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Nanoshilajit™: An Evidence-Based Narrative Review of Shilajit in Bioenergetics, Physical Performance, Male Endocrine–Reproductive Health, Recovery, and Physiological Resilience

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Abstract: Shilajit is a chemically complex organo-mineral phytocomplex used in Ayurvedic Rasayana practice and investigated for bioenergetic, musculoskeletal, endocrine, reproductive, antioxidant and tissue-maintenance effects. Nanoshilajit™ is best understood as a nanostructured or particle-engineered presentation of purified and standardised shilajit rather than as a distinct active ingredient. Because the underlying shilajit phytocomplex is retained, human and mechanistic evidence generated with purified or standardised shilajit constitutes the parent ingredient evidence base for Nanoshilajit™. Nano-structuring is a formulation strategy intended to improve dispersion, dissolution, surface interaction and potentially intestinal absorption and systemic exposure without changing the identity of the active matrix. General nanophytomedicine literature supports these delivery advantages, and shilajit-specific nanoformulation studies using nanochitosan conjugates and shilajit-based nanocarriers provide proof-of-principle that shilajit can be engineered at nanoscale dimensions and that such formulation can augment delivery or biological activity in experimental systems. Controlled human studies of purified shilajit support selected effects on testosterone, fatigue-associated muscular performance, collagen-related biomarkers, oxidative/inflammatory balance and bone preservation, while clinical and mechanistic studies further support male reproductive physiology, mitochondrial resilience, extracellular-matrix adaptation and cellular protection. The exact magnitude of any bioavailability advantage of the finished Nanoshilajit™ product has not yet been quantified in a comparative human pharmacokinetic study. Overall, Nanoshilajit™ can be positioned as an advanced delivery form of the same parent shilajit phytocomplex, combining the established biological evidence of purified shilajit with an additional nano-structuring rationale.

Keywords: Shilajit; Nanoshilajit™; fulvic acid; dibenzo-α-pyrones; mitochondrial bioenergetics; fatigue; testosterone; spermatogenesis; collagen; oxidative stress; physiological resilience

Abbreviations: 3β-HSD, 3β-hydroxysteroid dehydrogenase; 17β-HSD, 17β-hydroxysteroid dehydrogenase; AKT, protein kinase B; ARE, antioxidant response element; ATP, adenosine triphosphate; BALP, bone-specific alkaline phosphatase; Bax/Bcl-2, Bcl-2-associated X protein / B-cell lymphoma 2; BMD, bone mineral density; COL1A1, collagen type I alpha 1 chain; CTX-1, C-terminal telopeptide of

type I collagen; CYP11A1, cholesterol side-chain cleavage enzyme; CYP17A1, steroid 17α-hydroxylase/17,20-lyase; CYP19, aromatase; DBP, dibenzo-α-pyrone; DCN, decorin; DHEAS, dehydroepiandrosterone sulfate; ECM, extracellular matrix; ELN, elastin; ETC, electron transport chain; FBN1, fibrillin-1; FN1, fibronectin-1; FSH, follicle-stimulating hormone; FTIR, Fourier-transform infrared spectroscopy; GC-MS, gas chromatography–mass spectrometry; GPx, glutathione peroxidase; GSH, glutathione; HPLC, high-performance liquid chromatography; HPMC, hydroxypropyl methylcellulose; HPTLC, high-performance thin-layer chromatography; hsCRP, high-sensitivity C-reactive protein; ICP-MS, inductively coupled plasma mass spectrometry; Keap1, Kelch-like ECH-associated protein 1; LC-MS, liquid chromatography–mass spectrometry; LH, luteinizing hormone; LPO, lipid peroxidation; MDA, malondialdehyde; MMP, matrix metalloproteinase; MP-AES, microwave plasma atomic emission spectroscopy; MYOF, myoferlin; NF-κB, nuclear factor kappa B; NO, nitric oxide; Nrf2, nuclear factor erythroid 2-related factor 2; OPG, osteoprotegerin; PCNA, proliferating cell nuclear antigen; RANKL, receptor activator of nuclear factor kappa-B ligand; ROS, reactive oxygen species; SEM, scanning electron microscopy; SOD, superoxide dismutase; StAR, steroidogenic acute regulatory protein; TEM, transmission electron microscopy; TGFβ1, transforming growth factor beta 1; TNXB, tenascin XB; VEGFA, vascular endothelial growth factor A; XRF, X-ray fluorescence; ΔΨm, mitochondrial membrane potential.

1. Introduction

Shilajit is a dark brown to nearly black organo-mineral material that emerges from rock strata in mountainous regions and has long been incorporated into Ayurvedic Rasayana practice. Contemporary chemical analyses indicate that it is not a single defined compound, but a variable matrix containing humic and fulvic fractions, low-molecular-weight organic constituents, minerals, and source-dependent chemical markers[1–6]. This compositional variability makes provenance, purification, and standardisation important determinants when efficacy and safety findings are interpreted [4,6–8].

Contemporary human studies have evaluated measurable outcomes including serum androgen concentrations, semen parameters, fatigue-associated strength loss, collagen-related biomarkers, bone mineral density, oxidative stress, inflammation, skeletal-muscle gene expression and skin micro perfusion[9–15]. These outcomes provide a stronger basis for discussing vitality, performance and resilience than broad traditional claims alone.

Nanoshilajit™ is not a separate pharmacological ingredient from shilajit; it is a particle-engineered form of purified and standardised shilajit in which the parent phytocomplex remains the active matrix. Accordingly, clinical and mechanistic findings obtained with purified or standardised shilajit are directly relevant as parent-ingredient evidence for Nanoshilajit™. Nano-structuring adds a formulation layer intended to improve dispersion, dissolution, membrane interaction and potentially bioavailability rather than to create a new set of biological actions[16–20]. Particular attention is therefore given to energy-related physiology, physical performance, stamina, recovery, testosterone, male reproductive health, antioxidant defence, detoxification-related cytoprotection and cellular maintenance.

2. Data Collection and Evidence Selection

Relevant literature was identified from PubMed/MEDLINE and primary publisher databases, with cross-checking against records indexed in major scholarly databases including Scopus and Web of Science where applicable. Original human research was prioritised first, followed by original animal, cellular, mechanistic and analytical studies. Review articles were used mainly for historical context, evidence integration and safety interpretation. Studies available through 2026 were considered.

Human studies using purified or standardised shilajit were weighted above studies of uncharacterized native material. Multi-ingredient formulations, conference abstracts, repositories, non-peer-reviewed material and studies of isolated humic substances not demonstrably equivalent to shilajit were not used as primary evidence for product claims. Claim-to-reference alignment, study design, population, dose, endpoint and formulation identity were cross-checked before inclusion.

The review is narrative rather than systematic and does not calculate pooled effect estimates. Evidence obtained with purified shilajit, processed shilajit, Momiai, isolated fulvic/humic fractions or

other proprietary extracts is interpreted according to the actual tested material and is not automatically treated as direct evidence for Nanoshilajit™.

The expanded mechanistic appraisal also considered high-value analytical and molecular studies that identify chemical markers, enzyme systems, signalling proteins and cellular targets. Because shilajit is a heterogeneous organo-mineral phytocomplex rather than a single molecule, mechanistic conclusions were accepted only when the tested preparation, tissue and evidence level were explicit. A critical Journal of Ethnopharmacology review was retained to contextualise limitations of older pharmacological claims [21–27].

3. Shilajit: Rasayana Context and Biological Identity

Traditional literature positions shilajit within the Rasayana concept of maintaining vitality, resilience and functional capacity[1,2]. These historical concepts are relevant to the ethnopharmacological background but are not equivalent to modern clinical endpoints. In contemporary biomedical terms, the most defensible translational domains are mitochondrial function, fatigue resistance, endocrine-reproductive physiology, redox balance and tissue remodelling.

Chemical work also argues against treating shilajit as a conventional mineral supplement. Its organic matrix, humic fractions and mineral associations vary across sources and processing states, making analytical identity and purification essential prerequisites for reproducible biological interpretation[3–7].

Broader reviews have also discussed shilajit in relation to cognition and adaptation to high-altitude stress. These domains are retained as contextual evidence rather than core Nanoshilajit™ efficacy claims because the supporting literature is predominantly traditional, mechanistic or preclinical[28,29].

4. Chemical Composition and Contemporary Analytical Characterisation

Foundational studies described humic and fulvic fractions together with dibenzo-α-pyrone-related constituents as characteristic components of shilajit[3]. More recent work has expanded this picture using chromatographic, mass-spectrometric and elemental techniques.

Kohli and colleagues applied HPLC, HPTLC, LC-MS, gravimetric analysis and ICP-MS to raw material, extract and resin and demonstrated that marker composition, fulvic-acid-related content and mineral/heavy-metal profiles can be analytically differentiated [5]. A 2026 study of geographically diverse samples used ICP-MS with molecular-size fractionation and found large variation in major and trace elements; importantly, the authors cautioned that low-molecular-weight association should not be equated with demonstrated human bio accessibility [6].

This distinction is important for Nanoshilajit™: low molecular size, water solubility or a nano-oriented formulation concept is analytically interesting, but none is a substitute for comparative dissolution, absorption or pharmacokinetic data [6].

Recent analytical work substantially expands the chemical picture beyond the historical fulvic-acid/dibenzo-α-pyrone framework. HPLC/HPTLC/LC-MS profiling has identified or quantified fulvic acid together with marker compounds including hippuric acid, benzoic acid and urolithin A, while ICP-MS provides a parallel mineral and heavy-metal profile[5]. Comparative HPLC–MS/MS analysis across samples from five regions identified nine plant-derived phenolic acids—gallic, vanillic, syringic, caffeic, p-coumaric, ferulic, sinapic, chlorogenic and rosmarinic acids—with pronounced geographical variation [25].

Additional spectroscopic and chromatographic studies confirm that shilajit chemistry is source-dependent and comprises a heterogeneous organic–inorganic matrix. Humic acids isolated from geographically distinct samples show related physicochemical and spectroscopic characteristics, whereas crude-material studies using FTIR, GC-MS, HPLC and ICP-MS demonstrate meaningful regional variability[21–24]. DNA metabarcoding and biochemical profiling published in 2026 further support substantial botanical contributions to processed shilajit, reinforcing its interpretation as a biologically and geochemically derived complex mixture rather than a single defined phytochemical [26].

A foundational chemical-constituent report and subsequent reviews also describe historical classes such as benzoic and hippuric acids, fatty acids, triterpenic/sterol-like constituents, amino acids and phenolic lipids[21,24,30]. These compounds should be treated as composition-level observations unless the

same constituents are specifically quantified in the finished Nanoshilajit™ batch. Table 1 summarises the principal constituent classes reported in shilajit and the interpretive boundary attached to each.

Table 1: Principal phytochemical, humic and organo-mineral constituents reported in shilajit and their evidence-relevant interpretation.

Constituent class / representative markers	Analytical evidence	Potential biological relevance	Interpretive boundary
Humic substances: fulvic acid and humic acid	Spectroscopy, gravimetry and chromatographic profiling [5,21,24]	Major physicochemical fraction; redox, binding and carrier-like hypotheses	Heterogeneous mixtures with no single molecular formula; isolated fulvic/humic effects are not automatically whole-shilajit effects.
Dibenzo-α-pyrone-related constituents / DBP-associated fractions	Foundational chemistry and processed-extract standardisation [3,30,31]	Proposed redox and mitochondrial relevance	Direct human target engagement and pharmacokinetics remain incompletely established.
Hippuric acid, benzoic acid and urolithin A	HPLC/HPTLC/LC-MS marker profiling [5]	Useful chemical fingerprints and quality-control markers	Detection as a marker does not establish that the compound drives a clinical effect.
Phenolic acids: gallic, vanillic, syringic, caffeic, p-coumaric, ferulic, sinapic, chlorogenic and rosmarinic acids	Comparative HPLC–MS/MS across five regions [25]	Plausible contributors to antioxidant chemistry	Strong geographical variability; product-specific concentrations require direct assay.
Other reported organics: fatty acids, triterpenic/sterol-like compounds, amino acids and phenolic lipids	Historical and modern composition literature [21,24,30]	Contribute to overall chemical complexity	Often inconsistently quantified across source materials.
Mineral and trace-element fraction	ICP-MS, MP-AES, XRF and related methods [4–6,23]	Relevant to identity, exposure and quality control	Presence does not itself prove nutritional bioavailability or benefit.
Potentially toxic elemental contaminants	Elemental surveillance / ICP-MS [4,6,8,32]	Safety-critical quality attribute	Requires finished-batch specifications; source studies cannot represent all products.
Biological-source signatures	DNA metabarcoding plus biochemical profiling [26]	Supports plant/microbial contribution to formation	Source signatures do not establish therapeutic activity.

5. Molecular, Enzymatic and Cellular Sites of Action

Conceptual clarification. Shilajit does not possess a single molecular or "enzymatic" structure: it is a heterogeneous organo-mineral phytocomplex composed of variable humic substances, small organic molecules, phenolic constituents and minerals[21,24,25,30]. Accordingly, the mechanistic question is which cellular enzymes, signalling proteins, transcriptional programs and tissue compartments are altered by a defined shilajit preparation—not which single enzyme is intrinsic to shilajit.

Mitochondrial site of action. In a chronic-fatigue rat model, standardised processed shilajit attenuated abnormalities in respiratory-chain complexes I, II, IV and V, mitochondrial membrane potential, nitric oxide, lipid peroxidation, superoxide dismutase and catalase[31]. Earlier experimental work also

reported modulation of superoxide dismutase, catalase and glutathione-peroxidase-related antioxidant activity[33]. These findings support mitochondrial preservation and redox regulation as preclinical mechanisms, but they do not prove a universal increase in ATP synthesis in healthy humans.

Testicular steroidogenic and germ-cell pathways. The controlled human testosterone study establishes an endocrine outcome rather than a specific intracellular target[12]. In toxic-injury mouse models, shilajit improved steroidogenic function through changes in 3β-hydroxysteroid dehydrogenase and 17β-hydroxysteroid dehydrogenase activity; in the cyclophosphamide model, CYP11A1 increased, CYP19 decreased, and StAR showed little change. The same experimental work also reported modulation of Nrf2/Keap1 redox signalling, PCNA-related germ-cell proliferation, Sertoli-cell N-cadherin/β-catenin signalling, and the Bax/Bcl-2 apoptotic balance[34,35]. These observations provide mechanistic plausibility for androgen and spermatogenic effects, but they remain preclinical.

Skeletal-muscle extracellular matrix. Human muscle-biopsy transcriptomics identified coordinated increases in ECM-associated genes after purified shilajit, including tenascin XB (TNXB), decorin (DCN), myoferlin (MYOF), collagen-related genes, elastin (ELN), fibrillin-1 (FBN1), and fibronectin-1 (FN1)[10]. Functionally, this transcriptional pattern is consistent with matrix organisation, mechanical force transmission/mechanotransduction, elastic-fibre biology, and repair-associated remodelling. A separate randomised trial found higher circulating pro-c1α1, a marker used to estimate type-I collagen synthesis[11]. Together, the studies support musculoskeletal adaptation rather than a blanket claim of accelerated recovery.

Skin microvascular and matrix pathways. In healthy middle-aged women, oral shilajit shifted skin transcriptional networks associated with endothelial motility, angiogenic development, and extracellular-matrix organisation; VEGFA- and TGFβ1-associated networks were among the pathways identified. At the higher tested dose, skin perfusion also increased relative to baseline and placebo[15]. These human tissue-level findings are relevant to microvascular and ECM maintenance, but they do not demonstrate reversal of cellular age.

Bone and systemic redox pathways. During the 48-week randomised trial in postmenopausal women with osteopenia, both shilajit doses limited decline in bone mineral density at the lumbar spine and femoral neck. The intervention also shifted bone-turnover and systemic redox/inflammatory markers toward lower CTX-1, BALP, RANKL, MDA, and hsCRP and higher OPG and GSH[14]. These measured human outcomes provide one of the stronger clinical bridges between shilajit supplementation, tissue preservation, and physiological resilience.

Cellular remodelling in human periodontal-ligament cells. Responses varied with concentration: exposure at 2–3 mg/mL favoured cell migration, closure of the experimental wound gap, and proliferation while altering COL1A1, MMP2, and MMP9 expression; viability declined at concentrations above 4 mg/mL[36]. This concentration dependence is mechanistically useful because it shows that a larger exposure does not necessarily produce a larger beneficial response. Table 2 lists the enzymatic, molecular and cellular targets reported for shilajit in primary studies.

Table 2: Enzymatic, molecular and cellular targets reported for shilajit in primary studies.

Cellular site/tissue	Enzyme, pathway or marker	Observation	Evidence level/interpretation
Mitochondria / prefrontal cortex	ETC I, II, IV, V; ΔΨm; NO; LPO; SOD; catalase	Fatigue-model abnormalities attenuated	Rat chronic-fatigue model [31]; mitochondrial preservation, not human ATP proof
Brain redox systems	SOD; catalase; glutathione peroxidase; radical indices	Antioxidant-enzyme modulation	Preclinical [33]; supportive redox mechanism
Leydig/testicular steroidogenesis	StAR; CYP11A1; 3β-HSD; 17β-HSD; CYP19	3β-HSD/17β-HSD activity improved in toxic-injury models; in the cyclophosphamide	Preclinical [34,35]; supports steroidogenic plausibility alongside the human androgen endpoint [12]

		model CYP11A1 increased, CYP19 decreased, and StAR showed little change	
Sertoli/germ cells	PCNA; N-cadherin; β-catenin; Bax/Bcl-2	Proliferation, junctional and apoptotic balance improved	Preclinical [35]; reproductive mechanism
Testicular redox signalling	Nrf2 ↑ / Keap1 ↓; SOD ↑; LPO ↓	Shift toward antioxidant defence	Preclinical [35]; pathway-specific evidence
Skeletal-muscle ECM	TNXB; DCN; MYOF; collagen genes; ELN; FBN1; FN1	Coordinated ECM-gene regulation consistent with matrix organisation, mechanotransduction and repair-associated remodelling	Human muscle biopsy [10]; tissue-level mechanistic evidence
Systemic collagen marker	Serum pro-c1α1	Increased after 8 weeks	Human randomised trial [11]; biomarker, not clinical healing endpoint
Skin microvasculature / ECM	VEGFA/TGFβ1-associated networks; ECM genes	Transcriptional networks linked to endothelial motility, vascular development and ECM changed; higher dose increased skin perfusion.	Randomized human study [15]; microvascular/ECM maintenance
Bone / systemic redox	RANKL ↓; OPG ↑; CTX-1/BALP ↓; MDA ↓; GSH ↑; hsCRP ↓	Bone-turnover and redox/inflammation markers shifted favourably	48-week human RCT [14]
Human periodontal-ligament cells	COL1A1; MMP2; MMP9; PCNA; TNF-α; IL-1β	2–3 mg/mL favoured migration, proliferation and wound-gap closure; viability declined above 4 mg/mL	In vitro human cells [36]; concentration-dependent response

6. Purification, Standardisation and Safety as Determinants of Biological Activity

Earlier experimental work reported more reproducible pharmacological effects from processed or fractionated material than from native shilajit[7,37]. Modern elemental studies reinforce this requirement by demonstrating meaningful variation in both nutritional and potentially toxic elements among samples[4,6,8].

Aldakheel and colleagues detected several toxic elements in sampled commercial materials, in some cases above the referenced permissible limits, whereas the 2026 geographically diverse analysis reported toxic elements below established intake thresholds at realistic consumption doses[4,6]. These findings are best interpreted as evidence that source and product quality determine exposure and that batch-specific testing is indispensable.

For a finished formulation, scientifically relevant quality documentation includes provenance where available, validated purification, chemical fingerprinting, marker quantification, microbial quality, mycotoxin control and heavy-metal specifications. These parameters are more important for safety and reproducibility than broad statements about natural origin.

7. Nanoshilajit™: Product Composition, Relationship to Shilajit and Nano-Structuring Rationale

Nanoshilajit™ is a particle-engineered presentation of purified and standardised shilajit rather than a different active ingredient. The active chemical and biological matrix therefore remains shilajit, and the

human, preclinical and mechanistic literature generated with purified or standardised shilajit provides the direct parent-ingredient evidence base for Nanoshilajit™. Nano-structuring is best viewed as an additional delivery technology layered onto that established biological evidence[16,17].

According to the current product label shown in this manuscript, each vegetarian capsule contains 500 mg of shilajit standardised for Nanoshilajit™, declared as Asphaltum punjabianum, with hydroxypropyl methylcellulose (HPMC) as the capsule shell. These label-declared composition details define the commercial formulation but are not presented as clinical efficacy evidence. The product and its label-declared composition are shown in Figure 1 and Table 3.

Fig 1: Biotex Nanoshilajit™ product and current label-declared formulation.

Table 3: Label-declared composition of Biotex Nanoshilajit™ capsules.

Component	Label designation	Amount per capsule	Interpretive note
Active ingredient	Shilajit standardised for Nanoshilajit™; label source designation: Asphaltum punjabianum	500 mg	Purified/standardized shilajit is the active product. Ingredient-level evidence is evaluated in this review; the amount itself does not establish product-specific efficacy.
Capsule shell	Hydroxypropyl methylcellulose (HPMC)	Not separately quantified	Vegetarian capsule shell/excipient; no therapeutic claim is assigned to the shell.

Label note: the current product label states that the formulation is free from artificial flavours, sugar, starch, wheat or soy, gluten, dairy, sodium and yeast. These are product-label declarations rather than pharmacological endpoints.

The rationale for nano-structuring is supported at two levels. First, nanotechnology-based phytomedicine systems can improve dispersion, dissolution, stability, membrane interaction, and delivery of natural-product constituents[16,17]. Second, shilajit-specific formulation studies demonstrate technical feasibility. Alshubaily and Jambi produced shilajit-loaded chitosan nanoparticles with a mean diameter of approximately 248.4 nm; in their rat osteoporosis experiment, the nano-conjugated shilajit group showed the most favourable combined antioxidant and bone-related profile among the shilajit interventions[18]. Asadi and colleagues developed a shilajit-based nanoscale carrier, with the drug-loaded system reported at approximately 244 nm, supporting the feasibility of engineering shilajit into a nanocarrier rather than proving enhanced oral bioavailability of shilajit itself[19]. A later chitosan/shilajit/alendronate nanocomposite averaged approximately 218.4 nm and produced favourable experimental responses, but its multi-component design makes it supportive formulation evidence rather than isolated evidence for shilajit[20]. Collectively, these studies strengthen the nano-delivery rationale while leaving the magnitude of any pharmacokinetic advantage of the finished Nanoshilajit™ formulation to be quantified directly.

Consequently, evidence from purified and standardised shilajit should not be treated as evidence for an unrelated ingredient when discussing Nanoshilajit™. It is directly applicable to the identity, biological mechanisms and expected physiological domains of the parent shilajit matrix. Nano-specific studies add a formulation advantage—potentially greater dispersion, dissolution, absorption and systemic exposure—while the precise magnitude of that advantage in humans remains to be quantified for the finished product[16–20]. The intended delivery rationale is shown schematically in Figures 2 and 3.

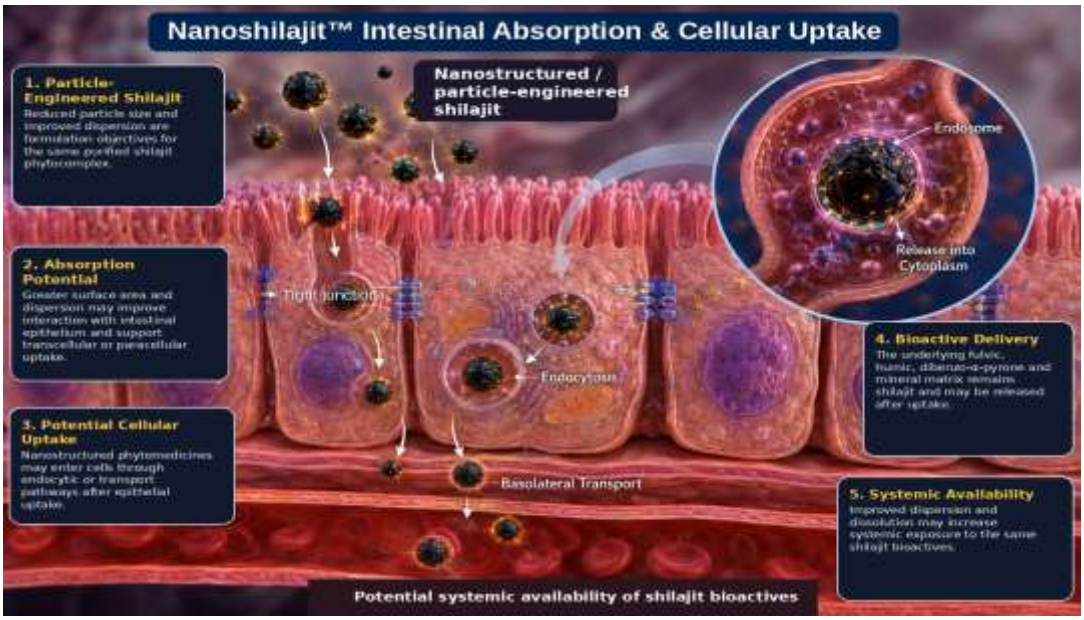

Fig 2: Nano-structuring rationale for intestinal absorption and systemic availability. The nanostructured form retains the same shilajit phytocomplex, while reduced particle size, greater surface area, dispersion and dissolution may improve delivery.

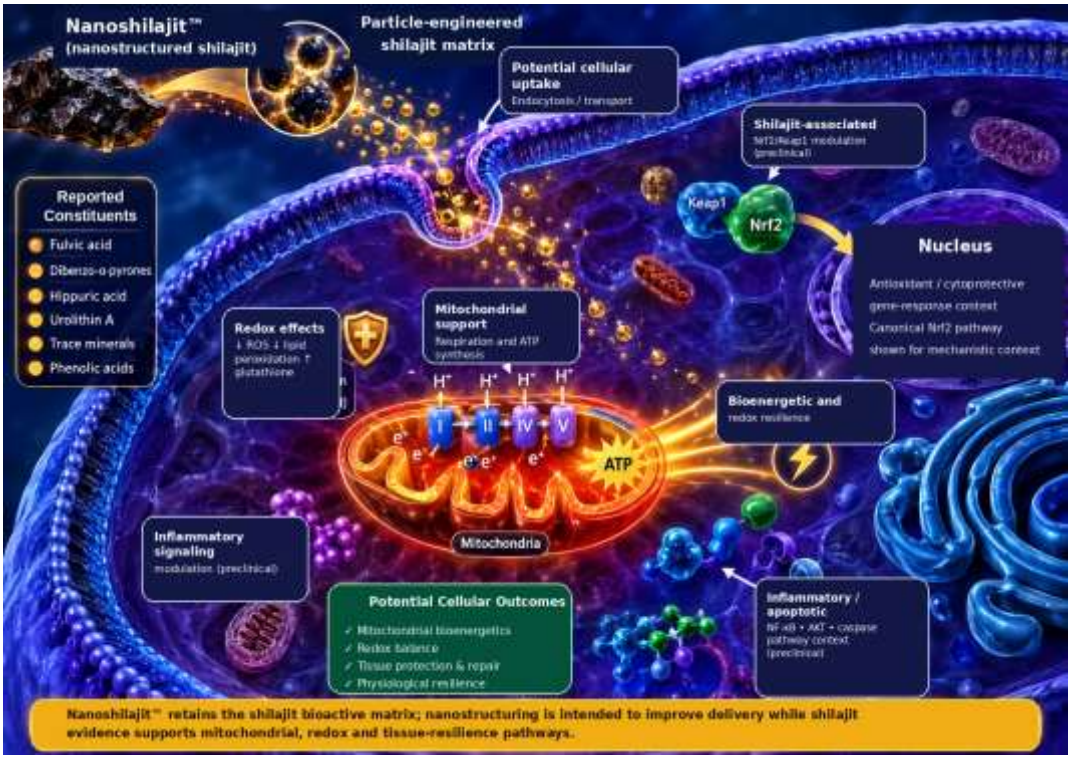

Fig 3: Cellular-level model for Nanoshilajit™. Nanostructuring is intended to improve delivery of the same shilajit bioactive matrix; mitochondrial, redox and cytoprotective pathways shown derive from the parent shilajit evidence base.

Formulation-specific characterisation such as particle-size distribution, polydispersity index, zeta potential, SEM/TEM morphology, dissolution behaviour and comparative pharmacokinetic data would constitute direct product-characterisation evidence. In the absence of such peer-reviewed formulation-specific data, nano-enabled superiority remains a formulation hypothesis rather than a demonstrated clinical advantage.

8. Cellular Bioenergetics and Energy-Related Mechanisms

The clearest experimental evidence for an energy-related mechanism comes from rats exposed to a chronic-fatigue paradigm. Processed shilajit partially normalised mitochondrial respiratory-complex measures, membrane potential, oxidative-stress indices, and hypothalamic-pituitary-adrenal-axis-associated changes[31]. The findings support preservation of mitochondrial function during physiological stress, but they do not establish a universal increase in ATP production in healthy humans.

Human evidence is indirect but relevant: resistance to fatigue-induced strength loss and adaptive skeletal-muscle transcriptional responses have been observed with purified shilajit supplementation[9,10]. Therefore, the appropriate wording is that shilajit may support cellular bioenergetic resilience and fatigue resistance rather than that it has been clinically proven to "boost ATP". Figure 4 summarises the mitochondrial and redox mechanisms concerned.

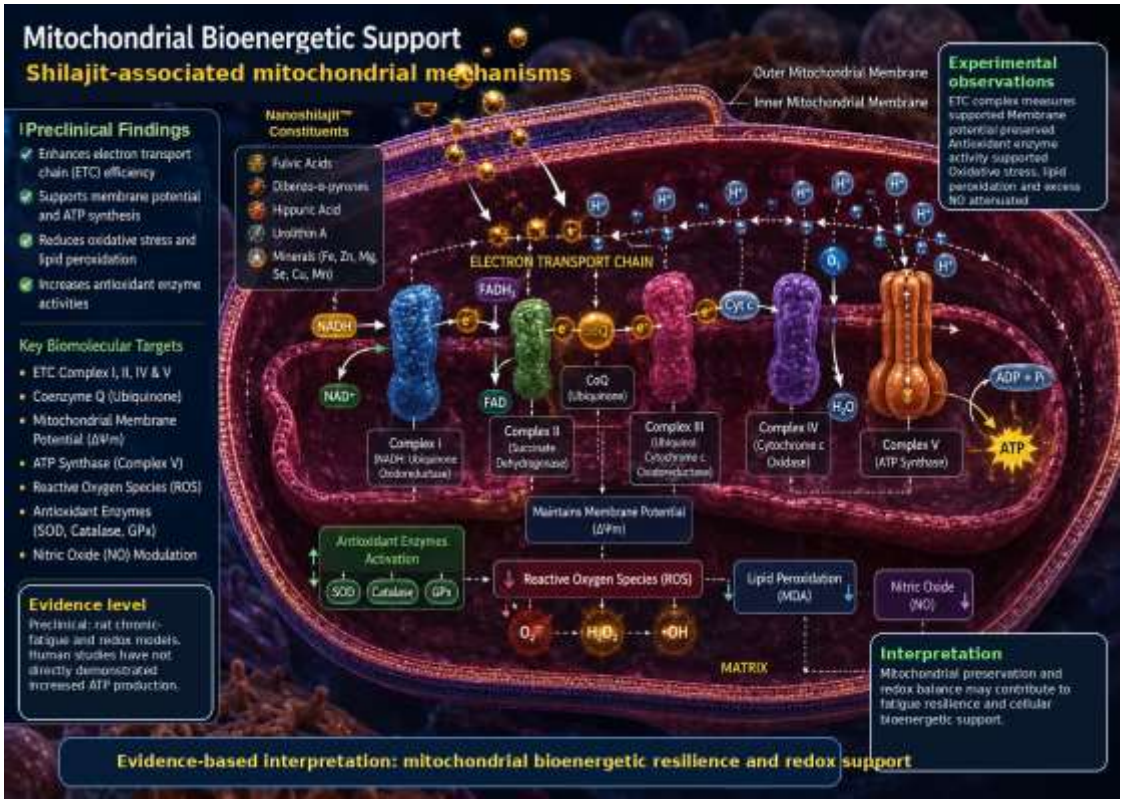

Fig 4: Mitochondrial bioenergetic and redox mechanisms relevant to shilajit-associated fatigue resilience and cellular energy metabolism.

9. Physical Performance, Stamina and Resistance to Fatigue

In a randomised, double-blind, placebo-controlled study, 63 recreationally active men received placebo, 250 mg/day, or 500 mg/day of standardised shilajit for eight weeks[9]. Under the study's fatigue protocol, the 500 mg/day group retained a greater proportion of maximal voluntary isometric force than placebo under defined analytical conditions. This finding supports fatigue-related muscular performance, but it should not be generalised to all forms of aerobic endurance.

A 2026 open-label, single-arm pilot in 25 healthy men receiving 500 mg/day shilajit resin for 28 days reported within-group improvements in strength, endurance, VO_2max and fatigue-related measures[38]. Because there was no placebo comparator, these findings are treated as emerging supportive evidence and do not replace the randomised Keller trial as the primary performance anchor.

The manuscript therefore separates muscular fatigue resistance, subjective stamina and cardiorespiratory endurance. The strongest direct evidence presently concerns fatigue-associated muscular performance.

10. Exercise Recovery, Collagen Metabolism and Skeletal-Muscle Remodelling

Human muscle-biopsy data show that purified shilajit changes expression of ECM-related genes involved in matrix architecture, force transmission, elastic-fibre function, and repair-associated remodelling [10]. Because these are tissue-level transcriptional findings, they provide mechanistic support for adaptation to mechanical loading rather than direct proof of faster clinical recovery.

In a randomised study of recreationally trained men, eight weeks of shilajit at 500 or 1000 mg/day increased serum pro-c1α1 relative to baseline, whereas the placebo group did not show a comparable change[11]. Pro-c1α1 is used as a circulating indicator of type-I collagen synthesis, so this result supports connective-tissue biology without demonstrating that every exercise injury will recover more quickly.

A randomised double-blind trial of Momiai—a related mineral-pitch material described by the authors as shilajit/mumie—in 160 patients with tibial fracture reported a shorter mean time to bone union than placebo[39]. This is clinically interesting for tissue repair but is treated as related-material evidence because Momiai cannot be assumed to be chemically equivalent to the standardised shilajit preparations used elsewhere in this review.

Recovery-related wording is therefore best framed as support for extracellular-matrix and connective-tissue adaptive processes, with fatigue-related performance and collagen biology treated as complementary but distinct domains. Figure 5 summarises the extracellular-matrix and collagen-related findings.

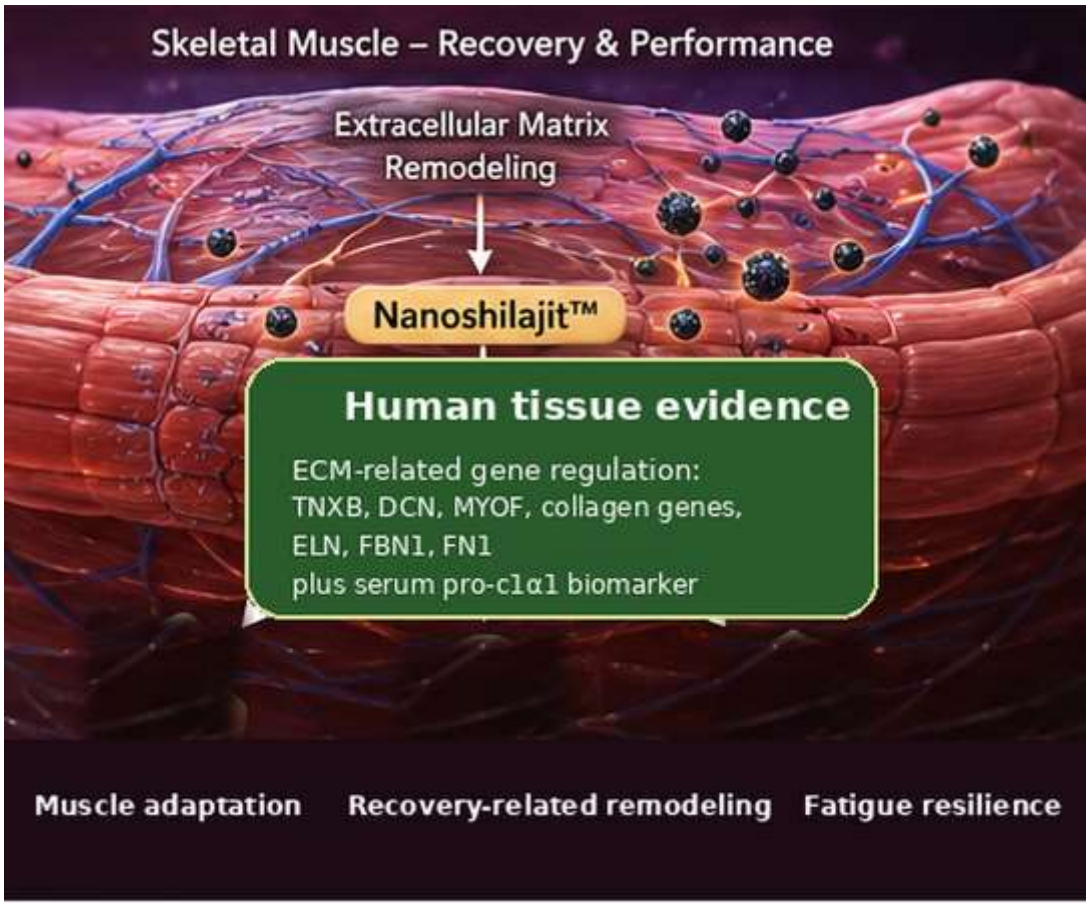

Fig 5: Skeletal-muscle extracellular-matrix remodelling, collagen-associated adaptation and recovery-related pathways.

11. Testosterone and Male Endocrine Physiology

Pandit and colleagues studied healthy men aged 45–55 years in a randomised, double-blind, placebo-controlled trial of purified shilajit at 250 mg twice daily for 90 days[12]. At the end of treatment, circulating total testosterone, free testosterone, and DHEAS were higher in the shilajit arm than in the placebo arm, while LH and FSH remained within maintained levels.

This supports the statement that purified shilajit can influence androgen-related physiology in the studied population. It does not establish treatment of hypogonadism and should not be generalised to every age group, sex or commercial shilajit preparation.

Experimental reproductive work provides mechanistic plausibility through effects on steroidogenic enzymes and testicular function, but these animal findings remain subordinate to the measured human hormonal outcomes[34,35].

12. Male Reproductive Health and Spermatogenesis

Processed shilajit was also evaluated for 90 days in men with oligospermia. Among the 28 participants who completed treatment, several semen-quality measures—including sperm concentration/total count, motility, and normal forms—improved from baseline; seminal malondialdehyde declined, and circulating testosterone increased[13]. The study is clinically relevant, but because it lacked a randomised placebo-controlled efficacy design, the magnitude of causality is less secure than in a conventional RCT.

Earlier rat research also reported dose-related increases in testicular and epididymal sperm numbers after chronic shilajit administration, providing historical experimental support for a spermatogenic effect[40].

Animal studies provide supportive biological plausibility for testicular antioxidant protection, steroidogenesis and spermatogenesis under toxic stress[34,35]. The clinically defensible conclusion is that processed or purified shilajit has shown supportive effects on selected parameters of male reproductive physiology, while evidence for treatment of infertility remains insufficient. Figure 6 summarises the steroidogenic, redox and germ-cell pathways involved.

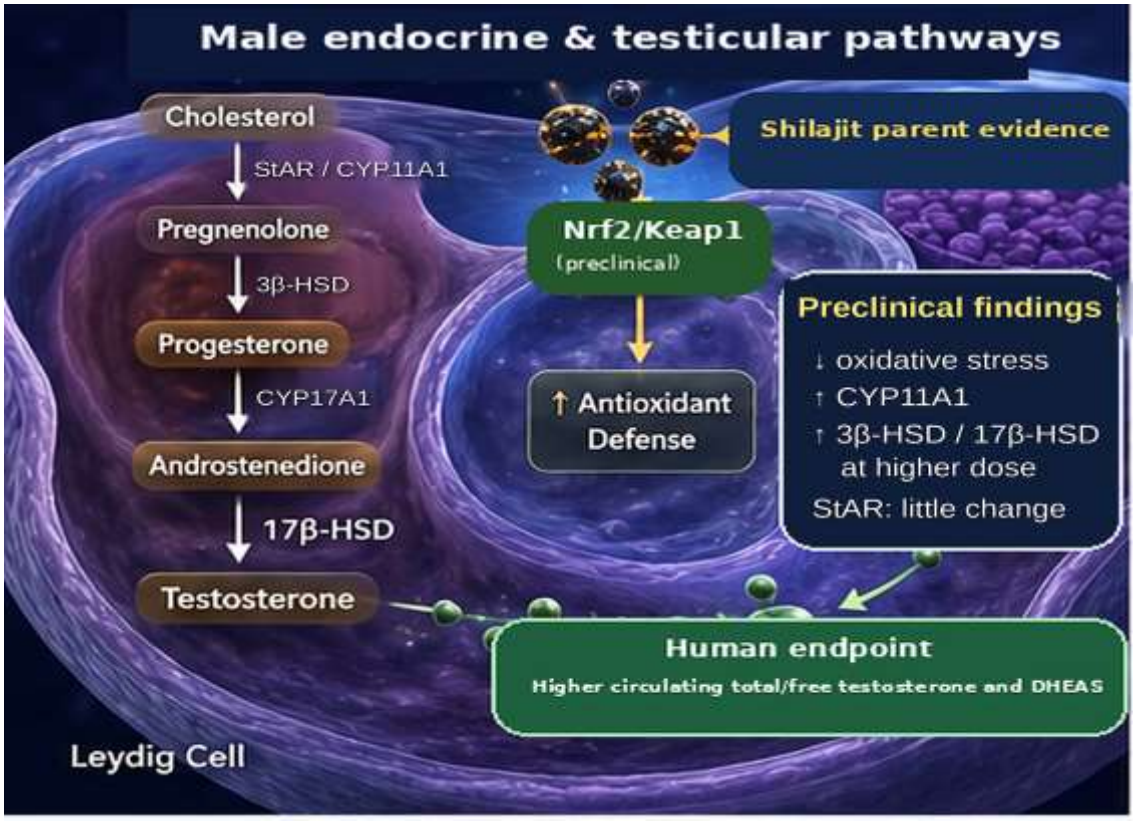

Fig 6: Testicular steroidogenic, antioxidant and reproductive pathways relevant to shilajit-associated male endocrine and reproductive physiology.

13. Antioxidant Defence, Inflammatory Balance and Physiological Resilience

A particularly informative human dataset comes from a 48-week randomised, double-blind, placebo-controlled trial in 60 postmenopausal women with osteopenia[14]. Compared with placebo, standardised shilajit reduced the extent of BMD decline at the lumbar spine and femoral neck and shifted redox/inflammatory measures toward lower MDA and hsCRP and higher GSH, alongside favourable changes in bone-turnover markers.

This study materially strengthens the review because it supplies long-duration human evidence for redox and inflammatory modulation rather than relying solely on in vitro antioxidant assays. It also provides an objective basis for the broader concept of physiological resilience through measurable tissue preservation and biomarker outcomes.

An older 45-day human study using 2 g/day reported reduced serum triglycerides and cholesterol, increased HDL cholesterol and improved antioxidant status without significant changes in blood pressure, pulse, body weight or haematology [41]. Its age and methodological limitations make it supportive rather than definitive evidence.

The findings complement earlier experimental evidence for anti-inflammatory activity, but the human randomised trial should receive greater evidentiary weight[14,42].

The principal human studies most relevant to the benefit domains discussed in this review are summarised in Table 4.

Table 4: Principal human studies of purified or processed shilajit.

Study/design	Population and intervention	Principal findings	Evidence interpretation
Pandit et al. [12] Randomised, double-blind, placebo-controlled	Healthy men aged 45–55 years; purified shilajit 250 mg twice daily for 90 days	After 90 days, total/free testosterone and DHEAS were higher than placebo; LH and FSH remained maintained.	Strongest direct human support for male androgen-related physiology; population-specific and not a hypogonadism-treatment trial
Keller et al. [9] Randomised, double-blind, placebo-controlled	63 recreationally active men; 250 or 500 mg/day for 8 weeks	500 mg/day reduced the fatigue-associated decline in maximal voluntary isometric contraction under defined conditions	Direct human support for muscular fatigue resistance; does not establish generalised aerobic endurance enhancement
Neltner et al. [11] Randomised controlled trial	35 recreationally trained men; 500 or 1000 mg/day for 8 weeks	Both shilajit doses increased circulating pro-c1α1; the high-dose group had a greater proportion of responders than placebo	Human biomarker support for connective-tissue adaptation; not proof of faster clinical recovery
Pingali & Nutalapati [14] Randomised, double-blind, placebo-controlled	60 postmenopausal women with osteopenia; 250 or 500 mg/day for 48 weeks	BMD decline at spine/femoral neck was reduced, with lower MDA/hsCRP and higher GSH plus favourable bone-turnover changes	Long-duration human evidence for redox/inflammatory modulation and tissue preservation
Das et al. [10] Human clinical mechanistic study	Adults with overweight/class I obesity; 250 mg twice daily for 8 weeks, followed by exercise phase	Muscle biopsies showed coordinated ECM-gene changes relevant to matrix organisation, force transmission, elasticity and repair-associated remodelling.	Human tissue-level mechanistic support for musculoskeletal adaptation
Das et al. [15]	Healthy middle-aged	The 250 mg twice-daily group	Human tissue-level support

Randomised controlled human study	women; 125 or 250 mg twice daily for 14 weeks	showed higher skin perfusion and transcriptional changes involving vascular development and ECM networks	for microvascular and ECM maintenance; not evidence of literal age reversal
Biswas et al. [13] Clinical study without placebo-controlled efficacy design	35 oligospermic men enrolled; 28 completed; processed shilajit 100 mg twice daily for 90 days	Among completers, sperm concentration/count, motility and normal forms improved from baseline; seminal MDA fell, and testosterone increased	Clinically relevant supportive evidence for male reproductive physiology; design limits causal certainty

Abbreviations: BMD, bone mineral density; DHEAS, dehydroepiandrosterone sulfate; ECM, extracellular matrix; GSH, glutathione; hsCRP, high-sensitivity C-reactive protein; MDA, malondialdehyde.

14. Cytoprotection and Endogenous Cellular Defence

The traditional concept of "detoxification" is more defensibly translated into measurable cytoprotective biology than into a nonspecific claim of systemic toxin removal. In an acetaminophen-challenge model, shilajit reduced biochemical and histological evidence of hepatic injury and altered signalling associated with oxidative stress, inflammation, and apoptosis, including NF-κB, AKT, and caspase-3[43].

A similar protective pattern has been reported in gastric models. Whole-shilajit preparations reduced gastric mucosal injury and inflammatory/oxidative changes in experimental ulcer and aspirin-lesion paradigms[42,44]. At the constituent level, fulvic-acid fractions and a shilajit-derived biphenyl also showed anti-ulcer activity in experimental systems[45]. These findings support tissue protection under defined chemical stress rather than generalised human toxin clearance.

Reproductive toxicology provides another tissue context. In cadmium- and cyclophosphamide-associated testicular injury models, shilajit improved redox status and steroidogenic function and supported germ-cell and Sertoli-cell parameters; the cyclophosphamide study also identified Nrf2/Keap1 pathway involvement[34,35]. The canonical Nrf2/Keap1–antioxidant-response-element axis summarised in Figure 7 is well characterised in general redox biology[46,47]; direct engagement of that axis by shilajit has so far been shown only in preclinical systems.

Accordingly, the most evidence-aligned interpretation for Nanoshilajit™ is support for endogenous antioxidant, inflammatory-control and cytoprotective mechanisms that contribute to cellular resilience. This positioning is scientifically supportive of the product while avoiding the broader and less testable claim that oral shilajit directly clears unspecified systemic toxins.

15. Cellular Maintenance, Tissue Remodelling and Regenerative Resilience

Several human and cellular studies support a broader tissue-maintenance role for purified shilajit. In middle-aged women, supplementation altered skin transcriptional programs linked with endothelial motility, vascular development, and extracellular-matrix organisation, and the higher dose increased skin microperfusion[15]. This provides human evidence for a microvascular and matrix-level response without implying literal reversal of skin ageing.

Human skeletal-muscle biopsies independently showed coordinated regulation of ECM-associated genes including TNXB, DCN, MYOF, collagen-related genes, ELN, FBN1, and FN1[10]. In a separate randomised study, serum pro-c1α1 increased after shilajit supplementation[11]. Together, these findings support connective-tissue adaptation and remodelling rather than an undefined "rejuvenation" effect.

Experimental evidence further extends this tissue-maintenance framework. Shilajit promoted osteogenic differentiation in human adipose-derived mesenchymal stem cells and produced concentration-dependent effects on migration, proliferation, experimental wound closure, and matrix-remodelling markers in human periodontal-ligament cells[36,48]. Complementing these cell-level findings, the 48-week randomised trial in postmenopausal women associated standardised shilajit with better preservation of bone mineral density and favourable redox/inflammatory biomarker changes[14].

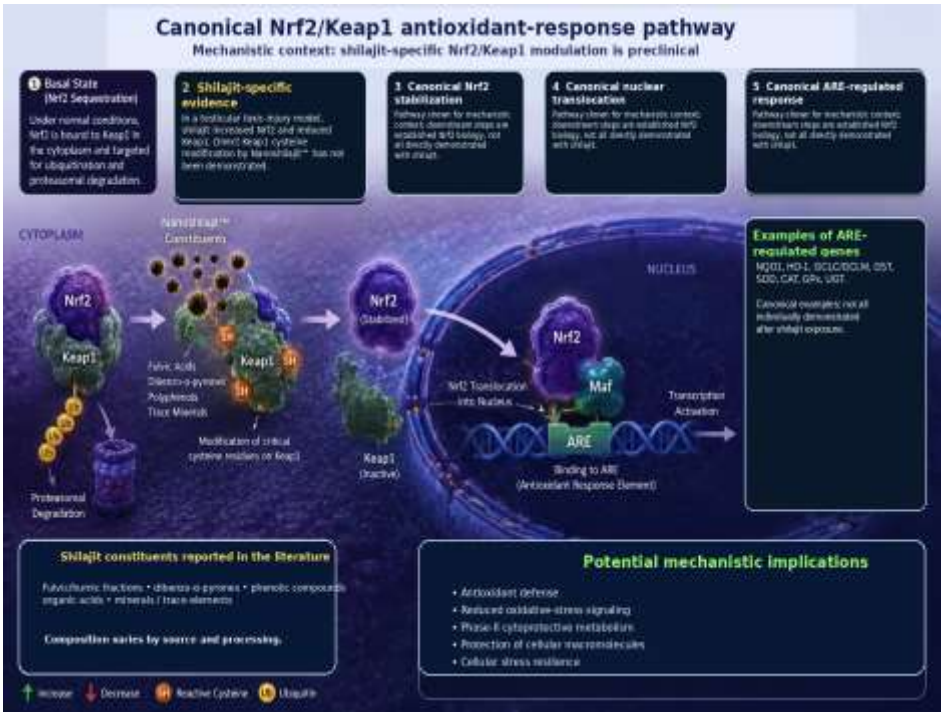

Fig 7: Nrf2/Keap1-centered antioxidant and cytoprotective signalling framework relevant to endogenous cellular defence.

Taken together, the evidence supports the product-relevant concepts of cellular maintenance, extracellular-matrix remodelling, microvascular support, adaptive repair and physiological resilience. These domains provide a defensible biomedical interpretation of "cellular rejuvenation" without implying reversal of biological age. Figure 8 summarises the skin microvascular and extracellular-matrix findings.

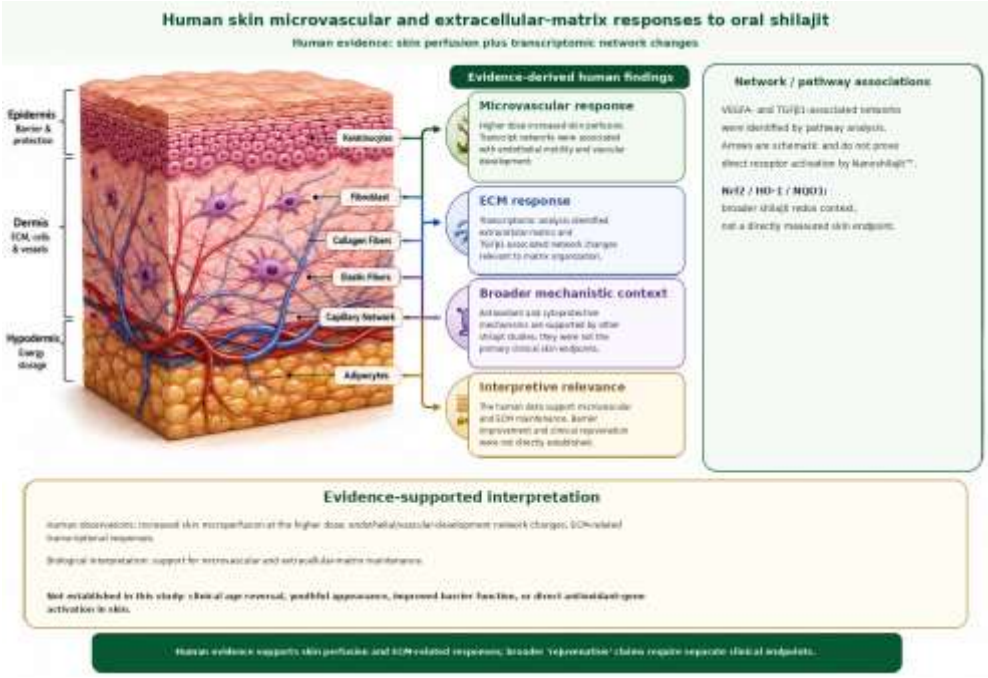

Fig 8: Skin microcirculation, extracellular-matrix maintenance and cellular-resilience pathways associated with oral shilajit exposure.

16. Integrated Evidence Framework

The strongest evidence can be organised into four interacting domains: (1) mitochondrial and fatigue-related physiology; (2) endocrine-reproductive physiology; (3) extracellular-matrix and tissue adaptation; and (4) redox/inflammatory resilience. This integrated model is preferable to a single-pathway explanation because shilajit is a heterogeneous material and the current evidence does not justify assigning all observed outcomes to one constituent or signalling pathway. Table 5 sets out the evidence-weighted interpretation of each proposed benefit domain.

Table 5: Evidence-weighted interpretation of proposed Nanoshilajit™ benefit domains.

Benefit domain	Best direct evidence	Evidence strength	Recommended wording
Energy/bioenergetics	Preclinical mitochondrial study [31]; indirect human fatigue/adaptation data [9,10]	Moderate mechanistic	Supports cellular bioenergetic resilience; avoid claiming proven ATP elevation in humans
Physical performance	Randomised double-blind placebo-controlled fatigue study [9]	Moderate human	May support maintenance of muscular performance during fatigue
Stamina	Indirect from fatigue/performance endpoints [9]	Limited-moderate	May support fatigue resistance; avoid equating with established aerobic endurance enhancement.
Recovery	Human muscle transcriptomics [10] + collagen biomarker RCT [11]	Moderate mechanistic-human	Supports musculoskeletal and connective-tissue adaptive processes
Testosterone	Randomized double-blind placebo-controlled human trial [12]	Moderate direct human	Purified shilajit increased total/free testosterone and DHEAS in the studied population.
Male reproductive health	Clinical oligospermia study [13] + preclinical support [34,35]	Moderate but limited	Supports selected male semen and endocrine parameters; not an infertility-treatment claim.
Vitality/resilience	48-week RCT on redox/inflammation/tissue preservation [14] + fatigue data [9]	Moderate integrative	Supports physiological resilience through redox, tissue and fatigue-related pathways
Detoxification	Primary preclinical cytoprotection in gastric and hepatic models [42–44]; reproductive toxicology support [34,35]	Moderate preclinical; no direct human detoxification endpoint	Supports endogenous antioxidant, anti-inflammatory and cytoprotective defences; avoid nonspecific toxin-removal claims
Cellular rejuvenation	Human muscle/skin tissue evidence [10,15]; collagen and bone/redox human data [11,14]; cellular remodelling studies [36,48]	Moderate mechanistic with human tissue/biomarker support	Prefer cellular maintenance, ECM remodelling, microvascular support and tissue resilience rather than literal age reversal

Nano-structuring advantage	General nanophytomedicine reviews [16,17]; shilajit-specific nanoformulation studies [18–20]	Moderate formulation/preclinical evidence; comparative human PK not yet available	Same parent shilajit evidence applies; nanostructuring may improve dispersion, dissolution, absorption and exposure, while the exact human magnitude remains unquantified.

17. Evidence Translation from Shilajit to Nanoshilajit™

Evidence translation from shilajit to Nanoshilajit™ is additive rather than substitutive. Because the finished formulation retains purified and standardised shilajit as its active phytocomplex, human studies of purified/processed shilajit are directly relevant as parent-ingredient evidence for the biological domains discussed here—fatigue resistance, ECM/collagen adaptation, androgen physiology, male reproductive parameters, redox balance, and tissue maintenance[9–15,34,35]. Nano-structuring does not create a new pharmacological ingredient; it is intended to improve delivery of the same parent matrix[16–20].

The evidence hierarchy can therefore be expressed as three complementary layers: established purified/standardized shilajit evidence defines the ingredient's biological activity; shilajit-specific and general nanoformulation studies support a delivery-enhancement rationale; and finished-product analytical or comparative pharmacokinetic studies would quantify the magnitude of the Nanoshilajit™ formulation advantage[16–20]. On this basis, Nanoshilajit™ may be positively positioned as an advanced delivery form of the same shilajit phytocomplex, with the full purified-shilajit evidence base remaining relevant to its biological rationale.

18. Safety, Heavy Metals and Product Quality

Purified shilajit used in clinical studies has generally been reported as well tolerated under the specific doses and durations tested[9,12–15]. This does not establish universal safety across all preparations or unlimited doses.

Elemental safety is especially important. Published analyses show substantial variability across samples: some studies reported elements above referenced permissible limits, while other geographically diverse samples had toxic elements below established thresholds; a 2025 supplement survey additionally detected measurable thallium in commercial shilajit products. Heavy-metal and humic-substance interactions in shilajit, including proposed detoxification mechanisms, have been reviewed separately. These differences reinforce the need for batch-specific testing rather than assumptions based on the generic name shilajit[4,6,8,32,49].

Accordingly, credible product characterisation requires authenticated sourcing, validated purification, chemical fingerprinting, heavy-metal testing, microbial and mycotoxin control and product stability. Proprietary certificates of analysis can support product quality but should be distinguished from peer-reviewed clinical efficacy evidence. The purification, standardisation, analytical-characterisation and quality-control sequence relevant to a finished shilajit product is summarised in Figure 9.

19. Limitations of the Available Evidence

Modern chemical reviews and comparative analyses show substantial variation by geography and processing, so chemical-marker findings from one source cannot be presumed for another product without direct assay[22,24–26].

A critical Journal of Ethnopharmacology review emphasised that much of the older shilajit literature suffered from inadequate controls, uncertain dosing relevance and insufficient systematic evaluation[27]. Newer controlled human and analytical studies improve the evidence base but do not erase those historical limitations.

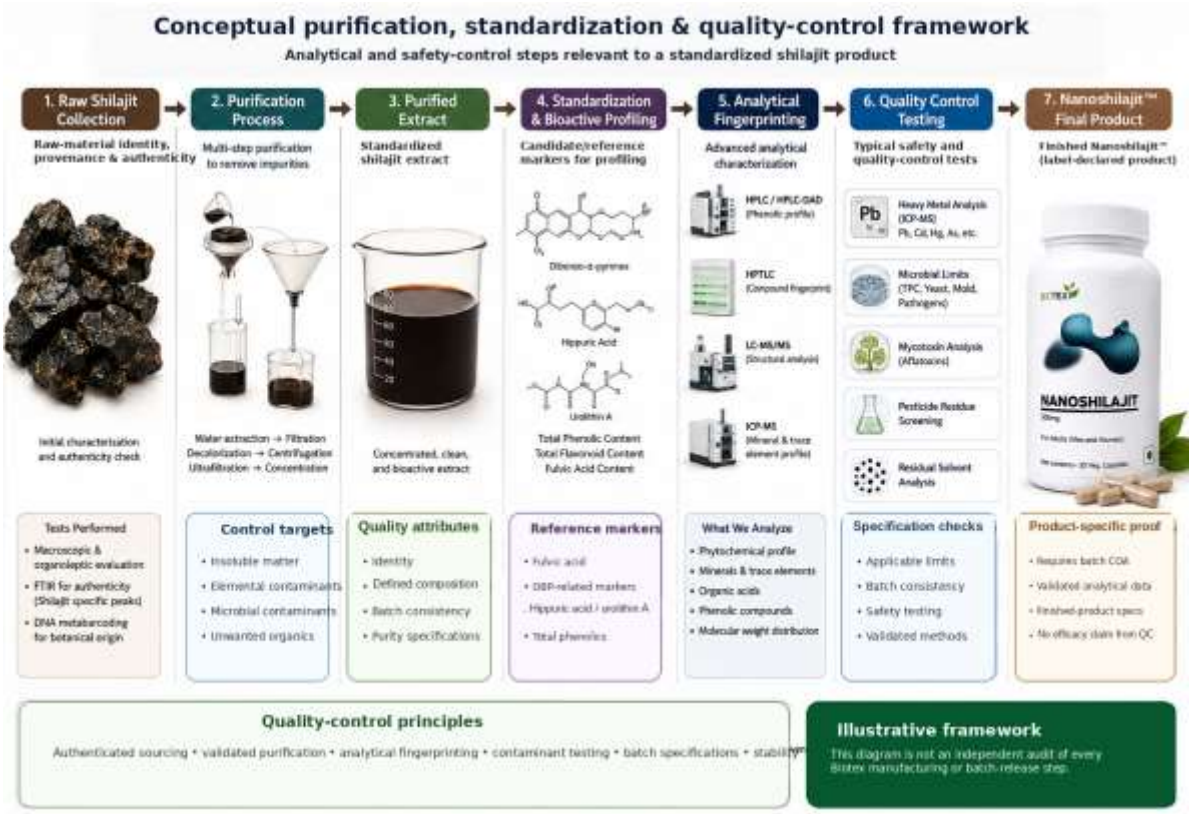

Fig 9: Purification, standardisation, analytical characterisation and quality-control pathway for Nanoshilajit™.

The human evidence base remains relatively small and heterogeneous. Several clinically relevant findings arise from single principal trials that have not yet been extensively replicated by independent groups. Some studies assess biomarkers or transcriptomic changes rather than patient-centred functional outcomes. The oligospermia study is clinically informative but is not a randomised placebo-controlled efficacy trial. The fatigue study uses a specific muscular-fatigue protocol and should not be generalised to all definitions of stamina or endurance.

Mechanistic work involving humic substances, isolated fractions or toxic-injury models can support plausibility but cannot establish equivalent effects in healthy humans. Findings from multi-ingredient formulations cannot be attributed solely to shilajit and were therefore not used as core evidence in this revised manuscript.

A comparative human pharmacokinetic study of the finished Nanoshilajit™ formulation was not identified. This limits the ability to quantify how much nano-structuring increases systemic exposure relative to a conventional shilajit preparation, but it does not negate the applicability of purified/standardized shilajit studies to Nanoshilajit™ as parent-ingredient evidence. Shilajit-specific nanoformulation studies nevertheless provide experimental support for improved delivery and biological performance at the formulation level[18–20].

20. Conclusion

The literature available through 2026 supports a differentiated rather than uniform interpretation of shilajit. The most convincing direct human evidence concerns selected androgen-related outcomes, fatigue-associated muscular performance, collagen-related biomarkers, oxidative/inflammatory balance, bone preservation and selected male reproductive parameters. Human transcriptomic studies add credible tissue-level evidence for skeletal-muscle extracellular-matrix adaptation and skin microvascular/ECM responses.

Experimental studies extend the biological rationale to mitochondrial preservation, reproductive protection, osteogenic differentiation, inflammatory modulation and wound-healing-related cellular

responses. These mechanistic findings are important but should remain subordinate to controlled human evidence when clinical claims are formulated.

Nanoshilajit™ can therefore be positioned scientifically as a nanostructured form of purified and standardised shilajit that preserves the parent phytocomplex and inherits its foundational ingredient-level evidence. Human studies of purified or processed shilajit remain directly relevant to the formulation's rationale for bioenergetic resilience, fatigue resistance, musculoskeletal adaptation, male androgen and reproductive physiology, redox balance, and tissue maintenance. Nano-structuring adds a credible delivery rationale because nanoscale phytomedicine systems can improve dispersion, dissolution, and biological availability, and shilajit-specific nanoformulation studies demonstrate technically feasible nanoscale systems with favourable experimental performance[16–20]. The precise size of any human bioavailability advantage for the finished Nanoshilajit™ product has not yet been established in a head-to-head pharmacokinetic study; this limits quantitative superiority claims but does not separate Nanoshilajit™ from the established shilajit parent evidence base.

Declarations

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Author Contributions

All authors contributed to the conceptualisation of the review, literature searching and evaluation, scientific interpretation, manuscript preparation, critical review, editing, and final approval of the manuscript. All authors have read and approved the final version and take responsibility for the integrity of the work.

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Conflict of Interest

All authors are affiliated with Biotex Life Solutions Pvt. Ltd., the company associated with the formulation and commercialisation of Nanoshilajit™. This relationship is disclosed in the interest of transparency. The review is based on published scientific literature, and evidence was interpreted according to study design, formulation identity, and level of evidence.

Data Availability

No new datasets were generated or analysed for this narrative review. All information discussed in the manuscript is derived from published sources cited in the reference list.

Ethics Approval and Consent to Participate

Not applicable. This article is a narrative review of previously published literature and did not involve new studies with human participants or animals.

Consent for Publication

Not applicable.

Use of AI-Assisted Tools

AI-assisted tools were used for literature searching, gathering relevant information, literature correction and organisation, language refinement, formatting, and preparation of illustrative scientific figures. Scientific evaluation of the evidence, interpretation of findings, verification of references and claims, and the conclusions of the manuscript were performed by the authors. The authors take full responsibility for the accuracy, integrity, and scientific content of the work.

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