authentic standards or orthogonal confirmation when claims are advanced.

4.4. Evidence ladder and translation readiness

Figure 2 highlights that some Asian actives have relatively higher evidence and readiness because they already have standardized extracts or extensive literature (e.g., Centella triterpenoids, ginsenosides, green tea catechins), while truly endemic leads start low and require staged evidence building. Translation readiness is constrained by standardization, safety, stability, and formulation compatibility. Universities can accelerate readiness by integrating stability testing, contaminant screening, and formulation studies earlier, rather than treating them as post publication concerns.

4.5. Governance and ethics as strategic capabilities

ABS compliance and ethical engagement with traditional knowledge are often treated as administrative barriers. The synthesis suggests reframing them as strategic capabilities: institutions with clear ABS workflows and benefit-sharing templates can form long-term partnerships and sustain access to endemic biodiversity in a legitimate way (Convention on Biological Diversity, 2011) [2]; (Oberthür & Rosendal, 2014) [11]; (Heinrich *et al*., 2020) [7]. Ethical governance also reduces reputational risk and supports downstream commercialization and cross-border collaboration.

4.6. Implications for higher education: program design

A robust university program should combine four capacities: (1) taxonomy and voucher systems; (2) analytical core facilities (LC–MS/MS, NMR, metabolomics bioinformatics); (3) mechanism-linked assay platforms (cellular, ex vivo skin models, anti-glycation systems); and (4) translational partnerships (dermatology clinics, cosmetic/pharma industry, SMEs). These capacities should be paired with open science and FAIR metadata practices to maximize reproducibility and collective progress.

Table 1: Key biochemical targets for anti-ageing claims and recommended assays for endemic plant research.

Target domain	Representative biomarkers/targets	Recommended assays/models	Interpretation notes
Oxidative stress	ROS, lipid peroxidation, antioxidant response	Cell-based ROS assays; ORAC/FRAP as support; lipid peroxidation markers	Use cell-relevant assays; control for cytotoxicity; antioxidant-only evidence is insufficient.
Inflammation	NF-κB signaling; cytokine surrogates	Reporter assays; cytokine panels; inflammation challenge models	Distinguish anti-inflammatory effect from general toxicity or solvent effects.
ECM degradation	MMP-1/3/9; collagen I; elastin	MMP inhibition assays; fibroblast collagen synthesis; ex vivo skin models	Prioritize skin-relevant models; link dose to mechanistic effect.
Glycation	AGE formation; collagen crosslinking	BSA-glucose anti-glycation assay; AGE fluorescence; crosslink inhibition	Report concentrations and kinetics; check interference in fluorescence assays.
Barrier function	TEWL surrogate; ceramides; tight junction markers	Keratinocyte barrier models; lipidomics; TEER assays	Barrier outcomes need formulation context; consider delivery system.
Senescence	SASP markers; β-gal; p16/p21	Senescence induction models; SASP readouts; DNA damage markers	Avoid overclaiming; senescence modulation requires careful controls.

Table 2: Evidence ladder for anti-ageing claims from endemic Asian plants: minimum reporting and quality criteria

Evidence level	Minimum deliverables	Quality criteria	Common failure modes
Chemical profiling	Voucher + metadata; LC–MS/MS/NMR profiles	Identification confidence; QC; repeatable profiles	Misidentification; missing metadata; batch effects
Mechanistic *in vitro*	Target-aligned assays (MMP/AGE/NF-κB)	Controls; cytotoxicity checks; dose–response	Non-specific antioxidant claims; assay interference
Skin-relevant models	Ex vivo skin/3D skin models	Replicates; realistic dosing; penetration considerations	Ignoring delivery; unrealistic concentrations
In vivo safety/efficacy	Animal or validated alternatives; irritation tests	Ethics; endpoints; reproducibility	Overgeneralization from single model
Human evidence	Patch testing; small clinical efficacy trials	Blinding; standardized extract; safety monitoring	Unstandardized extracts; underpowered designs
Translation	Stability, contaminants, formulation compatibility	Regulatory pathway; supply chain; sustainability	Overharvesting; unstable actives; unclear claims

Table 3: Challenges and opportunities in endemic plant anti-ageing biochemistry research in Asia (higher education)

Domain	Key challenges	Opportunity lever	Institutional actions
Biodiversity & access	ABS compliance; permits; ethical TK use	Trusted partnerships	ABS office; PIC/MAT templates; benefit-sharing plans
Taxonomy & vouchers	Misidentification; missing vouchers	Reproducibility	Herbarium vouchers; barcoding; expert validation
Chemotype variability	Season/site variability	Chemotype mapping	Metabolomics + metadata; marker panels; cultivation trials
Analytics & annotation	Limited MS/NMR; identification bottleneck	Local libraries	Core facilities; spectral library building; open repositories
Standardization & safety	Contaminants; batch variability	Quality systems	QA/QC SOPs; stability testing; contaminant screening
Translation readiness	Formulation stability; clinical evidence	Staged trials	Dermatology partnerships; pilot trials; TRL stage-gates

5. Conclusion

Biochemistry research on endemic and regionally unique Asian plants for anti-ageing has strong scientific and innovation potential, but it is constrained by variability, identification bottlenecks, and translation gaps. The most credible anti-ageing research programs move beyond generic antioxidant screening to mechanism-aligned assays and staged evidence generation, while ensuring standardization, safety, and formulation stability.

This synthesis provides a practical toolkit: a mechanism map (Figure 1), an evidence–translation matrix (Figure 2), and implementation tables for targets, evidence ladders, and institutional mitigations. Higher education institutions can accelerate progress by investing in shared analytical platforms, curated spectral libraries, governance readiness under ABS frameworks, and partnerships enabling clinical and real-world validation.

Future research should expand region-specific metabolite databases, develop accessible reference standards for endemic species, and test scalable governance and benefit-sharing models that protect biodiversity and community rights while enabling responsible anti-ageing innovation.

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