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A Matrix-Reduced Whole-Cactus Approach to San Pedro: A Two-Stage Framework for Selective Reduction of the Mucilage–Polysaccharide Matrix

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Abstract

San Pedro preparations derived from Echinopsis pachanoi contain mescaline together with minor alkaloids, soluble metabolites, mucilage, colloids, suspended solids, and other cactus-derived constituents. This physical matrix contributes substantially to the volume, viscosity, and material burden of conventional aqueous preparations while remaining chemically distinct from the principal low-molecular-weight alkaloids. This article proposes a matrix-reduced whole-cactus approach that separates primary botanical extraction from subsequent physical refinement. Fresh cactus tissue is extracted in mildly acidic water and filtered to remove coarse structural material. High-strength food-grade ethanol is then added to the retained aqueous extract to induce aggregation of an ethanol-responsive polymer-rich fraction, which is removed by a second filtration or decantation before the ethanol is reduced and the preparation returned to a defined aqueous volume. The process remains continuously derived from the original cactus extract without isolating or recombining mescaline. Performance is evaluated by paired mass balance, comparing mescaline recovery, minor-alkaloid retention, broader phytochemical continuity, dry matter, polysaccharide content, suspended solids, viscosity, and separated matrix mass. The framework provides a simple and experimentally testable intermediate between conventional cactus decoction and molecular mescaline isolation and establishes post-extraction matrix reduction as an independent variable in botanical preparation technology.

Keywords: San Pedro, Echinopsis pachanoi, Trichocereus pachanoi, Huachuma, mescaline, cactus mucilage, polysaccharides, hydrocolloids, matrix reduction, whole-cactus extraction, post-extraction separation.

1. Introduction

San Pedro refers to traditional Andean preparations based primarily on Echinopsis pachanoi (synonym: Trichocereus pachanoi) and related mescaline-containing columnar cacti. Its ceremonial and medicinal use is deeply established in northern Peru and neighboring Andean regions, with archaeological and ethnomedical continuity extending across approximately two millennia [1]. Mescaline, 3,4,5-trimethoxyphenethylamine, is the principal psychoactive alkaloid, while T. pachanoi also contains

phenethylamine-related compounds including 3-methoxytyramine, lophophine, homopiperonylamine, and lobivine [2,3]. A conventional San Pedro preparation is therefore a multicomponent botanical extract rather than a mescaline solution.

Two properties of the cactus create the technological problem addressed here. First, mescaline concentration varies markedly between plants and anatomical tissues [4,5], so preparation mass alone is an inadequate basis for chemical comparison. Second, aqueous processing transfers the comparatively small alkaloid fraction together with a much larger population of mucilage, polysaccharides, colloids, suspended particles, minerals, and other botanical solids. The desired soluble chemistry and the accompanying physical matrix therefore enter the same preparation even though they differ strongly in molecular scale and solvent behavior.

Cactaceae mucilage provides a mechanistic basis for separating these variables. Opuntia mucilage consists of highly hydrated carbohydrate polymers and can be precipitated from aqueous cactus extracts by alcohol [6,7]. Direct E. pachanoi processing provides the species-specific link: cactus material was processed with water, coarse fibre was removed, and the filtered liquid was treated with 96% ethanol to recover a precipitated fraction with pronounced flocculating activity [8]. This establishes ethanol-responsive physical separability in San Pedro itself.

The present framework converts that physical behavior into a preparation hypothesis: a conventional-type aqueous San Pedro extract is produced first, after which a separate post-extraction ethanol step is used to remove part of the polymer-rich matrix while retaining the mescaline-containing soluble fraction. The hypothesis is tested by paired mass balance from the same botanical batch. A favorable process is defined by substantial reduction of physical matrix together with high recovery of mescaline, defined minor alkaloids, and the broader soluble phytochemical profile.

2. Quantitative Alkaloid Architecture

The natural variability of San Pedro requires chemical composition to be measured rather than inferred from cactus weight. Ogunbodede et al. analyzed cortical stem chlorenchyma from 14 Echinopsis taxa and cultivars using a uniform procedure consisting of methanolic Soxhlet extraction, acid–base partitioning, and quantitative high-performance liquid chromatography, with representative confirmation by gas chromatography–mass spectrometry [4]. Mescaline was detected in all 14 specimens, with concentrations ranging from 0.053% to 4.7% of tissue dry weight. The mescaline concentrations measured across the 14 Echinopsis taxa and cultivars are summarized in Table 1.

Table 1. Mescaline concentrations in 14 Echinopsis taxa and cultivars analyzed under uniform conditions [4].

Taxon/cultivar	Geographic or collection origin	Mescaline (% dry weight)
E. pachanoi	Matucana, Lima Region, Peru	4.70
E. pachanoi cv. Juul's Giant	Cultivar	1.40
E. pachanoi, long-spined	Huancabamba, Piura Region, Peru	1.20
E. scopulicola	Tapecua, Bolivia	0.85
E. pachanoi	Río Marañón above Chagual, Peru	0.82

Taxon/cultivar	Geographic or collection origin	Mescaline (% dry weight)
E. pachanoi, short-spined	Huancabamba, Piura Region, Peru	0.54
E. lageniformis, monstrose	Cultivar	0.48
E. pachanoi complex cf. T. pallarensis	Pallar, Ancash, Peru	0.47
E. pachanoi complex cf. T. riomizquensis	Chuyllas, Río Mizque, Bolivia	0.40
E. santaensis	Santa Valley, Ancash, Peru	0.32
E. peruviana KK242	Matucana, Lima Region, Peru	0.24
E. lageniformis	Cultivar	0.18
E. puquiensis	Nazca–Puquio Road, Peru	0.13
E. uyupampensis	Backeberg collection	0.053

The highest concentration, 4.7% dry weight in the Matucana E. pachanoi specimen, was approximately 89 times the 0.053% measured in E. uyupampensis. Substantial variation also occurred within E. pachanoi, including a greater than twofold difference between two plants derived from the same Huancabamba source population [4]. These values characterize cortical chlorenchyma and demonstrate substantial biological variability under standardized tissue and analytical conditions.

Spatial variation within individual plants adds a second source of heterogeneity. Lin et al. divided a complete T. pachanoi specimen into 55 longitudinal sections and separately analyzed epidermal and fleshy tissues after lyophilization [5]. Mescaline concentrations ranged from 0.14 ± 0.01 to 102.6 ± 3.49 µg/mg. Epidermal tissue contained significantly more mescaline than corresponding fleshy tissue, and the highest concentrations occurred in active meristematic and protruding regions. A validated ultra-high-performance liquid chromatography–electrospray ionization tandem mass spectrometry (UHPLC–ESI–MS/MS) method developed specifically for Trichocereus provides a contemporary analytical basis for direct mescaline quantification and provides preliminary independent support for greater mescaline abundance in chlorenchymatous than parenchymatous tissue [9].

Process comparisons must therefore use the same botanical batch and defined anatomical composition. Mescaline is reported as absolute mass as well as concentration because removal of water or non-alkaloidal solids can increase concentration without increasing chemical recovery.

Mescaline recovery (%) = mescaline mass in evaluated fraction / mescaline mass in starting fraction × 100

3. Aqueous Extraction of the San Pedro Alkaloid Fraction

Aqueous processing provides the established botanical foundation of San Pedro preparation. Among Saraguro yachakkuna in southern Ecuador, cactus pulp used for visionary oral administration is cooked for approximately 7 h until a viscous consistency is obtained [10]. This provides a documented Andean reference for prolonged atmospheric aqueous processing with simple equipment.

Analytical work independently establishes mescaline recovery from fresh T. pachanoi under mildly acidic aqueous conditions. Gennaro et al. ground fresh cactus and extracted the resulting pulp with either a

methanolic-ammoniacal system or an aqueous phosphate-buffered solution at pH 4.0; the analyzed T. pachanoi material contained approximately 3.10 mg mescaline per gram fresh cactus [11]. Van Der Sypt subsequently validated mescaline quantification in fresh cactus tissue and aqueous cactus extracts, including E. pachanoi, E. peruviana, and E. lageniformis [12]. These studies support water-based San Pedro fractions as directly measurable chemical systems.

For the present framework, the primary extraction stage has a specific function: it transfers mescaline, minor alkaloids, and broader water-soluble cactus constituents away from macroscopic structural tissue into a common liquid. The subsequent ethanol step begins after aqueous extraction and coarse removal of plant material, making primary extraction and matrix reduction experimentally separable operations.

4. The Mucilage–Polysaccharide Matrix as a Quantitative Variable

Cactus mucilage is physically distinct from the mescaline-containing small-molecule fraction. In Opuntia ficus-indica, isolated mucilage contains arabinose, galactose, rhamnose, xylose, and galacturonic acid and has been characterized at approximately 4.3 × 10^6 daltons (Da) [6]. Its high hydration and colloidal behavior provide the physicochemical basis for treating the polymer-rich matrix separately from low-molecular-weight alkaloids.

Sepúlveda et al. quantified aqueous mucilage extraction and alcohol precipitation from Opuntia cladodes [7]. Across tested extraction conditions, recovered mucilage represented approximately 1.33–1.56% of fresh cladode mass and 16.50–19.26% of dry mass; the reported average was 1.48% fresh weight and 19.4% dry weight. In a precipitation experiment using ethanol or isopropanol at aqueous-extract-to-alcohol ratios of 1:3 and 1:4, the recovered mucilage fraction was approximately 20.8% of dry mass, with no significant yield difference between the tested alcohols or ratios [7]. These values provide a quantitative Cactaceae benchmark for the physical scale of an alcohol-responsive polymer fraction.

Direct *E. pachanoi* processing establishes the corresponding separation behavior in the target species. Mature cactus material was processed with distilled water at a reported 1:1 ratio, passed through a 1000-µm mesh, and the filtered juice was treated with 96% ethanol at an initial 1:2 juice-to-solvent ratio [8]. The recovered precipitated fraction retained strong flocculating activity [8]. These data establish directly in *E. pachanoi* the sequence of aqueous processing, coarse fibre removal, and ethanol-responsive recovery of a mechanically separable cactus-derived fraction. The Cactaceae evidence relevant to post-extraction matrix separation is summarized in Table 2. Quantitative Opuntia values serve as comparative Cactaceae benchmarks for evaluating E. pachanoi-specific matrix yields.

Table 2. Cactaceae evidence relevant to post-extraction matrix separation

Species	Processing condition	Result	Relevance
E. pachanoi	Reported cactus:water 1:1; 1000-µm separation; filtered juice + 96% ethanol initially at 1:2, followed by solvent changes [8]	Recoverable precipitated cactus-derived fraction with strong flocculating activity	Direct San Pedro evidence for ethanol-responsive post-aqueous separation
Opuntia spp.	Aqueous extraction followed by ethanol or isopropanol precipitation [7]	16.50–19.26% dry-weight mucilage across extraction conditions	Quantitative Cactaceae benchmark
Opuntia spp.	Extract:alcohol 1:3 or 1:4 [7]	Approximately 20.8% dry-mass mucilage in precipitation experiment	Demonstrates robust alcohol-responsive polymer recovery

Species	Processing condition	Result	Relevance
O. ficus-indica	Isolated mucilage characterization [6]	Molecular weight ~4.3 × 10^6 Da	Molecular-scale distinction from mescaline
O. ficus-indica fruit	Chemical mucilage characterization [13]	23.4% galacturonic acid and multiple polysaccharide fractions	Demonstrates chemical heterogeneity of cactus mucilage

Matsuhiro et al. further showed that O. ficus-indica fruit mucilage is chemically heterogeneous: the isolated material contained 23.4% galacturonic acid and arabinose, rhamnose, xylose, and galactose in an approximate molar ratio of 1.0:1.7:2.5:4.1, while gel-permeation chromatography resolved multiple polysaccharide fractions [13].

The combined evidence supports a quantitative separation model in which physical matrix and soluble phytochemistry are measured independently. Dry mass, carbohydrate or polysaccharide content, suspended solids, and viscosity describe the matrix response; mescaline, defined minor alkaloids, and chromatographic profiles describe chemical retention. The key process question is therefore the selectivity of the ethanol-induced separation, not the mere presence of a precipitate.

5. Gastrointestinal and Sensory Burden of Traditional San Pedro

Mescaline itself produces dose-dependent gastrointestinal effects and must therefore be controlled when preparation tolerability is compared. In a randomized, double-blind, placebo-controlled crossover study, 16 healthy participants received placebo and 100, 200, 400, and 800 mg mescaline [14]. Emesis occurred in 2 of 16 participants at 400 mg and 7 of 16 at 800 mg; nausea increased at the higher doses [14]. A pooled analysis of two controlled studies comprising 48 participants and 96 mescaline administrations likewise identified nausea as dose-limiting [15].

A whole-cactus decoction adds preparation-dependent exposures that are absent from isolated mescaline administration, including dissolved botanical dry matter, hydrated polysaccharides, colloidal material, suspended particles, viscosity, liquid volume, bitterness, odor, and texture. These variables can be quantified individually as preparation-level factors potentially associated with tolerability.

The appropriate practical comparison therefore uses conventional and matrix-reduced preparations derived from the same aqueous batch and normalized to the same absolute mescaline exposure.

6. Proposed Matrix-Reduced Whole-Cactus Preparation

The proposed method preserves the simple logic of an aqueous San Pedro preparation and adds one post-extraction separation stage. The practical equipment consists of a cutting tool, an ordinary cooking vessel, water, food-grade citric acid, inexpensive pH paper, a coarse woven cloth or sieve, a measuring vessel, high-strength food-grade ethanol, and a heat source. Instrumental analysis establishes operating conditions, process selectivity, and mass balance, while the physical separation itself relies on the simple operations described below.

6.1 Preparation of the cactus material

Spines and the manually separable thin translucent or waxy surface film are removed from fresh E. pachanoi while the underlying green cortex is preserved. The removed surface film is treated operationally as a distinct superficial structural fraction. Plant cuticles are generally composed of a cutin matrix and

associated cuticular waxes [16], whereas mescaline in T. pachanoi is preferentially enriched in epidermal and chlorenchymatous tissues [4,5,9]. Preserving the green cortex therefore protects the anatomically mescaline-rich outer living tissue while the removed superficial material can be weighed and analyzed separately during validation.

A preliminary freeze–thaw treatment may be evaluated as an optional aid to superficial film removal. Freeze-based peeling has been shown in plant food processing to loosen the outer surface layer while reducing loss of underlying tissue compared with thermal peeling [17]. In the present framework, its value would be determined by the mass and mescaline content of the removed superficial fraction.

The pale central fibrous core is removed as a second defined structural fraction. Its removal reduces the amount of structural tissue entering the extraction, while its chemical contribution is quantified because mescaline is heterogeneously distributed across T. pachanoi tissues [5]. The removed core is therefore weighed and sampled for mescaline analysis during process characterization.

The retained green cortical and fleshy tissue is cut into small pieces and crushed or macerated sufficiently for uniform contact with the extraction water. This operation can be performed manually or with ordinary food-processing equipment. A representative aliquot of each fresh botanical batch is dried to constant mass to determine initial dry-matter content. The practical preparation remains defined on a fresh-tissue basis, while extraction recovery and matrix reduction are additionally normalized to the starting dry matter.

6.2 Mildly acidic aqueous extraction

The prepared cactus is placed in the cooking vessel and combined with water. Direct E. pachanoi processing used a reported 1:1 cactus-to-water ratio [8]. For reproducible implementation, the present protocol operationalizes this starting condition as 1 kg of prepared fresh cactus tissue per 1 L of water; the exact mass and volume used are recorded for each batch.

After the cactus tissue and water have been combined, food-grade citric acid is added until the resulting cactus–water mixture reaches approximately pH 4. The pH is measured in the mixed liquid phase and readjusted after equilibration where necessary to compensate for the intrinsic buffering capacity of the plant material. Fresh T. pachanoi has been extracted analytically in an aqueous phosphate-buffered system at pH 4.0 [11]. Citric acid has independently been shown to replace hydrochloric acid in mescaline sample preparation from Trichocereus macrogonus var. pachanoi without loss of extraction performance and with improved recovery under some tested conditions [18]. Together these data support approximately pH 4 as the starting extraction condition and citric acid as a compatible acidifying agent.

The mixture is heated at atmospheric pressure for approximately 7 h, using the Saraguro preparation as the temporal reference [10]. Gentle boiling or simmering is sufficient, with water added as required to maintain a filterable liquid phase; the total added water is recorded. Cactaceae mucilage contains galacturonic-acid-rich polysaccharides [6,13], and prolonged heating of pectic polymers under mildly acidic conditions can decrease molecular weight and viscosity through acid hydrolysis and, depending on esterification state, β-elimination [19]. Extraction time is therefore evaluated against three coupled outcomes: mescaline recovery, retention of minor alkaloids and the broader soluble phytochemical profile, and preservation of a sufficiently polymeric matrix for subsequent ethanol-induced separation. Time-course analysis identifies the shortest extraction period at which mescaline recovery approaches a plateau while minor-alkaloid retention, broader phytochemical continuity, and matrix-separation efficiency remain high.

6.3 First filtration: removal of coarse cactus material

The cooked preparation is passed through a coarse woven cloth, kitchen-type sieve, or comparable filter and the yellow-brown liquid is retained. Direct E. pachanoi processing used a 1000-µm mesh [8], corresponding to approximately 1 mm. A cloth or sieve producing a similar coarse separation is therefore sufficient for the practical process.

This first filtration removes macroscopic fibres and cooked plant pieces while allowing the liquid, fine suspended material, colloids, mucilage/polysaccharides, mescaline, minor alkaloids, and other soluble constituents to pass. In experimental runs, the retained liquid is mixed thoroughly before subdivision and the coarse residue is collected for dry-mass and mescaline mass balance.

6.4 Ethanol-induced matrix redistribution

High-strength food-grade ethanol is added directly to the filtered aqueous San Pedro liquid. The direct E. pachanoi study used 96% ethanol at an initial ratio of one volume of filtered cactus juice to two volumes of solvent [8]. For an approximately aqueous starting extract, combining 1 volume extract with 2 volumes of 95–96% ethanol produces a nominal ethanol fraction of approximately 63–64% volume/volume (v/v) before non-additive ethanol–water volume contraction and dissolved botanical solids are considered.

The published procedure included repeated solvent changes until decolorization [8], whereas the present approach evaluates a single ethanol-treatment step followed by mechanical separation. The present method deliberately isolates the first ethanol-induced separation event from that more extensive solvent-exchange procedure: one 1:2 addition is used as the initial test condition so that the process remains simple and the selectivity of a single post-extraction precipitation can be measured directly.

After mixing, the hydroethanolic preparation is left at ambient temperature. Room-temperature precipitation with 95% ethanol is established for O. ficus-indica mucilage [20]. A separate O. cochenillifera procedure used a 30-min ethanol precipitation period after aqueous extraction and filtration [21]. Approximately 30 min at ambient temperature therefore provides the initial Cactaceae-derived contact condition for the single-step San Pedro process. Visible flocs, cloudy aggregates, gelatinous material, or sediment indicate that matrix redistribution has occurred; the recovered material is operationally termed the ethanol-precipitable polymer-rich fraction until its composition is measured.

6.5 Second filtration: removal of the precipitated matrix

After the ethanol-contact period, the preparation is filtered a second time through a clean woven cloth or coarse filter. Where the aggregated material settles clearly, the upper liquid may first be decanted and the remaining material then filtered. The liquid is retained and the aggregated polymer-rich material is removed.

This second separation is mechanistically distinct from the first. Coarse filtration removes original cactus tissue, whereas the second filtration removes material that remained in the aqueous preparation but became mechanically separable after ethanol addition. Both the retained liquid and the removed fraction are collected quantitatively. Mescaline measured in the separated fraction captures losses through precipitation, adsorption, physical entrapment, or co-precipitation with the aggregated matrix. Selectivity is therefore determined experimentally from the complete alkaloid mass balance across the retained liquid and separated fraction.

Mescaline recovery (%) = mescaline mass in retained liquid / mescaline mass before ethanol treatment × 100

Matrix reduction (%) = dry mass of removed precipitate / dry matter before ethanol treatment × 100

6.6 Ethanol reduction and return to an aqueous phase

The retained liquid after the second separation contains the soluble cactus fraction in a hydroethanolic medium. It is transferred to a broad vessel and ethanol is progressively removed under atmospheric conditions using adequate ventilation and an ignition-free controlled heat source; open flame and other ignition sources are excluded because ethanol produces readily ignitable vapors [22]. Pure ethanol has a normal atmospheric boiling point of approximately 78.4 °C [23], while the boiling and evaporation behavior of an ethanol–water extract changes continuously as its composition changes.

Residual ethanol and final liquid volume define the scientific endpoint of solvent reduction. Experimental work with heated ethanol-containing liquid foods shows that remaining ethanol concentration is strongly related to the starting concentration and the remaining liquid-volume fraction [24]. During process characterization, starting volume, vessel geometry, temperature, elapsed time, final volume, and residual ethanol are recorded. After ethanol reduction, water is added as required to restore a predetermined final volume.

Once a reproducible relationship between ordinary heating conditions, final volume, and residual ethanol has been established, the validated observable endpoint can be used for routine preparation without requiring instrumental ethanol measurement for every batch.

6.7 Complete practical sequence

In practical terms, the protocol begins by removing the spines and superficial translucent film, cutting out the central fibrous core, and cutting or crushing the retained green and fleshy cactus tissue. The tissue is combined with the defined 1:1 cactus-to-water starting condition, adjusted with citric acid to approximately pH 4, and heated for the reference extraction period. The cooked material is filtered through coarse cloth or a sieve, and the yellow-brown liquid is retained. Two volumes of 95–96% food-grade ethanol are then added for each volume of filtered aqueous extract. After mixing and approximately 30 min at ambient temperature, the preparation is filtered or decanted a second time. The aggregated polymer-rich fraction is removed, the liquid is retained, ethanol is reduced by atmospheric heating, and the final preparation is restored to a defined aqueous volume.

The technological operations are therefore cutting, aqueous cooking, coarse filtration, alcohol-induced aggregation, a second mechanical separation, and evaporation. The scientific measurements quantify the performance and operating tolerances of this simple sequence.

7. Chemical Continuity and Distinction from Mescaline Isolation

The term matrix-reduced whole-cactus preparation is used here operationally to describe a preparation whose retained chemistry remains continuously derived from the same original cactus extract while selected structural and polymer-rich fractions are physically removed. No purified mescaline intermediate is produced and no isolated alkaloids are recombined into the final liquid.

This differs from molecular isolation in both objective and analytical criterion. Mescaline isolation seeks chemical selectivity toward one target molecule. Matrix reduction seeks physical selectivity: the retained liquid should preserve mescaline together with characteristic soluble co-constituents while carrying less structural and polymeric material. Because T. pachanoi contains 3-methoxytyramine, lophophine, homopiperonylamine, and lobivine in addition to mescaline [2,3], mescaline recovery alone cannot establish chemical continuity.

Chemical continuity is therefore tested at three levels: absolute mescaline recovery, retention of defined minor alkaloids where validated standards are available, and similarity of the broader chromatographic profile before and after matrix reduction. The term whole-cactus-derived is supported when these measurements show broad continuity of the soluble botanical fraction despite measurable reduction of physical matrix.

8. Practical Accessibility and Process Robustness

The physical process is intentionally designed for ordinary botanical-processing equipment. Practical reproducibility is established by defining operating tolerances for ordinary preparation steps. The experimental program therefore tests the operating ranges of acidity, aqueous extraction time, coarse filtration, ethanol strength, extract-to-ethanol ratio, contact time, settling or filtration efficiency, and evaporation endpoint. A robust method is one in which modest variation within these ranges produces comparable mescaline recovery and matrix reduction.

The direct E. pachanoi evidence makes 95–96% ethanol the primary starting condition [8], while lower-strength ethanol is an accessibility variable for subsequent testing. Different starting strengths can be compared by the resulting total ethanol fraction, precipitated dry mass, viscosity, suspended solids, and phytochemical recovery. This empirically identifies the simplest solvent condition that preserves process selectivity.

Once acceptable ranges have been established, routine preparation can rely on observable operations such as pH paper, measured liquid ratios, ambient standing, cloth filtration, and a validated final-volume endpoint.

9. Experimental Evaluation and Mass Balance

The experimental design separates preliminary tissue reduction from the main post-extraction matrix-separation experiment. During preliminary characterization, the superficial film, central fibrous core, and retained extraction tissue are weighed separately and analyzed for dry matter and mescaline. This establishes the structural mass removed per unit of alkaloid lost before extraction.

For the principal experiment, retained cactus tissue from each botanical batch is processed as one aqueous extraction. After the first coarse filtration, the liquid is mixed thoroughly and divided into paired aliquots. One aliquot remains the aqueous reference; the other undergoes ethanol-induced matrix redistribution, second filtration, ethanol reduction, and restoration to the same final volume. This paired split-extract design controls botanical composition and primary extraction history while isolating the effect of the post-extraction matrix-reduction stage.

Initial process characterization should include multiple independent botanical batches; a minimum of three independent batches provides an initial estimate of between-batch variability, with replicate analytical measurements within each batch. Confirmatory sample size can then be based on the observed variance

in mescaline recovery and matrix removal. Processing condition is evaluated within batch, preventing natural cactus variability from being mistaken for a treatment effect.

Mescaline is quantified as both concentration and absolute mass in the starting retained tissue, primary aqueous extract, coarse structural residue, filtered aqueous liquid before ethanol addition, retained liquid after the second separation, separated polymer-rich fraction, and final preparation. Because these fractions differ substantially in polymer content, dissolved solids, and overall matrix composition, liquid chromatography–electrospray ionization tandem mass spectrometry (LC–ESI–MS/MS) quantification includes explicit assessment and compensation of matrix effects [25]. An isotope-labelled internal standard such as mescaline-d9 is used where available [26]; matrix-matched calibration or standard addition provides alternative control of differential ion suppression or enhancement. The minor-alkaloid panel includes 3-methoxytyramine, lophophine, homopiperonylamine, and lobivine [2,3], using targeted quantification where authentic standards are available and semi-quantitative relative liquid chromatography–mass spectrometry (LC–MS) profiling otherwise. Broader LC-based profiling compares normalized feature patterns before and after matrix reduction using peak retention, relative abundance, and multivariate similarity measures.

The separated ethanol-responsive fraction is characterized by dry mass, total carbohydrate, uronic-acid content, and complementary polymer analysis such as monosaccharide profiling, Fourier-transform infrared spectroscopy, or size-exclusion chromatography. The retained liquid is characterized by total dry matter, suspended solids, viscosity, pH, final volume, and residual ethanol. These measures establish whether the visually separated fraction is genuinely enriched in polymeric matrix and whether the physical properties of the retained preparation change correspondingly.

The primary result is the paired relationship between mescaline recovery (%) and matrix reduction (%). Secondary chemical outcomes are minor-alkaloid recovery and broader chromatographic similarity. Secondary physical outcomes are reduction in dry matter, carbohydrate/polysaccharide burden, suspended solids, and viscosity. Sensory and gastrointestinal comparisons constitute a separate subsequent human-study stage. They are conducted only after chemical equivalence has been established, using matched absolute mescaline exposure and standardized assessment of nausea, vomiting, abdominal discomfort, sensory intensity, and ease of ingestion under prospective research-ethics approval [27].

10. Discussion

The evidence supporting the proposed method falls into three complementary levels. Direct T. pachanoi studies establish strong anatomical variability in mescaline distribution and direct recovery of mescaline from fresh cactus under mildly acidic aqueous conditions [5,11]. Direct E. pachanoi processing establishes that a filtered aqueous cactus fraction responds to 96% ethanol with recovery of a precipitated, strongly flocculating material [8]. Comparative Cactaceae studies establish the high molecular mass, carbohydrate composition, and alcohol-responsive precipitation of mucilage-rich fractions [6,7,13,20,21]. Together these datasets support the process architecture, with Opuntia yields serving as quantitative Cactaceae benchmarks and San Pedro yields determined directly.

The methodological contribution lies in separating primary extraction from secondary physical refinement. Conventional-type aqueous processing first generates the botanical liquid; only afterward is the solvent environment changed to make part of the accompanying matrix mechanically separable. This design allows the post-extraction operation to be evaluated independently using paired aliquots from the same filtered batch.

The present method tests whether the initial ethanol-induced aggregation event alone removes sufficient matrix while preserving the mescaline-containing soluble fraction. The 30-min ambient contact condition derived from Cactaceae precipitation work [20,21] is evaluated for San Pedro by time-course mass balance.

The gastrointestinal rationale is similarly testable. Mescaline itself produces dose-dependent nausea and vomiting [14,15], while the conventional cactus preparation introduces additional dry matter, polymers, suspended solids, viscosity, volume, and sensory intensity. A paired comparison at matched mescaline exposure directly tests whether reduction of these preparation variables changes tolerability.

The framework therefore occupies a defined technological space between concentrated decoction and molecular isolation. Success is defined by demonstrating that simple physical operations remove a disproportionately large amount of matrix while preserving the characteristic soluble chemistry of the original cactus extract.

11. Broader Applications and Future Research

The framework is directly testable in other mescaline-containing cacti such as peyote (Lophophora williamsii) [3], with species-specific optimization of the matrix-reduction conditions.

Ayahuasca provides a relevant future test system because its aqueous preparation contains N,N-dimethyltryptamine (DMT) together with the β-carbolines harmine, harmaline, and tetrahydroharmine [28]. A finished aqueous batch could be mixed and divided into paired aliquots, with one serving as the reference and the other undergoing an experimentally defined post-extraction alcohol-induced matrix-separation step followed by solvent reduction. DMT, the major β-carbolines, broader chromatographic composition, dry matter, suspended solids, and viscosity could then be followed by the same mass-balance logic used here.

The transferable principle is a research architecture: established botanical extraction first, controlled matrix redistribution second, and quantitative comparison of physical removal with chemical retention. Different plants may require different solvent compositions or separation conditions, but the same framework can determine whether direct botanical preparations can be physically refined while preserving their direct botanical continuity.

12. Conclusion

San Pedro combines a mescaline-containing soluble fraction with a substantially larger structural, colloidal, suspended, and polysaccharide-rich cactus matrix. Direct studies establish marked botanical and anatomical variation in mescaline content [4,5], recovery of mescaline from fresh T. pachanoi under mildly acidic aqueous conditions [11], and ethanol-responsive recovery of a precipitated cactus-derived fraction from filtered E. pachanoi material [8]. Cactaceae polymer studies provide the complementary physicochemical basis for alcohol-responsive matrix separation [6,7,13,20,21].

These findings support a two-stage preparation framework in which aqueous extraction is completed before physical refinement begins. The practical method uses simple operations—cutting, aqueous heating, coarse cloth or sieve filtration, ethanol addition, ambient standing, a second filtration or decantation, and atmospheric ethanol reduction—while quantitative analysis determines how much chemistry is retained and how much matrix is removed.

The decisive endpoint is selectivity: high recovery of mescaline, minor alkaloids, and the broader soluble phytochemical profile together with substantial reduction of dry matter and polymer-rich physical burden.

By treating extraction chemistry and physical matrix as separate variables, the approach provides a falsifiable preparation technology between conventional cactus decoction and molecular mescaline isolation and establishes a broader experimental model for post-extraction refinement of complex botanical preparations.

Conflict of Interest

The author declares no conflict of interest.

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Informed Consent Statement

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