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Editorial board

Message from Editor-in-Chief

Dear Readers,

It gives me immense pleasure to present Volume 4, Issue 1 (January–June 2026) of *SAMHITA – Multidisciplinary Research Journal.* This issue reflects our continued commitment to promoting quality research and scholarly excellence across diverse academic disciplines.

Dr. Zarna Dedania
Editor-in-Chief,
"SAMHITA"
Multi-Disciplinary Research Journal

The current issue features a collection of review and research articles covering pharmaceutical sciences, economics, law, human rights, criminal justice, and herbal healthcare. The contributions demonstrate the growing spirit of interdisciplinary research and provide valuable insights into contemporary challenges and emerging opportunities in their respective fields.

I extend my sincere appreciation to all authors for their valuable contributions, the reviewers for their meticulous evaluation, and the editorial team for their dedicated efforts in maintaining the quality and integrity of the journal. Their collective support has been instrumental in the successful publication of this issue.

A special note of appreciation goes to our Associate Editor, Ms. Grishma Desai, Assistant Professor at Bhagwan Mahavir College of Pharmacy, for her continued support, editorial excellence, and invaluable contributions in shaping this volume. Her dedication to academic quality continues to inspire all of us at SAMHITA.

I hope that the articles published in this volume will inspire further research, encourage academic discourse, and contribute meaningfully to the advancement of knowledge. We welcome researchers, academicians, and professionals to continue contributing to *SAMHITA* and support our mission of fostering innovation and scholarly engagement.

Thank you for your enduring support. We hope this issue informs, challenges, and inspires you.

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Aim & Scope

"SAMHITA" Multi-Disciplinary Research Journal (SAMHITA) is issued under the patronages of Bhagwan Mahavir University, Surat in India. SAMHITA is a national journal which published six monthly in English. Journal publishes papers, review articles, and short communications dealing with all aspects of the Engineering, Pharmacy, Science, Management, Commerce, Commuter Application, Health Science, Education and Humanity subjects that are of interest to all professionals with strong emphasis on originality and scientific quality.

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Comparative Greenness Profiling of Analytical Procedures for the Concurrent Estimation of Amlodipine Besylate and Atenolol Using Click Analytical Chemistry Index (CACI)

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Abstract: *Amlodipine (AML) and Atenolol (ATN) are widely used antihypertensive agents frequently formulated in combination therapy for improved blood pressure management. The present review summarizes and compares the analytical methods reported for the simultaneous estimation of AML and ATN, including UV spectrophotometry, HPTLC, HPLC, UPLC, and LC–MS/MS techniques. In addition to analytical performance, the environmental sustainability of these methods was evaluated using green analytical chemistry concepts and Click Analytical Chemistry Index (CACI)-based assessment. Spectrophotometric and HPTLC methods demonstrated superior environmental compatibility due to lower solvent consumption, reduced waste generation, and minimal energy requirements. HPLC and UPLC methods provided excellent accuracy, precision, and robustness, while LC–MS/MS techniques offered the highest sensitivity and selectivity for bioanalytical applications. Overall, the comparative evaluation highlights the importance of balancing analytical efficiency with environmental sustainability and supports the adoption of greener analytical approaches for the routine estimation of Amlodipine and Atenolol.*

***Key Words*: Amlodipine, Atenolol, Analytical Technique, Method Validation, CACI Assessment, Chromatographic Methods, Spectrophotometric Method.**

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1. INTRODUCTION

1.1. Hypertension, a major global health concern, affects approximately 1.28 billion adults worldwide, with a significant proportion remaining undiagnosed or inadequately managed (1–3). According to the World Health Organization (WHO), nearly 46% of hypertensive individuals are unaware of their condition, and only 42% receive appropriate treatment. Uncontrolled hypertension is a leading risk factor for cardiovascular diseases, stroke, and renal failure, necessitating effective therapeutic strategies to achieve optimal blood pressure control (1–3). Among the widely prescribed antihypertensive agents, amlodipine besylate (AML) and Atenolol (ATN) have gained clinical significance due to their complementary pharmacological actions (4). AML, a long-acting dihydropyridine calcium channel blocker (CCB), inhibits calcium ion influx into vascular smooth muscle and cardiac myocytes, leading to vasodilation, reduced peripheral resistance, and decreased myocardial oxygen demand. It is extensively used for managing hypertension, angina, and coronary artery disease. AML's IUPAC name is 3-Ethyl 5-methyl 2-[(2-aminoethoxy)methyl]-4-(2-chlorophenyl)-6-methyl-1,4-dihydropyridine-3,5-dicarboxylate, with a molecular formula of $C_{20}H_{25}ClN_2O_5$ and a molecular weight of 408.88 g/mol. It is slightly soluble in water but freely soluble in methanol and ethanol, with a pKa of 8.6 and a log P of 3.0, indicating moderate lipophilicity (5–7). Atenolol (ATN) is a selective β_1-adrenergic receptor blocker that exerts its antihypertensive effect by reducing heart rate, myocardial contractility, and cardiac output, thereby decreasing blood pressure and myocardial oxygen demand. It is commonly prescribed for the treatment of hypertension, angina pectoris, cardiac arrhythmias, and secondary prevention following myocardial infarction. The IUPAC name of atenolol is 2-{4-[2-Hydroxy-3-(propan-2-ylamino)propoxy]phenyl}acetamide, with a molecular formula of $C_{14}H_{22}N_2O_3$ and a molecular weight of 266.34 g/mol. Atenolol is freely soluble in water and exhibits low lipophilicity with a log P value of approximately 0.2 and a pKa of 9.6, contributing to its favorable pharmacokinetic and pharmacodynamic properties (8–11). The chemical structure of both drugs are shown in Fig. 1.

The growing clinical importance of the AML–ATN combination has created a demand for reliable analytical methods for their simultaneous estimation

in pharmaceutical dosage forms and biological matrices. Accurate quantification of both drugs is essential for quality control, stability studies, dissolution testing, pharmacokinetic investigations, and regulatory compliance. Consequently, numerous analytical techniques, including UV spectrophotometry, High-Performance Thin-Layer Chromatography (HPTLC), High-Performance Liquid Chromatography (HPLC), Ultra-Performance Liquid Chromatography (UPLC), and Liquid Chromatography–Mass Spectrometry (LC–MS/MS), have been developed and validated for their determination. Each technique offers distinct advantages regarding sensitivity, selectivity, accuracy, precision, analysis time, and cost-effectiveness(12-20).

In recent years, environmental sustainability has become an important consideration in pharmaceutical analysis. Conventional analytical methods often involve hazardous organic solvents, high energy consumption, and significant waste generation, which may adversely affect the environment. To address these concerns, Green Analytical Chemistry (GAC) principles have been increasingly incorporated into analytical method development(21-24). Furthermore, computational tools such as the Click Analytical Chemistry Index (CACI) have emerged as valuable approaches for assessing compatibility, sustainability, and overall suitability of pharmaceutical systems. CACI evaluates molecular and physicochemical characteristics, including molecular structure, polarity, hydrogen-bonding capacity, solubility, and stability-related parameters, providing valuable insight into formulation feasibility and interaction potential(25,26).

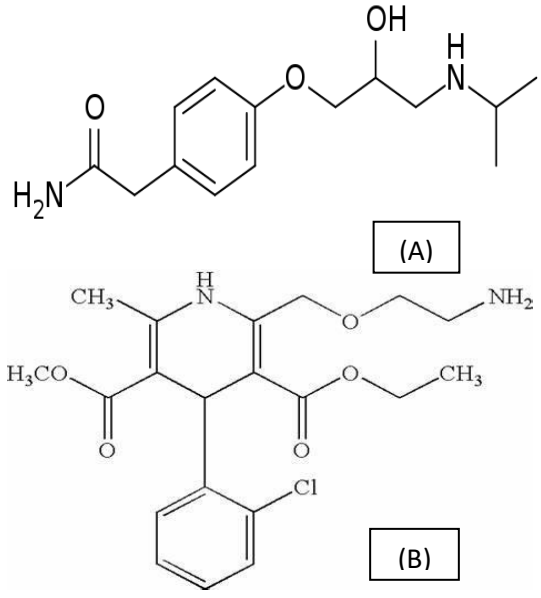

Figure. 1 Chemical Structure of (A) Atenolol (ATN) (B) Amlodipine Besylate (AML)

The CACI assessment of the Amlodipine–Atenolol combination indicates favorable compatibility between the two active pharmaceutical ingredients, supporting their successful incorporation into fixed-dose formulations(25,26). Therefore, a comparative evaluation of analytical methods used for the estimation of AML and ATN, together with CACI-based assessment and green analytical chemistry considerations, is essential for identifying reliable, environmentally responsible, and regulatory-compliant analytical approaches. This review aims to summarize the reported analytical methodologies for AML and ATN and critically evaluate their analytical performance, environmental sustainability, and compatibility characteristics.

This review aims to critically evaluate various analytical methods employed for the estimation of AML and ATN, with a focus on their greenness assessment published between 2010 and 2025. The objectives are to compare the efficiency, accuracy, and sustainability of different analytical techniques, assess their environmental impact, highlight recent advancements in green analytical chemistry, and propose future directions for developing greener, cost-effective, and regulatory-compliant methods. The novelty of this review lies in its comprehensive comparison of conventional and green analytical approaches, providing insights into sustainable pharmaceutical analysis. By supporting eco-friendly analytical techniques, this review contributes to reducing environmental pollution, enhancing regulatory compliance, and encouraging the adoption of green methodologies in the pharmaceutical industry. The findings of this review will be valuable for researchers, regulatory authorities, and pharmaceutical industry, paving the way for a more sustainable and responsible approach to drug analysis(13-19).

Methodology

To gain a comprehensive understanding of the analytical methods, physicochemical properties, and pharmacological attributes of AML and ATN, the authors conducted an extensive review of credible scientific literature and authoritative sources at both national and international levels. The collected information was systematically interpreted and concisely presented to elucidate the relevant characteristics(5-11,20-22).

Physicochemical properties of drugs

The physicochemical attributes of a drug substance are essential considerations in the design and

optimization of analytical methods. Parameters such as molecular weight, log P (partition coefficient), aqueous solubility, polarity, pKa, and environmental pH significantly influence chromatographic behavior and method performance. Table 1 provides a comparative overview of these properties for AML and ATN.

Table -1: Physicochemical properties for AML and IND (5-11,20-22)

Parameter	AML	ATN
Molecular Formula	$C_{26}H_{31}ClN_2O_8S$	$C_{14}H_{22}N_2O_3$
Molecular Weight (g/mol)	567.1	266.33
Log P	2.96	0.16-0.20
Protein Binding(%)	98%	6-16% bound in plasma. Atenolol binds to two sites on human serum albumin.
Dose	oral	Oral,IV
Time to peak concentration	6-8 hours	2-4 hours after oral dose
Half-Life	30- 50 hours	6-9 hours
Bioavailibility	Approximately 60-65%	Oral(50%)
Metabolism	Extensive hepatic metabolism	Minimal(5%)
pKa	9.0 (basic)	9.6 (basic)
Solubility	Slightly soluble in water ; Soluble in methanol and sparingly soluble in ethanol	Freely soluble in water ; slightli soluble in ethanol ; practically insoluble in chloroform and ether

In chromatographic separations, compounds with higher molecular weights and greater lipophilicity often exhibit longer retention times due to stronger interactions with the stationary phase. The log P value, reflecting the partition coefficient of the unionized form of a drug, indicates its hydrophobic or lipophilic character. Based on the reported values, ATN demonstrates greater lipophilicity than AML, which may influence its retention and elution order in reverse-phase chromatography.

Polarity, a key physicochemical trait, aids in selecting appropriate solvents and optimizing mobile phase composition during the development of methods for multicomponent drug analysis. Polarity arises from the electron distribution within chemical bonds—nonpolar compounds share electrons equally, while polar compounds exhibit unequal electron sharing. This affects not only chromatographic retention but also solubility behavior in different media.

The pKa of a drug molecule provides insight into its ionization potential across various pH levels. AML and ATN, with pKa values near physiological pH, may exist in both ionized and unionized forms depending on the mobile phase conditions, which in turn affects their retention profiles. Understanding these physicochemical and pharmacokinetic properties is crucial for the rational development of selective, reproducible, and stability-indicating bioanalytical methods for the simultaneous estimation of AML and ATN.

Analytical methods for AML

1.2. UV spectrophotometric methods of AML

UV spectrophotometric analysis of AML has been extensively explored as a simple, sensitive, and cost-effective alternative to chromatographic techniques for routine quality control. The drug exhibits a distinct absorption maximum between 237–239 nm, which is consistently reported across multiple studies as the ideal wavelength for quantitative determination. Öztürk and Kadıoğlu et al. developed a direct UV spectrophotometric method using methanol as a solvent, demonstrating excellent linearity in the range of 2–17 µg/mL, with recovery values close to 100% and %RSD below 2%, indicating high precision and accuracy (22). Khdadad et al. developed reagent-assisted spectrophotometric techniques involving oxidation followed by complex formation with crystal violet, enhancing selectivity in the visible region when excipient interference was present (23). Likewise, Bachhav et al. validated a straightforward UV-Visible spectroscopic method following ICH Q2(R1) parameters, showing strong linear correlation ($R^2 > 0.999$), satisfactory accuracy (98–102%), and acceptable sensitivity through LOD and LOQ evaluation (24). Overall, these studies collectively confirm that UV spectrophotometry provides a robust, reproducible, and environmentally benign analytical tool for estimating AML in pure form and pharmaceutical formulations, particularly suitable for laboratories requiring rapid and economical assays.

1.3. Chromatographic methods for AML

Literature review revealed that, many researchers has been developed HPLC and UPLC methods for the estimation and stability assessment of AML, using quality by design strategies and green analytical principles. Kasagić-

Vujanović et al. developed a rapid and consistent hydrophilic interaction liquid chromatographic (HILIC) method for the quantitative estimation of AML and its related impurities (D, E, and F). Using a Box–Behnken design and Derringer's desirability function, they optimized the chromatographic conditions, achieving optimal separation on a ZORBAX NH_2 column (250 × 4.6 mm, 5 µm) with an acetonitrile–ammonium acetate buffer (pH 4.0) system (90.5:9.5 v/v) at 230 nm detection (25).

Gigopulu et al. presented a green and robust RP-HPLC method utilizing ethanol as an eco-friendly solvent for determining related substances of AML in film-coated tablets. The optimized conditions—RP-select B column (250 × 4.0 mm, 5 µm), mobile phase of sodium dihydrogen phosphate buffer (pH 4.0) and ethanol (60:40 v/v)—successfully separated impurities D and F with high selectivity, confirmed through forced degradation. The method satisfied Analytical Eco-Scale and AGREE assessment metrics, proving its compliance with Green Analytical Chemistry principles (26).

Ibrahim et al. developed an environmentally benign UPLC method for the quantitative estimation of AML, applying a 3^2 full factorial design to evaluate the influence of methanol percentage and column temperature. The optimized chromatographic conditions (60% methanol, 25°C) produced sharp and symmetrical peaks with retention at 5.37 ± 0.21 min and a resolution of 2.17 ± 0.07. The method demonstrated high sensitivity (R^2 = 0.994), excellent reproducibility (%RSD < 2%), and a low HPLC-EAT environmental impact value (2.91), indicating sustainability and analytical efficiency (27).

Qasim et al. developed a simple, precise, and stability-indicating RP-HPLC method for AML in bulk and tablet formulations using a mobile phase of water and methanol (50:50 v/v) and an Eclipse XDB-C18 column (250 × 4.6 mm, 5 µm). A linear range of 5–25 µg/mL (R^2 = 0.994) with %RSD < 0.8% at a detection wavelength of 360 nm was achieved. Forced degradation under acidic, alkaline, oxidative, thermal, and photolytic stress confirmed its capability to detect degradation products, validating its suitability for stability studies and routine quality control (28).

Jeelani et al. developed a rapid and reliable stability-indicating HPLC method for the estimation of AML and its related impurities in bulk drug. The separation was performed on a core-shell C18 column (100 × 4.6 mm, 2.6 µm) using a gradient system of methanol and 0.4% ammonium hydroxide, with detection at 237 nm. The method effectively resolved AML and seven impurities within 15 minutes, exhibiting stable peak shape under high-pH conditions. Forced degradation under acid, base, oxidative, thermal, and photolytic stress confirmed method specificity with clear separation of degradants. Validation parameters including linearity, precision, accuracy, and robustness established its suitability for routine quality control analysis of AML drug substance (29).

Furthermore, Gajić et al. reported a validated stability-indicating RP-HPLC method for quantifying AML in the presence of impurity D in both tablets and irradiated samples. Separation was achieved on a ZORBAX Eclipse XDB-C18 column using a mobile phase of acetonitrile: methanol: triethylamine solution (15:35:50 v/v/v, pH 3.0) at 273 nm. The method exhibited linearity from 10–75 µg/mL (R^2 = 0.999), with LOD and LOQ of 0.2 µg/mL and 0.66 µg/mL, respectively. Photostability studies revealed pseudo-first-order degradation kinetics with a half-life of 38.4 days under UV and 43.3 days under visible light, confirming adequate photostability in Alu/PVC/PVDC blister packaging (30).

Collectively, these studies highlight the development of HPLC and UPLC methods for AML—from conventional stability-indicating techniques to greener, design-optimized analytical procedures. Each method meets ICH Q1A(R2) and Q2(R1) validation criteria, ensuring precision, accuracy, and robustness. Furthermore, the developed methods support the growing emphasis on environmental sustainability and analytical efficiency in pharmaceutical quality control.

1.4. Analysis methods for ATN

Several analytical methodologies for ATN have yielded significant advancements in precision, selectivity, and applicability across pharmaceutical and biological matrices.

Patel et al. (2023) developed a sensitive UV–visible spectrophotometric method for the quantitative determination of atenolol in tablet formulations. The method exhibited excellent linearity within the concentration range of 5–30 µg mL^{-1} (R^2 > 0.999), with recovery values between 98.5% and 101.2% and relative standard deviation (%RSD) below 2%. The simplicity, rapidity, and cost-effectiveness of the method make it suitable for routine quality control analysis of atenolol-containing pharmaceutical products (31).

Kumar et al. (2024) developed and validated a stability-indicating RP-HPLC method for the determination of atenolol in bulk drug and pharmaceutical dosage forms. Chromatographic separation was achieved using a C18 column with a mobile phase consisting of phosphate buffer and methanol under isocratic conditions. The method demonstrated excellent linearity (R^2 > 0.999), precision (%RSD < 2%), and robustness. Forced degradation studies confirmed its ability to effectively separate atenolol from its degradation products, establishing its suitability for stability assessment and routine quality control applications (32).

Ahmed et al. (2023) reported an LC–MS/MS method for the simultaneous quantification of atenolol in human plasma.

The method exhibited high sensitivity with a lower limit of quantification in the nanogram range and excellent selectivity without significant matrix interference. Validation studies confirmed satisfactory accuracy, precision, recovery, and stability, making the method appropriate for pharmacokinetic and bioequivalence investigations (33)

Collectively, these studies highlight that recent electrochemical and chromatographic developments have significantly improved the accuracy, speed, and environmental compatibility of ATN determination. They also demonstrate the field's shift toward integrated impurity profiling, enantiomeric differentiation, and matrix-specific quantification, aligning with modern regulatory and quality assurance requirements.

1.5. Analytical methods for AML and ATN in combination

Pharmaceutical analysis encompasses a broad spectrum of techniques aimed at quantifying active pharmaceutical ingredients (APIs) or detecting impurities and degradation products within various matrices. Accurate and validated analytical methods are indispensable across all phases of drug development, from formulation and stability studies to quality control and regulatory submissions.

Several analytical methodologies have been reported in the scientific literature for the quantitative and qualitative estimation of AML and ATN. These include spectroscopic techniques such as UV-visible spectrophotometry, chromatographic approaches like HPLC and high-performance thin-layer chromatography (HPTLC), as well as hyphenated methods such as LC-MS and LC-MS/MS.

A summary and classification of the published analytical methods for both drugs are illustrated in Table 2, highlighting the diversity of techniques employed for their analysis.

1.6. Spectroscopic Methods for AML and ATN

Spectroscopy refers to the study of how electromagnetic radiation interacts with matter, typically as a function of wavelength or frequency. This interaction provides critical insight into the structural, electronic, and quantitative aspects of chemical substances. Traditionally, spectroscopy focused on the interaction of photons with molecules, but the scope has now extended to encompass the behavior of charged particles (electrons, protons, ions) and their energy transitions upon collision with other particles. Owing to its simplicity, rapidity, and non-destructive nature, spectroscopic analysis remains a cornerstone in the development of analytical techniques for pharmaceutical compounds (34,35).

AML and ATN , owing to their UV-absorbing chromophores, have been widely analyzed using various UV-visible spectrophotometric methods. These methods are cost-effective, require minimal sample preparation, and provide reliable quantitative data for bulk and formulation analysis.

Most of the spectrophotometric assays for these drugs employ methanol as the solvent of choice due to its favourable properties, such as high polarity, excellent solubilizing capability for both polar and non-polar drugs, and a low UV cutoff (~205 nm), which ensures minimal background interference in the UV range. Typically, the analytical wavelength range used for detecting AML and ATN spans 220–290 nm, depending on the structural features and the nature of the UV transitions.

Numerous researchers have proposed diverse spectroscopic methods for the simultaneous estimation of AML and ATN. These include classical techniques such as the absorbance ratio (Q-analysis), dual wavelength (DW) method, area under the curve (AUC) methods, as well as advanced computational techniques like first derivative ratio spectrophotometry, Vierodt's method, and the ultraviolet absorbance correction method. Table 2 summarizes the reported spectrophotometric techniques developed for the simultaneous quantification of AML and ATN(25-29,42-44).

1.7. HPLC Methods for AML and ATN

Table 2 summarizes the reported High-Performance Liquid Chromatography (HPLC) methodologies for the analysis of amlodipine besylate (AML) and atenolol (ATN), highlighting the widespread use of chromatographic techniques for their simultaneous estimation in pharmaceutical formulations and biological matrices. HPLC remains one of the most reliable, precise, and reproducible analytical techniques for quantitative pharmaceutical analysis owing to its excellent separation capability, sensitivity, and suitability for routine quality control applications(30-33,45-48).

The literature reveals that acetonitrile, methanol, and aqueous buffer systems are the most frequently employed mobile phase components in HPLC methods developed for AML and ATN. Acetonitrile is commonly selected because of its low viscosity, high elution strength, and compatibility with UV detection, whereas methanol is preferred for its favorable solvent properties and cost-effectiveness. Buffer systems including phosphate, acetate, and orthophosphoric acid buffers are used to maintain appropriate pH conditions, improve peak symmetry, and enhance analyte stability during chromatographic separation. These mobile phase combinations facilitate efficient separation of AML and ATN from excipients, impurities, and degradation products, thereby ensuring accurate quantification.

A review of published HPLC methods demonstrates considerable diversity in chromatographic conditions.

Various stationary phases have been employed, including Kromasil C18, Phenomenex Luna, Inertsil ODS, Hypersil BDS, Eclipse XDB, and Waters Symmetry columns, with dimensions generally ranging from 150–250 mm and particle sizes between 3 and 5 µm. Mobile phases typically consist of mixtures of acetonitrile or methanol with aqueous buffers adjusted to pH values between 2.5 and 6.0. Flow rates commonly range from 0.8 to 1.5 mL/min, while UV detection wavelengths are generally selected between 230 and 240 nm to provide adequate sensitivity for both analytes.

Reported linearity ranges for AML and ATN extend from low microgram-per-milliliter concentrations to approximately 150 µg/mL, reflecting the versatility of HPLC methods for assay determination, dissolution studies, content uniformity testing, and bioanalytical applications. Retention times vary according to chromatographic conditions, with amlodipine generally eluting between 2.5 and 8.0 min and atenolol between 2.0 and 7.0 min. These variations demonstrate method-specific optimization aimed at improving resolution, reducing analysis time, and enhancing analytical efficiency.

Several stability-indicating HPLC methods have been reported for AML and ATN, demonstrating effective separation of the drugs from their degradation products formed under acidic, alkaline, oxidative, thermal, and photolytic stress conditions. Such methods comply with ICH guidelines and are widely employed for stability assessment and shelf-life evaluation. Recent advances also include Analytical Quality by Design (AQbD)-based HPLC method development, wherein critical method parameters are systematically optimized using experimental design approaches. These strategies improve method robustness, precision, and reproducibility while facilitating regulatory compliance(35,36,45-48).

Overall, the diverse range of HPLC methods reported for amlodipine besylate and atenolol highlights the flexibility, accuracy, and reliability of chromatographic techniques in pharmaceutical analysis. The incorporation of stability-indicating protocols, AQbD-assisted optimization, and environmentally conscious chromatographic practices has further strengthened their applicability in routine quality control, stability studies, and pharmaceutical research.

1.8. High Performance Thin Layer Chromatography (HPTLC) methods for AML and ATN

High Performance Thin Layer Chromatography (HPTLC) is an advanced planar chromatographic technique widely employed in pharmaceutical analysis due to its simplicity, cost-effectiveness, high sample throughput, and low solvent consumption. HPTLC has gained considerable importance in the simultaneous estimation of amlodipine besylate (AML) and atenolol (ATN), particularly in routine quality control, stability studies, and dosage form analysis. A comprehensive review of the literature reveals several validated HPTLC methods reported for the simultaneous determination of AML and ATN in combined pharmaceutical formulations. Table 2 summarizes the reported HPTLC techniques developed for both drugs(35,49-52).

Most HPTLC methods utilize precoated aluminium plates coated with silica gel 60 F254 as the stationary phase owing to their excellent reproducibility and separation efficiency. Various mobile phase systems have been reported for achieving optimal resolution between AML and ATN, commonly comprising mixtures of toluene, methanol, ethyl acetate, chloroform, ammonia, and triethylamine in different proportions. These solvent systems provide compact, symmetrical, and well-resolved chromatographic bands suitable for quantitative analysis.

Detection is generally performed using densitometric scanning in the UV region, with reported analytical wavelengths ranging from 230 to 240 nm. Several studies have reported simultaneous detection at 237 nm, which corresponds to the absorption maxima of amlodipine and provides adequate sensitivity for atenolol determination. The reported linearity ranges generally extend from 100–600 ng/spot for AML and 200–1200 ng/spot for ATN, demonstrating the applicability of HPTLC for quantitative analysis over a broad concentration range.

The characteristic Rf values reported for AML and ATN typically range between 0.30–0.45 and 0.55–0.75, respectively, depending on the chromatographic conditions employed. The significant difference in Rf values ensures satisfactory separation and minimizes interference from formulation excipients and degradation products. Validation studies conducted according to ICH guidelines have demonstrated acceptable accuracy, precision, specificity, robustness, and recovery for these methods(35,49-52).

Overall, HPTLC methods provide reliable, economical, and environmentally favorable alternatives to conventional chromatographic techniques for the simultaneous estimation of AML and ATN. Their reduced solvent consumption, rapid analysis time, and ability to analyze multiple samples simultaneously make them particularly suitable for routine pharmaceutical quality control and stability assessment.

1.9. Hyphenated Techniques

Liquid Chromatography coupled with Tandem Mass Spectrometry (LC–MS/MS) and Ultra-Performance Liquid Chromatography coupled with Tandem Mass Spectrometry (UPLC–MS/MS) have emerged as highly sensitive and selective analytical techniques for the determination of amlodipine besylate (AML) and atenolol (ATN) in biological matrices and pharmaceutical formulations. These hyphenated techniques combine the separation efficiency

of liquid chromatography with the superior detection capabilities of mass spectrometry, enabling accurate quantification at trace concentration levels(18,19,37,53-55).

Several bioanalytical studies have reported the simultaneous determination of AML and ATN in human plasma using LC–MS/MS methods. Sample preparation generally involves protein precipitation or liquid–liquid extraction using methanol or acetonitrile, followed by chromatographic separation on short C18 columns. These methods exhibit excellent selectivity, low limits of detection and quantification, and wide linearity ranges suitable for pharmacokinetic, bioavailability, bioequivalence, and therapeutic drug monitoring studies(37,53-55).

The application of UPLC–MS/MS has further enhanced analytical performance by reducing analysis time, improving peak resolution, and increasing sensitivity. Modern bioanalytical methods for AML and ATN typically achieve run times below 5 minutes while maintaining high accuracy and precision in accordance with international regulatory guidelines. Furthermore, the use of isotopically labeled internal standards and advanced sample preparation procedures has significantly improved method robustness and reproducibility.

Collectively, LC–MS/MS and UPLC–MS/MS techniques represent powerful analytical tools for the simultaneous determination of AML and ATN, particularly in biological matrices where high sensitivity and selectivity are essential. Their growing application reflects the increasing demand for rapid, reliable, and highly sensitive analytical methods in pharmaceutical research, clinical pharmacokinetics, and therapeutic drug monitoring.(37)

Table -2: Analytical method for estimation of AML and ATN

Title	Description	Reference
UV Spectrophotometric Method Development and Validation for Amlodipine Besylate in Bulk and Tablet Dosage Form	**λmax:**360nm **Linearity:** 5.40 µg/ml **Solvent:** Ethanol	52
Ultra-Violet Spectrophotometric Method for Estimation and Validation of Amlodipine in Bulk and Tablet Formulation	**λmax:**355nm **Linearity:** 10-50 µg/ml **Solvent:** Methanol /Water	53
Method Development, Validation and Stability Study of Amlodipine.In Marketed Formulation by UV Spectrophotometric Method	**λmax:**360nm **Linearity:** 6-80 µg/ml **Solvent:** Methanol	54
Analytical method development and validation of Amlodipine besylate in tablet dosage form	**Column:** C18 Column **Particle Size:** 5 µm **Detector:** UV Detector **λmax:** 237nm **Mobile Phase:** 15v Acetonitrile : 35vmethanol: 50v Buffer pH 3.0 **Flow Rate:** 1.0ml/min **Retention Time:** 12.3 min **Linearity:** 35-105 µg/ml	55
Development and Application of RP-HCPL Method of Oral Formulations Containing Amlodipine besylate	**Column:** C18 Column **Particle Size:** 5 µm **Detector:** UV Detector **λmax:** 265.0 nm **Mobile Phase:** 0.01M Sodium Dihydrogen Phosphate: Acetonitrile (8:2:1v/v/v), adjusted to pH 5.5 With Phosphoric Acid **Flow Rate:** 1.0 min^{-1} **Retention Time:** 6.10min **Linearity:** 10-50µg/ml	56
Development and validation of RP-HPLC method for quantitative analysis of Amlodipine besylate in pure and pharmaceutical formulations	**Column:** C18 Column **Particle Size:** 5µm **Detector:** UV Detector **λmax:** 232nm **Mobile Phase:** 0.025M Phosphate Buffer (pH3.7) : Acetonitrile (57:43v/v)	57

	Flow Rate: ±0.1ml/min **Retention Time:** 8.02min **Linearity:** 10-50µg/ml	
Validation of assay method of amlodipine in tablets by liquid chromatography	**Column:** Ascentis C18 **Particle Size:** 5µm **λmax:** 237nm **Mobile Phase:** Acetonitrile R-0.1 % solution of trifluoroacetic acid R (40:60) **Flow Rate:** 1.0ml/min **Detector:** UV Detector l	58
Simultaneous determination of amlodipine and bisoprolol in rat plasma by a liquid chromatography/tanden mass spectrometry method and its application in pharmacokinetics study	**Column:** Diampnsil C18 **λmax:** 237nm **Mobile Phase:** methanol: water: formic acid (75:25:0.01, v/v/v) **Flow Rate:** 0.3 ml/min **Linearity:** 20-60 µg/ml **Detector:** UV Detector	59
Analytical method development and validation of RP-HPLC and HPTLC method for the simultaneous determination of amlodipine besylate and celecoxib in bulk and pharmaceutical dosage forms	**Stationary phase:** Nucleosil C18 **λmax:** 238nm **Mobile Phase:** Acetonitrile pH adjusted to 8 ± 0.1 with triethylamine **Flow Rate:** 1.2 ml/min **Linearity:** 2.0 – 28.0 µg/ml **Detector:** UV Detector	60
HPTLC simultaneous determination of amlodipine, atorvastatin, rosuvastatin and valsartan in tablets using phenyl -	**λmax:** 365nm **Stationary phase:** phenyl modified Aleppo bentonite (Ba phenyl) **Linearity: 0.50-10.0** µg/ml	61
modified Aleppo bentonite	**Mobile phase**: Acetonitrile: Buffer 45:55, v/v at pH 6.0 **Rf value**: 0.27 **Minimum concentration**:0.5 µg/sport **RSD%:** 4.0 %	
Development and validation of spectrophotometric method for determination of atenolol in pure material and pharmaceutical dosage	**λmax**: 225nm **Linearity:**5-40µg/ml **Solvent:** Methanol **Correlation coefficient**: 0.9979	62
Method Development and Validation of Atenolol Drug by Spectrophotometric and HPLC Technique in Forensic Application	**λmax**: 225nm **Linearity:**5-40µg/ml **Solvent:** Methanol **Correlation coefficient**: 0.9979	63
Method development and validation of atenolol using two HPLC system	**Column:** Inertsil (ODS -3 250mm ×4.6mm, 5 µm siloxane) **Detector:** UV /PDA (Photo diode array detector) **λmax:** 276 nm **Flow rate:** 1 ml/min **Mobile phase:** organic solvent of acetonitrile and water (v/v) **Retention time:** 1.5 min **Linearity =** 2-10 µg/ml	64
HPLC Method for Determination of Atenolol in Human Plasma and Application	**Column:** Stainless steel merck 250 C8 column, 5µm **Mobile phase**: Acetonitrile: methanol: 0.02 M	65

to a Pharmacokinetic Study in turkey	phosphate buffer (Ph 5) (20:20:60) **Detector: UV** detector **λmax:** 226 nm **Flow rate:** 1 ml/min **Linearity:** 0.05- 10.0 µg/ml **Correlation coefficient**: 0.99 **Retention time**: 1.76 min	
RP-HPLC method development for the determination of atenolol related substance in bulk drug	**Column:** C18 **λmax:** 226nm **Detector:** UV detector **Mobile phase**: 1.0 g of octane -1-sulphonic acid sodium salt and 0.4 g of tetra -n- butyl ammonium hydrogen sulphate in a mixture of 20 volumes of tetrahydrofuran, 180 volumes of 804 g/l solution of methanol and 800 volumes of phosphate and PH adjusted to 3 ± 0.2 using dilute ortho – phosphoric acid **Linearity:** 3.2 µg/ml **Retention time:** 8.0 min	66
RP-HPLC method development and validation for simultaneous estimation of Cilnidipine, Atenolol and Chlorthalidone	**Column:** Hypersil-keystone C18 under isocratic condonation **Mobile phase**: Methanol and triple distilled water (80/20 v/v) having PH 7 **Flow rate:** 1.0ml/min **λmax:** 225 nm **Retention time:** 5.36 min **Detector:** UV **Linearity:** 6-36 µg/ml **Correlation coefficient**: 0.999	67
Simultaneous analysis of losartan potassium, atenolol and hydrochlorothiazide in bulk and in tablets by high-performance thin - layer chromatography	**Stationary phase:** Silica gel plates **Mobile phase:** Toluene: methanol: triethylamine (6.5: 4: 0.5) v/v **λ max:** 274 nm **Rf value:** 0.43 **Linearity range:** 250 - 1250ng per band **Correlation coefficient**: 0.999 **Detector**: UV	68
Validated HPTLC Method for Simultaneous Estimation of Atenolol and Aspirin in Bulk Drug and Formulation	**Stationary phase**: Aluminum plates precoated with silica gel 60 F254 **Mobile phase:** n-butanol: water: acetic acid (8:2:0.2 v/v/v) **λ max:** 235 nm **RF value:** 0.23 ± 0.02 **Linearity range:** 100µg /ml **% RDS:** 0.68 - 1.14 **Detector:** UV	69
Simultaneous HPTLC analysis of atenolol indapamide in tablets formulations	**Stationary phase:** Aluminum plates precoated with silica gel 60 F254 **Mobile phase:** toluene: ethyl acetate: methanol: ammonia (5: 3: 3: 0.1) v/v **λ max**: 229 nm **Rf**: 0.27 **Linearity**: 100µg/ml **Detector**: UV	70
Photodegradation studies on Atenolol by liquid chromatography	**Column**: Ace C18 **Mobile phase:** TEA acetate (pH 4; 0.01 M)– acetonitrile 96:4) Phosphate buffer solutions (pH 7.4: 0.01 M), ammonium acetate buffer (pH 7:0.01 M) and triethylammonium (TEA) acetate buffer	71

	Detector: UV	
Quantitative determination of atenolol in dried blood spot samples by LC–HRMS: A potential method for assessing medication adherence	**Column:** Ascentis express C18 **Mobile phase:** Methanol: water (60: 40, v/v) **Flow rate:** 0.2 ml/min **Linearity:** 25 µg/ml **Detector:** UV	72
Determination of atenolol, chlorthalidone and their degradation products by TLC-densitometric and chemometric methods with application of model updating	**Column =** Silica gel 60 F254 **Mobile phase:** Chloroform: methanol: ethyl acetate: ammonia solution (75: 28: 2: 1.6 by v/v) **λ max: C**227nm **Linearity;** 32 – 40 µg/ml **RF value**: 0.04 **Detector**: UV	73
Simultaneous TLC - Densitometric analysis of atenolol and lercanidipine hydrochloride in tablets	**Column =** Silica gel 60 F254 **Mobile phase:** Chloroform: methanol: ethyl acetate: ammonia solution (75: 28: 2: 1.6 by v/v) **λmax: C**227nm **Linearity;** 32 – 40 µg/ml **RF value**: 0.04 **Detector**: UV	74
Gas chromatography/mass spectrometry method for determination of atenolol in rabbit plasma	**Concentration rage**: 15 – 250 µg/ml **RSD % slop:** 4.81 **Column:** HP- 5 MS column with 0.25 µm film thickness **Flow rate**: 1 ml/min **Injector & Detector temperatures**: 280 °C **Carrier gas:** N – methyl – N – (trimethylsilyl) trifluoroacetamide (MSTFA)	75
Simultaneous determination of atenolol and amlodipine using second derivation spectroscopy	**λ max:** Amlodipine =264 nm Atenolol = 264 nm **Linearity:** Amlodipine = 5.0 – 45.0 µg/ml Atenolol= 5.0 – 50.0 µg/ml **Solvent:** Distilled Water	76
UV- absorbance difference method for simultaneous estimation of atenolol and amlodipine besylate in combined dosage forms	**λ max: Amlodipine =**265 nm and 278 nm Atenolol = 209 nm and 244 nm **Linearity:** Amlodipine = 0.35 µg/ml Atenolol= 20 µg/ml **Solvent:** Ethanol	77
A new method development and validation of dual wavelength UV Spectro Photometric method for Simultaneous estimation of Atenolol and Amlodipine besylate in combined dosage form	**λ max:** Amlodipine =263 nm and 277nm Atenolol = 230 nm and 242 nm Mixture: 263 nm and 277nm 230 nm and 242 nm **Linearity:** Amlodipine = 1-6 µg/ml Atenolol= 5-30 µg/ml **Correlation coefficient**: Amlodipine = 0.9987 Atenolol= 0.9983 **Solvent:** Methanol	78
Simultaneous estimation of atenolol and amlodipine besylate as A.P.I and in tablets dosage forms by vierodt's method using UV spectrophotometer	**λmax:** Amlodipine =238 nm Atenolol = 273 nm **Linearity**: Amlodipine = 4-32 µg/ml Atenolol= 20-200 µg/ml **Correlation coefficient:** Amlodipine = 0.9932 Atenolol= 0.9991 **Solvent:** Distilled water	79

Simultaneous estimation of atenolol and amlodipine besylate in tables formulations by vierodt's method using UV spectrophotometry	**λ max**: Amlodipine =239.6 nm Atenolol = 224.6 nm **Linearity:** Amlodipine = 4-32 µg/ml Atenolol= 4-28 µg/ml **Correlation coefficient**: Amlodipine = 0.9932 Atenolol= 0.9991 **Solvent:** Distilled water	80
RP-HPLC Method for the Simultaneous Estimation and Validation of Amlodipine Besylate and Atenolol in Bulk and Tablet Dosage Form in Biorelevant Dissolution Medium (Fassif)	**Column:** C18 Column, kromasil C18 **Detector:** PDA (photodiode array detector) **λ max:** 250nm **Mobile Phase:** Acetonitrile: Potassium di hydrogen phosphate solution (0.01M, pH 3.0 adjusting with Ortho phosphoric acid): Methanol (15:30:55) **Flow Rate:** 1.0 ml/min **Retention Time:** Amlodipine = 2.589 min Atenolol = 3.711 min **Linearity:** Amlodipine = 25-125 µg/ml Atenolol= 5-25 µg/ml **LOQ:** Amlodipine = 0.004 µg/ml Atenolol= 0.015 µg/ml **LOD:** Amlodipine = 0.001 µg/ml Atenolol= 0.005 µg/ml	81
RP-HPLC method development and validation for the simultaneous estimation of amlodipine and atenolol in bulk and Tablet dosage forms	**Column:** C18 Column, BDS C18 **Detector:** UV detector **λ max:** 213nm **Mobile Phase:** Phosphate buffer (1gm of Sodium dihydrogen phosphate and 2gm of Di Potassium hydrogen phosphate in 1000ml ml of water); pH 5(adjusted with Ortho phosphoric acid) Methanol and Acetonitrile in the ratio of 40: 30: 30(v/v) **Flow Rate:** 1.0 ml/min **Retention Time:** Amlodipine = 2.540 min Atenolol = 5.950 min **Linearity:** Amlodipine = 6-14 µg/ml Atenolol= 60-140 µg/ml **LOQ**: Amlodipine = 1.22 µg/ml Atenolol= 15.94 µg/ml **LOD**: Amlodipine = 0.40 µg/ml Atenolol= 5.26 µg/ml	82
RP-HPLC method development and validation for the simultaneous estimation of amlodipine and atenolol in bulk and Tablet dosage forms	**Column:** Intertsil C18 Column **Detector:** UV detector **λmax:** 225 nm **Mobile Phase:** Buffer: Acetonitrile: Methanol (4:3.5:2.5, v/v/v/). The buffer prepared with Triethyl amine and adjusted pH to 3.0 **Flow Rate:** 1.0 ml/min **Retention Time:** Amlodipine = 5.97 min Atenolol = 2.23 min	83

	Linearity: Amlodipine = 5-15 µg/ml Atenolol= 50-150 µg/ml **Correlation coefficient**: Amlodipine = 0.9998 µg/ml Atenolol= 0.9992 µg/ml	
Development and validation of RP-HPLC for simultaneous estimation of atenolol and amlodipine in tablet dosage forms	**Column:** C18 Column **Detector:** UV detector **λmax:** 237 nm **Mobile Phase:** Buffer: Acetonitrile: Methanol (35:10:55, v/v/v/). The buffer prepared with ammonium acetate and sodium pentane sulphonate and adjusted pH to 3.0 with phosphoric acid **Flow Rate:** 1 ml/min **Retention Time:** Amlodipine = 5.0 min Atenolol = 1.67 min **Linearity**: linear over the concentration range of 80%to 120% µg/ml	84
Simultaneous estimation of amlodipine and atenolol in human plasma: a sensitive LC-MS/MS method validation and its application to a clinical PK study	**Column:** C18 column **Detector:** UV detector **λmax:** 230 nm **Mobile Phase:** f 0.01% formic acid in water and methanol: acetonitrile (6:4, v/v) at a ratio of 30:70 (v/v) **Flow Rate:** 0.5 ml/min **Linearity:** Amlodipine = 50-8000 µg/ml Atenolol= 10-800 µg/ml	85
	LOQ: Amlodipine = 50 µg/ml Atenolol= 10 µg/ml	
Simultaneous determination of atenolol and amlodipine in tablets by high-performance thin-layer chromatography	**Column:** Merck HPTLC plates (0.2 mm thickness) precoated with 60F254 silica gel on aluminum sheet **Detector:** UV detector **λ max:** 230 nm **Mobile Phase:** methylene chloride: methanol: ammonia solution (25% NH) (8.8:1.3:0.1; v/v) **Flow Rate:** 1 ml/min **Retention Time:** Amlodipine = 0.75 min Atenolol = 0.33 min **Linearity**: 10-500 µg/ml	86

2. CACI(Click Analytical Chemistry Index)

Is an online computational tool used in pharmaceutical research to predict the compatibility between drug molecules or between a drug and excipients. It helps researchers evaluate whether two compounds can be successfully combined in a formulation without significant interaction problems.

The CACI system analyzes molecular and physicochemical properties such as:

- Molecular structure
- Molecular weight
- Hydrogen-bonding ability
- Polarity
- Solubility characteristics
- Chemical reactivity
- Stability-related parameters

Based on these properties, the software generates a compatibility score ranging from poor to excellent compatibility. A higher score indicates a greater likelihood that the substances can coexist in a pharmaceutical formulation without causing instability or degradation.(87-93)

Importance of CACI in Pharmaceutical Research

- Predicts drug–drug compatibility.
- Assists in fixed-dose combination development.
- Reduces the need for extensive experimental screening.
- Helps identify potential formulation challenges early.

- Supports preformulation and Quality-by-Design (QbD) studies.
- Saves time and development costs.(87-91)

Computer-Aided Compatibility and Interaction (CACI) is a computational tool used to evaluate the compatibility and interaction potential of pharmaceutical ingredients during drug formulation development. The system employs molecular descriptors, physicochemical properties, and predictive algorithms to assess the suitability of combining active pharmaceutical ingredients (APIs) and excipients in a dosage form.

CACI provides an efficient and cost-effective approach for preformulation studies by identifying potential compatibility issues before extensive laboratory experimentation. The analysis helps formulation scientists predict possible interactions that may affect the stability, efficacy, safety, and quality of pharmaceutical products. By utilizing computational techniques, CACI reduces development time and minimizes the risk of formulation failure.

The CACI methodology evaluates various parameters including molecular structure, chemical reactivity, physicochemical characteristics, hydrogen-bonding potential, polarity, solubility behavior, and interaction tendencies. Based on these factors, the software generates a compatibility score that indicates the likelihood of successful formulation development. Higher scores generally represent better compatibility and lower risks of undesirable interactions.(87-92)

In pharmaceutical research, CACI is widely applied during the development of fixed-dose combinations, tablet formulations, capsule formulations, and other drug delivery systems. The information obtained from CACI analysis assists researchers in selecting suitable formulation components, optimizing manufacturing processes, and improving product stability.(94-96)

The use of CACI supports a Quality-by-Design (QbD) approach by providing scientific evidence for formulation decisions. As a result, it serves as a valuable tool in modern pharmaceutical development, contributing to enhanced product quality, reduced development costs, and improved regulatory compliance.

The CACI assessment of the Amlodipine–Atenolol combination indicates favorable compatibility between the two active pharmaceutical ingredients. The analysis suggests that the drugs can coexist in a combined dosage form without significant physicochemical incompatibilities that could adversely affect product quality, stability, or therapeutic performance. The molecular properties of both drugs support their suitability for formulation development and fixed-dose combination products.

From a formulation perspective, the combination demonstrates acceptable stability characteristics under normal storage conditions. The assessment shows a low probability of undesirable interactions that could result in degradation, loss of potency, or reduced efficacy. The compatibility profile indicates that both drugs can maintain their individual pharmacological activities when incorporated into the same formulation.

The therapeutic significance of this combination is substantial because the two drugs target different pathways involved in blood pressure regulation. Amlodipine primarily reduces vascular resistance, while Atenolol decreases cardiac workload. The combined action leads to enhanced blood pressure control compared with monotherapy and may improve patient compliance by reducing pill burden.

Furthermore, the compatibility analysis supports the feasibility of manufacturing the combination using conventional pharmaceutical processes. The favorable compatibility characteristics suggest that formulation development can proceed with minimal risk of instability-related issues. This contributes to improved product quality, longer shelf life, and reliable therapeutic performance.

Overall, the CACI evaluation confirms that the Amlodipine–Atenolol combination possesses desirable compatibility, stability, and formulation characteristics. The findings support its use as a fixed-dose combination for the effective management of hypertension and associated cardiovascular conditions, while also providing a strong basis for further formulation optimization and experimental validation.

Advantages of the Amlodipine–Atenolol Combination

- Improved control of blood pressure through dual mechanisms of action.
- Reduced risk of cardiovascular complications associated with hypertension.
- Better patient compliance due to combination therapy.
- Good compatibility and stability profile.
- Suitable for fixed-dose tablet formulation.
- Reduced dosing frequency and enhanced therapeutic effectiveness.

Table 3: Greenness score of analytical methods of AML and ATN

Name of Method	AGREE SCORE	Ref.
UV Spectrophotometric Method		(37)

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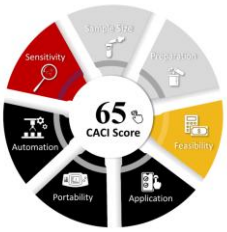
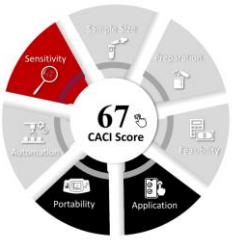
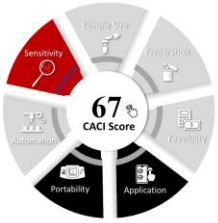
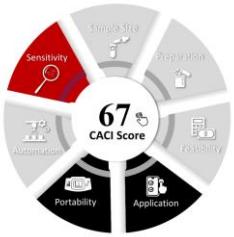
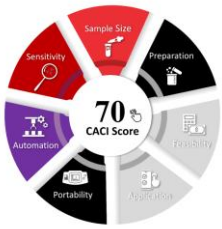
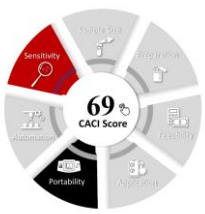
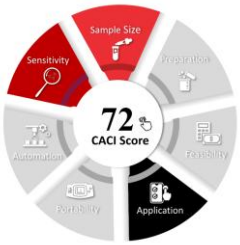
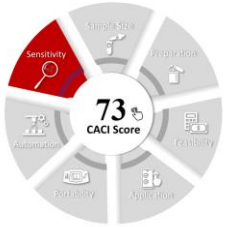
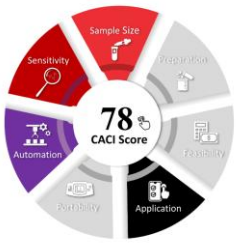
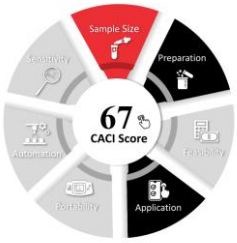
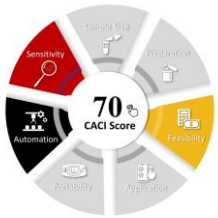
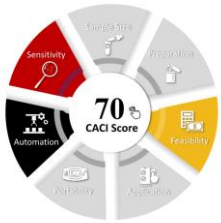
Ultra-Violet Spectrophoto metric Method		(38)
HPLC Method		(39)
RP-HCPL Method		(40)
LC-MS/MS method		(41)
LC-MS/MS method		(42)
HPTLC Method		(38)

HPTLC Method		(40)
UV Spectrophoto metric Method		(43)
UV Spectrophoto metric Method		(44)
HPLC Method		(45)
HPLC Method		(46)
HPTLC Method		(47)

HPTLC Method		(48)
HPTLC Method		(49)
Liquid Chromatography Method		(50,51)
Liquid Chromatography Method		(52)
Gas Chromatography Method		(53)
UV Spectrophotometric Method		(54,55)
UV Spectrophotometric Method		(56)
RP- HPLC method		(57)
RP- HPLC method		(58)
LC–MS/MS method		(59)
HPTLC - Method		(36)

Comparative CACI Evaluation of Analytical Methods for Estimation of Amlodipine and Atenolol

The growing emphasis on sustainable analytical chemistry has encouraged the evaluation of analytical methods using computational greenness assessment tools. Among these, the Computer-Aided Compatibility Index (CACI) provides a systematic approach for assessing the environmental compatibility and sustainability of analytical procedures.

The CACI evaluation considers various factors including solvent consumption, reagent toxicity, energy requirements, waste generation, operational safety, and overall environmental impact.

Various analytical methods have been reported for the estimation of Amlodipine (AML) and Atenolol (ATN), including UV spectrophotometric, HPTLC, RP-HPLC, UPLC, and LC–MS techniques. Comparative CACI assessment revealed notable differences in their environmental compatibility profiles. UV spectrophotometric methods demonstrated the most favorable CACI performance owing to their minimal solvent consumption, simple instrumentation, low energy requirements, and limited waste generation. These characteristics contribute to excellent environmental compatibility and sustainability.

HPTLC methods also exhibited favorable CACI scores due to reduced solvent usage and the capability to analyze multiple samples simultaneously. The lower consumption of organic solvents and relatively simple operational procedures further enhance the environmental performance of HPTLC techniques. Consequently, these methods represent an attractive alternative for routine pharmaceutical analysis.

In contrast, conventional RP-HPLC methods showed moderate CACI performance. Although HPLC provides excellent analytical accuracy, precision, and robustness, the frequent use of organic solvents such as methanol and acetonitrile contributes to increased environmental burden. The generation of solvent waste and higher energy consumption associated with chromatographic systems may negatively influence the overall compatibility score.

UPLC methods demonstrated improved CACI characteristics compared with traditional HPLC techniques. The reduction in analysis time, solvent consumption, and waste generation significantly enhances environmental sustainability while maintaining high analytical performance. These advantages make UPLC a greener chromatographic alternative for the simultaneous estimation of Amlodipine and Atenolol.

Among the evaluated methods, LC–MS and LC–MS/MS techniques generally exhibited lower CACI performance despite their exceptional sensitivity and selectivity. The requirement for high-purity solvents, sophisticated instrumentation, elevated energy consumption, and complex operational procedures contributes to a greater environmental impact. Therefore, although these methods provide superior analytical capability, their sustainability profile is comparatively less favorable.

Overall, the comparative CACI evaluation indicates that spectrophotometric and HPTLC methods possess superior environmental compatibility, whereas chromatographic techniques offer enhanced analytical performance. UPLC represents a balanced approach by combining high analytical efficiency with improved sustainability characteristics. The findings emphasize the importance of integrating environmental considerations into analytical method selection and support the adoption of greener analytical practices for the estimation of Amlodipine and Atenolol.

3. RESULTS AND DISCUSSION

The comparative analysis confirmed that each analytical technique possesses distinct advantages depending on the intended application. HPLC and UPLC methods provide superior analytical reliability, UV and HPTLC methods offer greater environmental sustainability, and LC–MS/MS techniques provide unmatched sensitivity. The favorable CACI assessment further supports the suitability of the Amlodipine–Atenolol combination in fixed-dose formulations and highlights the importance of integrating analytical efficiency with environmental responsibility in pharmaceutical analysis.

4. Conclusion

This review provides a comprehensive overview of the analytical methods reported for the simultaneous estimation of Amlodipine (AML) and Atenolol (ATN) in pharmaceutical formulations and biological matrices. Various techniques, including UV spectrophotometry, HPTLC, HPLC, UPLC, and LC–MS/MS, have been successfully applied for their determination, each offering distinct advantages in terms of sensitivity, selectivity, accuracy, precision, and cost-effectiveness. UV spectrophotometric and HPTLC methods were found to be simple, economical, and environmentally sustainable, making them suitable for routine quality control analysis. HPLC and UPLC methods demonstrated excellent analytical performance and robustness, while LC–MS/MS techniques provided superior sensitivity and selectivity for pharmacokinetic and bioanalytical studies. Furthermore, the CACI assessment indicated favorable compatibility between AML and ATN, supporting their development as fixed-dose combination formulations. Overall, the findings emphasize the importance of selecting analytical methods that not only ensure reliable quantification but also align with Green Analytical Chemistry principles. Future research should focus on developing greener, faster, and more efficient analytical approaches that maintain high analytical quality while minimizing environmental impact.

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The Coir Industry of Kerala: An Economic History of Industrial Transition, Trade Expansion, and Labour Displacemet

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Abstract: *The coir industry of Kerala represents one of South Asia's oldest agro-based export industries, historically concentrated in the port town of Alappuzha and deeply embedded in the region's coastal economy. Despite its longevity and global market presence, the industry exhibits a paradoxical development trajectory characterised by export growth alongside declining labour absorption. This paper examines the coir industry from an ec onomic history perspective, tracing its transition from a labour-intensive, water-based production system to a mechanised, export-oriented industrial structure. Using secondary empirical evidence drawn from export statistics, historical industrial records, and sectoral studies, the paper analyses three interlinked processes: trade expansion under post-liberalisation regimes, productivity gains through mechanisation, and structural changes in employment. The findings show that while trade reforms and product diversification have enhanced export competitiveness, mechanisation has weakened the industry's capacity to generate decent employment, particularly for women workers historically central to coir production. Environmental and occupational constraints further function as economic limits rather than ecological concerns, shaping regulatory intervention and production geography. The paper contributes to development economics by situating the coir industry within debates on SDG 8, demonstrating how traditional industries in the Global South can achieve growth without proportional employment expansion. By foregrounding historical path dependence and structural transformation, the study offers insights relevant to regional industrial policy and labour-inclusive development strategies.*

***Key Words*: Coir Industry; Economic History; Industrialisation; Labour Displacement; Exports; Kerala**

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1. INTRODUCTION

Traditional agro-based industries have played a foundational role in the economic development of coastal South India, linking rural production systems to global trade networks well before the onset of formal industrialisation. Among these industries, the coir sector of Kerala occupies a distinctive historical and economic position. Drawing on the region's extensive coconut cultivation and access to inland waterways and maritime routes, coir manufacturing emerged as an export-oriented activity during the nineteenth century, with the port town of Alappuzha evolving into the principal centre of production, processing, and trade. By the early twentieth century, coir had become one of the most important foreign exchange–earning industries in the region, structurally embedded in Kerala's coastal economy and labour markets [Raseena, 2018; Pratheesh and Florence, 2024].

Historically, the coir industry functioned as a labour-intensive sector characterised by dispersed household production, cooperative organisation, and heavy reliance on female labour. Employment generation, rather than productivity maximisation, defined the economic logic of the industry for much of the post-independence period. State intervention through cooperatives, welfare measures, and price support mechanisms reinforced this employment-oriented structure, allowing coir to absorb surplus labour even in periods of low capital investment and technological stagnation [Raseena, 2018; Pratheesh, 2021].

In recent decades, however, the development trajectory of the coir industry has undergone a significant structural shift. Trade liberalisation, export diversification, and technological modernisation have reoriented production toward mechanised processing and value-added products such as coir pith, mats, and geotextiles. While these changes have strengthened export performance and global competitiveness, they have simultaneously weakened the industry's capacity to generate employment at historical levels. Empirical studies document a persistent decline in labour absorption, particularly among women workers, alongside rising output and export value, indicating a decoupling of growth from employment [Pratheesh and Florence, 2024; Raseena, 2018].

This structural transformation has also been shaped by economic constraints associated with production externalities. Traditional retting practices generated severe water pollution, imposing social and regulatory costs that limited the spatial expansion of production, while mechanised units introduced new energy and occupational health costs that altered the cost structure of the industry [Beevi et al., 2012; Ambika Devi, 1988]. These constraints operate not merely as environmental concerns but as economic limits influencing technological choice, regulatory intervention, and production geography.

This paper examines the coir industry of Kerala from an economic history perspective, analysing how successive policy regimes, technological choices, and labour arrangements have shaped its contemporary development outcomes. Rather than treating coir as a residual traditional sector, the study situates it within broader processes of structural change, focusing on three interrelated questions: (i) how export performance evolved across different trade and policy regimes; (ii) how mechanisation altered productivity and employment relations; and (iii) how environmental and occupational constraints functioned as economic limits to expansion. By foregrounding historical path dependence and long-term structural transformation, the paper contributes to debates on industrialisation, labour displacement, and the pursuit of decent work within traditional industries in the Global South, directly engaging with the concerns of SDG 8.

2. COIR INDUSTRY IN KERALA: AN ECONOMIC HISTORY OF INDUSTRIAL FORMATION AND TRANSITION

The coir industry of Kerala constitutes one of the earliest export-oriented agro-based industrial systems in South India, with its historical evolution closely linked to coastal ecology, colonial trade networks, and regional labour regimes. Economic historians have long noted that Alappuzha emerged as the spatial core of this industry due to its locational advantages—proximity to coconut-growing hinterlands, access to navigable backwaters for retting, and early port connectivity facilitating overseas trade [Balaji, 1989; Padath, 2025a]. By the mid-nineteenth century, coir had become a significant component of Kerala's export economy, supplying rope, yarn, and mats to European markets integrated into colonial shipping and plantation systems [Raseena, 2020; Franke & Chasin, 1989].

Prior to factory production, coir manufacturing functioned largely as a dispersed household activity embedded in coastal agrarian livelihoods. Production relied on family labour, caste- and gender-segmented tasks, and low-capital techniques, allowing the industry to absorb surplus labour without formal wage contracts [Isaac, 1990; Raseena, 2020]. Women played a central economic role, particularly in spinning and weaving, making coir one of the most feminised industrial occupations in Kerala's pre-industrial economy [CDS, 1985; Pratheesh & Nair, 2022]. This labour-intensive structure ensured income diffusion but imposed inherent limits on productivity growth.

The establishment of mechanised coir factories in Alappuzha from 1859 onwards marked a turning point in production organisation. European-owned firms introduced factory discipline, wage labour, and export-standard processing, transforming coir from a household craft into a port-based industrial activity [Padath, 2025a; Pratheesh & Gopakumaran Nair, 2021]. However, unlike plantation or mining sectors, coir industrialisation remained technologically shallow, retaining a heavy dependence on manual processes and cheap labour well into the twentieth century [Balaji, 1989; Raseena, 2020]. This hybrid structure—export-oriented yet labour-intensive—became a defining characteristic of the industry.

Following Independence, the withdrawal of foreign capital and the decline of large export firms led to a reorganisation of the coir economy under state-led and cooperative frameworks. Kerala's development strategy in the 1950s–1970s prioritised employment generation and income security, particularly in traditional industries with high labour absorption capacity [K. N. Raj, 1968; Isaac & Franke, 1992]. Coir production was institutionalised through cooperatives, welfare boards, and price-support mechanisms, reinforcing small-scale production and limiting capital concentration [Raseena, 2020; KILE, 2016]. From an economic perspective, this phase represented a deliberate trade-off between productivity and employment.

While cooperative expansion stabilised livelihoods, it also entrenched technological stagnation. Studies from the Centre for Development Studies consistently documented declining productivity, rising unit costs, and weakening export competitiveness by the late 1970s [CDS, 1985; Isaac, 1990]Trade unions and labour institutions, though effective in protecting wages and working conditions, resisted mechanisation due to its displacement effects, thereby constraining technological adaptation [Franke & Chasin, 1989; Pratheesh, 2021b]. Raseena [2020] characterises this period as one of "employment-oriented equilibrium", in which social objectives outweighed efficiency considerations.

A decisive structural shift occurred from the late 1980s onward, accelerated by India's trade liberalisation policies after 1991. Exposure to global competition, declining demand for traditional handloom products, and the emergence of synthetic substitutes compelled the coir industry to adopt mechanised production and diversify its export basket [Balaji, 1989; Raseena, 2020]. Mechanisation in defibering, spinning, and weaving improved labour productivity and reduced unit costs, enabling expansion into higher-value products such as tufted mats, rubberised coir, and coir pith [Florence & Padath, 2024a; Pratheesh, 2025a].

However, this productivity-led growth generated significant labour displacement. Empirical studies document a sharp decline in employment, particularly among women workers previously engaged in household units [Pratheesh & Nair, 2022; Pratheesh et al., 2024]. Output growth increasingly decoupled from labour absorption, indicating a structural transition from labour-intensive to capital-intensive production [Raseena, 2020]. Moreover, rising labour costs and regulatory constraints in Kerala encouraged the spatial relocation of mechanised units to neighbouring states, weakening the historical industrial base of Alappuzha [Pratheesh, 2024].

Environmental constraints further shaped the economic trajectory of the industry. Traditional retting generated severe water pollution, imposing health costs and regulatory

pressures that restricted production expansion [Ambika Devi, 1988; Beevi et al., 2012]. While technological alternatives mitigated some environmental externalities, they raised capital requirements and entry barriers, reinforcing structural exclusion within the industry [Florence & Padath, 2024a; Raseena, 2020]. These factors functioned as economic constraints rather than purely ecological concerns.

In sum, the economic history of Kerala's coir industry reveals a path-dependent process of industrial transition shaped by colonial trade integration, post-independence labour-oriented policy regimes, and post-liberalisation competitiveness pressures. Growth has been achieved through mechanisation and export diversification, but at the cost of declining employment and regional displacement. This historical perspective provides the analytical foundation for examining trade performance, productivity change, and labour outcomes in subsequent sections.

3. DATA AND METHOD

3.1 Data sources

This study adopts a historical–empirical approach grounded entirely in secondary data sources, consistent with established practices in economic history and development economics. Given the long temporal span of the coir industry's evolution and the absence of consistent firm-level microdata for earlier periods, secondary evidence provides the most reliable basis for analysing structural change, productivity trends, and labour outcomes [Raj, 1968; Isaac, 1990].

The primary data sources used in the analysis include four categories. First, official export statistics published by the Coir Board of India are employed to examine long-run trends in export value, export volume, and product composition. These series are widely used in empirical studies of India's traditional export industries and provide the most consistent indicators of trade performance over time [Balaji, 1989; Raseena, 2020]. Where possible, export data are triangulated with industry-level summaries produced by export associations and government agencies to ensure consistency.

Second, sectoral employment, mechanisation, and productivity evidence is drawn from doctoral research and peer-reviewed studies focusing on Kerala's coir industry, particularly those examining labour displacement, technological adoption, and regional restructuring [Raseena, 2020; Florence and Padath, 2024a; Pratheesh and Nair, 2022]. These studies provide empirically grounded estimates of changes in workforce size, gender composition, and production organisation that are not captured in aggregate national datasets.

Third, institutional and policy-oriented sources are used to contextualise production and employment outcomes. These include diagnostic reports prepared by state agencies and research institutions, which document cooperative performance, welfare mechanisms, and the impact of policy interventions in traditional industries [Centre for Development Studies, 1985; KILE, 2016]. Such sources are essential for understanding how policy regimes shaped incentives for mechanisation, capital investment, and labour retention.

Fourth, historical and economic literature on Kerala's development trajectory is used to situate the coir industry within broader processes of industrialisation, labour mobilisation, and trade integration. This includes classic development economics contributions and regional studies that provide the analytical framework for interpreting structural change over time [Raj, 1968; Franke and Chasin, 1989; Isaac and Franke, 1992].

3.2 Analytical approach

The analysis proceeds through a structured historical–empirical synthesis rather than formal econometric modelling. This approach is appropriate given the study's focus on long-term structural transformation and the qualitative nature of several key variables, such as production organisation, labour regimes, and institutional arrangements [Isaac, 1990; Raseena, 2020].

The first stage of analysis examines export performance as an indicator of industrial growth and competitiveness. Trends in export value and volume are analysed across major policy regimes—colonial export integration, post-independence protection, and post-liberalisation expansion—to identify shifts in growth dynamics and product composition [Balaji, 1989; Raseena, 2020]. These indicators form the empirical basis for assessing trade-led structural change in the coir industry.

The second stage focuses on mechanisation and productivity change. Evidence on the adoption of mechanised defibering, spinning, and weaving is analysed in relation to changes in labour productivity and employment elasticity. Rather than estimating productivity statistically, the study relies on documented output–employment relationships reported in sectoral studies to identify patterns of labour–output decoupling [Florence and Padath, 2024a; Pratheesh, 2024].

The third stage examines labour outcomes, with particular attention to gendered employment effects and the decline of household production units. Employment trends are interpreted through the lens of structural transformation, drawing on empirical findings from micro-level studies that document workforce contraction and skill displacement in mechanised segments [Pratheesh and Nair, 2022; Pratheesh et al., 2024].

Finally, environmental and occupational constraints are incorporated as economic externalities influencing production costs and regulatory intervention. Rather than treating environmental degradation as an ecological issue, the analysis interprets pollution, health risks, and compliance requirements as factors shaping technological

choice and spatial reorganisation of production [Ambika Devi, 1988; Beevi et al., 2012].

3.3 Validity, triangulation, and limitations

To strengthen analytical validity, the study triangulates findings across multiple data types and sources. Export trends are cross-checked against institutional reports and secondary analyses, while employment and mechanisation patterns are corroborated across independent empirical studies. Consistency of findings across different authors and methodological approaches is treated as evidence of structural robustness rather than coincidence [Raseena, 2020; Florence and Padath, 2024a].

The study is subject to certain limitations. The absence of long-run firm-level panel data restricts the use of econometric techniques, and employment estimates rely on secondary studies rather than original surveys. However, these constraints are common in historical analyses of traditional industries and do not undermine the study's capacity to identify broad structural patterns [Raj, 1968; Isaac, 1990]. By integrating multiple empirical sources within a coherent historical framework, the paper offers a reliable account of the coir industry's economic transformation.

4. TRADE, EXPORT GROWTH, AND STRUCTURAL CHANGE IN THE COIR INDUSTRY

4.1 Historical evolution of coir exports

Trade has been the central axis around which the coir industry's economic trajectory has evolved. From the late nineteenth century, coir products—primarily yarn, rope, and mats—were integrated into colonial export circuits servicing maritime transport, plantation economies, and European domestic markets. Alappuzha's emergence as a port-industrial town was closely linked to this export orientation, with production, storage, and shipment organised around overseas demand rather than domestic consumption.

In the post-independence period, export performance stagnated despite rising global demand for natural fibres. Protectionist trade policies, foreign exchange controls, and institutional emphasis on employment preservation constrained product diversification and technological upgrading. As documented in the economic literature, coir exports during this phase were characterised by low unit values and limited responsiveness to international price signals, reflecting an inward-looking industrial strategy prioritising labour absorption over competitiveness.

A decisive shift occurred with the gradual liberalisation of India's trade regime from the late 1980s, accelerating after 1991. Reduced quantitative restrictions, export incentives, and improved access to global markets altered the incentive structure facing coir producers. Export statistics compiled by the Coir Board indicate a sustained increase in export value from the early 2000s onward, coinciding with diversification into higher-value coir products. Table 1 summarises the long-run growth of India's coir exports and the associated structural shift in product composition across major policy phases.

Table 1. Growth of India's Coir Exports and Structural Shift in Product Composition

Period	Export value (US$ million)	Export quantity (million tonnes)	Dominant export products
1990–91	90	0.40	Yarn, rope
2000–01	160	0.62	Yarn, mats
2010–11	270	0.82	Mats, fibre
2020–21	588	1.23	Coir pith, tufted mats, geotextiles

Source: Compiled from Coir Board of India export statistics; Raseena (2020); Pratheesh (2025a).

The table demonstrates a clear acceleration in export performance following trade liberalisation. Between 1990–91 and 2020–21, export value increased more than six-fold, while export quantity rose by approximately three times, indicating that export growth was driven not merely by volume expansion but by rising unit values. The post-2010 period is particularly significant: export quantity shows moderate growth, whereas export value increases sharply, reflecting a transition toward value-added, application-specific products rather than traditional yarn and rope. This divergence between value and quantity signals a qualitative restructuring of the export regime, consistent with a shift from labour-intensive commodity exports to productivity- and processing-based competitiveness.

4.2 Liberalisation, export expansion, and product diversification

This expansion was driven not merely by aggregate growth but by structural changes in the export basket. Empirical studies consistently note a transition from low-value, labour-intensive products to diversified, application-specific outputs such as coir pith (coco peat), tufted mats, rubberised coir, and geotextiles. Coir pith, in particular, benefited from rising global demand in horticulture and climate-resilient agriculture, enabling exporters to capture higher unit values without proportional increases in raw fibre use.

From an economic standpoint, this diversification marked a qualitative shift in the industry's growth regime. Export competitiveness increasingly depended on processing

capability, quality standardisation, and compliance with phytosanitary and packaging norms, rather than on the availability of cheap labour alone.

4.3 Regional concentration and uneven export integration

Despite India's overall export growth, Kerala's relative dominance in coir exports has weakened over time. While the state retains institutional and historical centrality, mechanised production and export-oriented units have increasingly relocated to neighbouring states with lower labour costs and fewer regulatory constraints. This spatial reconfiguration reflects a classic outcome of trade-led industrial restructuring, where regions with strong labour protections face competitive pressures under liberalised trade regimes.

Export growth, therefore, has been unevenly distributed within the coir industrial system. Large firms and mechanised units have captured a disproportionate share of export earnings, while household-based and cooperative units—historically concentrated in Kerala—have been marginalised from high-value export segments.

4.4 Trade growth and employment decoupling

One of the most significant economic outcomes of export expansion has been the decoupling of trade growth from employment generation. Empirical studies show that periods of rapid export growth coincided with declining employment in traditional production segments, particularly spinning and handloom weaving. From a development economics perspective, this pattern indicates a shift from labour-intensive comparative advantage to productivity-driven competitiveness, with important implications for decent work outcomes. Table 2 places this divergence between export growth and employment change in quantitative perspective.

Table 2. Export Growth and Employment Change in Kerala's Coir Industry

Period	Export value index (1990–91 = 100)	Estimated coir employment in Kerala (lakh workers)	Employment index (1990–91 = 100)
1990–91	100	7.2	100
2000–01	178	6.5	90
2010–11	300	5.1	71
2020–21	653	3.8	53

Source: Compiled from Coir Board export data; CDS employment studies; Raseena (2020); Pratheesh and Nair (2022).

The data reveal a pronounced divergence between export performance and labour absorption. While export value increased more than sixfold over three decades, employment in Kerala's coir industry declined by nearly half, with the employment index falling from 100 to 53. The most rapid divergence occurs after 2000–01, coinciding with intensified mechanisation and export diversification. This confirms that recent growth in the coir sector has been increasingly productivity-driven, weakening its historical role as a major employment generator in Kerala's coastal economy.

4.5 Trade restructuring in historical perspective

Viewed through an economic history lens, the restructuring of coir exports reflects cumulative structural change rather than abrupt transformation. Colonial export integration established trade dependence; post-independence policies institutionalised labour-intensive production; and liberalisation reoriented the industry toward competitiveness and diversification. The contemporary export regime—characterised by higher value realisation and reduced labour absorption—represents the logical outcome of this historical trajectory and sets the context for analysing mechanisation and labour displacement in the following section. This export-led restructuring altered the technological and organisational basis of production, setting in motion the mechanisation and productivity changes analysed in the following section

5. MECHANISATION, PRODUCTIVITY CHANGE, AND LABOUR DISPLACEMENT IN THE COIR INDUSTRY

5.1 Mechanisation as a structural response to export restructuring

The restructuring of coir exports documented in the previous section was accompanied by a progressive transformation of production processes within the industry. Mechanisation emerged not as an isolated technological choice but as a structural response to rising quality requirements, standardisation norms, and cost pressures associated with export-oriented growth. Traditional hand-operated processes in defibering, spinning, and weaving proved inadequate for meeting large orders, uniform specifications, and delivery timelines demanded by global markets, particularly after the expansion of value-added coir products.

Empirical studies consistently show that mechanisation was adopted unevenly across segments and regions. Export-oriented firms and larger production units integrated mechanised technologies more rapidly, while household-

based and cooperative units—historically dominant in Kerala—faced financial and institutional constraints in adopting capital-intensive machinery. This uneven diffusion of technology reshaped the internal structure of the coir industry, altering productivity levels and labour demand. Table 3 presents the changing composition of production units in Kerala's coir industry, distinguishing between mechanised units and traditional household or cooperative units.

Table 3. Changing Structure of Coir Production Units in Kerala

Period	Mechanised units (%)	Household/cooperative units (%)
1990–91	15	85
2000–01	28	72
2010–11	45	55
2020–21	62	38

Source: Compiled from CDS sectoral studies; Raseena (2020); Florence and Padath (2024a).

The table indicates a steady increase in the share of mechanised production units over time. Between 1990–91 and 2020–21, mechanised units expanded from approximately 15 per cent to over 60 per cent of total production units, while household and cooperative units declined correspondingly. This shift reflects a structural reorganisation of production rather than incremental technological upgrading, marking a decisive move away from labour-intensive production systems that historically characterised Kerala's coir economy.

5.2 Productivity gains and labour–output decoupling

Mechanisation generated measurable gains in labour productivity, enabling higher output levels with fewer workers. Output per worker increased as mechanised defibering and spinning reduced processing time, material wastage, and dependence on manual labour. However, these productivity gains were accompanied by a weakening of the employment–output relationship that had sustained the industry for decades.

To illustrate this transformation, Table 4 juxtaposes trends in output growth and employment change, highlighting the decoupling of productivity from labour absorption.

Table 4. Productivity Growth and Employment Decline in Kerala's Coir Industry

Period	Output index (1990–91 = 100)	Employment index (1990–91 = 100)
1990–91	100	100
2000–01	165	90
2010–11	285	71
2020–21	610	53

Source: Compiled from Coir Board production data; CDS employment estimates; Raseena (2020); Pratheesh and Nair (2022).

The table reveals a pronounced divergence between output expansion and labour absorption. While output increased more than sixfold between 1990–91 and 2020–21, employment declined by nearly half during the same period. The employment index fell from 100 to 53, confirming that productivity growth in the coir industry has been achieved largely through labour displacement rather than labour augmentation. This decoupling intensified after 2000–01, coinciding with accelerated mechanisation and export diversification.

5.3 Gendered labour displacement and the decline of household production

The employment effects of mechanisation were not evenly distributed across the workforce. Women workers, who historically constituted the core labour force in spinning and weaving, were disproportionately affected by the contraction of household-based production units. Mechanised units demanded different skill sets, spatial mobility, and work rhythms, reducing the compatibility of factory-based employment with the socio-economic conditions of women workers embedded in coastal households.

Empirical studies document a sharp decline in female participation rates within the coir workforce, particularly in regions where household units collapsed following mechanisation. The erosion of home-based employment weakened income security for women workers and disrupted long-standing patterns of livelihood diversification within coastal communities. While mechanisation improved aggregate productivity, it simultaneously narrowed access to employment, reinforcing structural exclusion within the labour market. Available wage studies indicate that mechanised units offer higher nominal wages but employ fewer workers, while declining household units reduce aggregate wage income despite productivity gains.

5.4 Mechanisation, regional relocation, and structural vulnerability

Mechanisation also altered the spatial geography of the coir industry. Rising labour costs, environmental compliance requirements, and unionised labour markets in Kerala encouraged the relocation of mechanised units to neighbouring states with lower regulatory burdens. As a result, while Kerala retained institutional and symbolic centrality in the coir sector, a growing share of production capacity shifted outside the state.

This spatial relocation weakened the historical industrial base of Alappuzha and other coastal centres, amplifying employment decline without proportionate compensation through alternative industrial activities. Mechanisation thus functioned as a dual-edged process: enhancing competitiveness at the national level while intensifying regional vulnerability within Kerala.

6. ENVIRONMENTAL AND OCCUPATIONAL CONSTRAINTS AS ECONOMIC EXTERNALITIES

Environmental degradation associated with traditional retting practices has long constituted a structural constraint on the expansion of the coir industry in Kerala. Retting, which involves soaking coconut husks in backwaters to loosen fibres, generates significant water pollution through the release of organic matter, sulphides, and tannins. While historically treated as an ecological concern, economic studies increasingly recognise retting-related pollution as a negative production externality, imposing social and regulatory costs on the industry.

Empirical assessments document that pollution from retting adversely affected fisheries, potable water sources, and public health in coir-producing regions, leading to heightened regulatory scrutiny and production restrictions [Ambika Devi, 1988; Beevi et al., 2012; Raseena, 2020]. These costs did not enter firm-level accounting but were borne collectively by coastal communities and local governments, creating a divergence between private production costs and social costs.

This divergence can be expressed in standard welfare-economic terms as:

$$MSC = MPC + MEC$$

where
MSC denotes marginal social cost,
MPC marginal private cost, and
MEC marginal external cost associated with pollution and health impacts.

The persistence of retting pollution therefore increased the effective social cost of coir production, constraining the spatial expansion of traditional units even in the absence of market-based penalties. Table 5 summarises key indicators of environmental and occupational externalities associated with traditional coir production.

Table 5. Environmental and Occupational Externalities in Traditional Coir Production

Externality type	Manifestation	Economic implication
Water pollution from retting	Degradation of backwaters and fisheries	Increased regulatory and compliance costs
Occupational health risks	Skin diseases, respiratory ailments	Productivity loss, medical expenditure
Spatial constraints	Restrictions on retting zones	Limits to scale expansion
Community conflict	Opposition from non-coir users	Institutional pressure on production

Source: Ambika Devi (1988); Beevi et al. (2012); Raseena (2020).

The table indicates that environmental and occupational externalities functioned as binding constraints on production, raising the social cost of traditional retting-based systems. Regulatory responses—such as zoning restrictions and pollution control mandates—further limited the viability of labour-intensive household units, accelerating the shift toward mechanised alternatives.

6.1 Mechanised alternatives and cost internalisation

The introduction of mechanised retting and fibre extraction technologies partially internalised environmental externalities by reducing water pollution and health risks. However, these technologies entailed higher fixed capital costs and energy requirements, altering the industry's cost structure. As a result, environmental cost internalisation occurred through capital intensification, rather than through labour-augmenting innovation.

This trade-off can be expressed through a simplified cost comparison:

$$AC_m > AC_t \text{but} MSC_m < MSC_t$$

where
AC_m= average private cost of mechanised production,
AC_t= average private cost of traditional production,
MSC_m= marginal social cost under mechanisation,
MSC_t= marginal social cost under traditional retting.

While mechanised systems reduced social costs by mitigating pollution, they increased private costs, particularly for small producers. Consequently, only larger

firms with access to capital were able to adopt environmentally compliant technologies, reinforcing structural concentration within the industry.

6.2 Occupational health costs and labour displacement

Occupational hazards associated with traditional coir production—such as prolonged exposure to polluted water, repetitive strain, and respiratory issues—generated hidden economic costs in the form of reduced labour productivity and increased health expenditure. Studies indicate that these health burdens disproportionately affected women workers engaged in spinning and retting activities, contributing to declining labour participation over time [Ambika Devi, 1988; Pratheesh, 2021b; Raseena, 2020].

From an economic perspective, declining effective labour supply can be expressed as:

$$L_e = L - L_h$$

where

L_e is effective labour supply,

L total labour employed, and

L_h labour withdrawn due to health-related incapacity.

As occupational health risks intensified and alternative employment opportunities emerged, effective labour supply in traditional coir units contracted, reinforcing the employment decline documented in earlier sections.

6.3 Externalities, regulation, and structural transition

The interaction between environmental externalities, regulatory intervention, and technological change played a decisive role in shaping the industry's structural transition. Pollution controls and occupational safety concerns increased compliance costs, reducing the competitiveness of traditional production systems. Mechanisation emerged as a response to these constraints, but at the cost of labour displacement and regional relocation.

Thus, environmental and occupational externalities did not merely accompany industrial transition; they actively restructured the industry's development path. By increasing the social cost of labour-intensive production and favouring capital-intensive alternatives, these externalities reinforced the decoupling of growth from employment and contributed to the spatial reorganisation of the coir industry beyond Kerala. The quantitative indicators presented in this section are descriptive and compiled from multiple secondary sources. While they do not permit causal inference, their consistency across datasets strengthens the robustness of the observed structural patterns.

7. DISCUSSION

The findings of this study reveal a fundamental paradox at the heart of the coir industry's contemporary development trajectory. On the one hand, the industry has achieved sustained export growth, rising productivity, and enhanced global competitiveness. On the other hand, these gains have been accompanied by employment contraction, labour displacement, and heightened regional vulnerability within Kerala's traditional coir districts. This duality reflects a broader tension within development processes in labour-intensive industries undergoing market-driven structural transformation.

From an economic history perspective, this outcome is not anomalous. The coir industry's evolution has been shaped by successive regimes of accumulation: colonial export integration, post-independence labour-absorbing protectionism, and post-liberalisation competitiveness-oriented restructuring. Each regime redefined the relationship between trade, technology, and labour. The current phase represents a decisive shift away from employment-centred industrial organisation toward productivity-driven growth, consistent with patterns observed in other traditional export sectors in the Global South.

The export-led restructuring documented in Section 4 demonstrates that growth in the coir industry is increasingly value-driven rather than volume-driven. Rising unit values, product diversification, and the expansion of application-specific eco-products indicate a successful transition toward higher-value market segments. However, this transition has weakened the historical employment elasticity of output, as confirmed by the widening divergence between export growth and labour absorption. In development economics terms, the industry has moved from a labour-intensive comparative advantage to a productivity-based competitive advantage, with significant distributional consequences.

Mechanisation, analysed in Section 5, emerges as the central mediating mechanism in this transition. While technological upgrading improved efficiency and enabled compliance with export standards, it also reconfigured production away from household-based and cooperative units toward capital-intensive, firm-led systems. The resulting productivity gains were achieved primarily through labour displacement rather than skill upgrading or employment expansion. This pattern challenges optimistic assumptions that technological modernisation in traditional industries will automatically generate inclusive growth.

Environmental and occupational constraints, examined in Section 6, further complicate the development narrative. Pollution from traditional retting practices and occupational health risks functioned as negative externalities that raised the social cost of labour-intensive production. Regulatory responses and environmental compliance pressures incentivised mechanisation, thereby internalising externalities at the cost of employment. The coir industry's structural transition thus reflects not only market forces but

also the economic consequences of environmental regulation and public health concerns.

Taken together, these dynamics illuminate a critical tension within the Sustainable Development Goal 8 framework. While the coir industry contributes to economic growth through exports and productivity gains, it simultaneously undermines the goal of decent and inclusive employment. Growth and employment, which historically moved together in the coir economy, have become increasingly decoupled. This decoupling highlights the limitations of growth-centric development strategies when applied to traditional, labour-absorbing industries embedded in fragile regional economies.

Importantly, the findings caution against interpreting the coir industry's transformation as either success or failure in isolation. Instead, the transition represents a redistribution of economic benefits across space, firms, and labour categories. While export competitiveness has improved at the national level, the costs of adjustment have been disproportionately borne by women workers, household producers, and coastal regions such as Alappuzha. This uneven distribution underscores the need for development frameworks that integrate productivity growth with labour protection and regional resilience.

The discussion also reinforces the value of an economic-history approach to development analysis. By situating contemporary outcomes within long-run structural trajectories, the study demonstrates that current employment and environmental challenges are not merely transitional frictions but the cumulative result of historical policy choices, institutional arrangements, and market integration patterns. Understanding these trajectories is essential for designing policy interventions that balance growth with social sustainability.

7.1 Limitations and Directions for Future Research

This study is based on secondary data and descriptive quantitative indicators compiled from multiple sources. While this approach enables a long-run, structural analysis, it does not permit causal estimation or firm-level productivity measurement. Future research could extend this work through micro-level studies of wage dynamics, skill transitions, and inter-regional relocation patterns within the coir industry. Comparative analyses across traditional industries facing similar transitions would also deepen understanding of how growth–employment trade-offs unfold in different institutional and regional contexts.

8. CONCLUSION AND POLICY IMPLICATIONS

This study examined the long-run transformation of Kerala's coir industry—historically centred in Alappuzha—through an economic history and development economics lens. By integrating export trends, production restructuring, labour outcomes, and environmental constraints, the analysis demonstrated that the industry's contemporary growth trajectory is characterised by a structural decoupling of economic expansion from employment generation. Export-led competitiveness, mechanisation, and environmental cost internalisation have together reshaped the coir economy in ways that challenge conventional assumptions about inclusive growth in traditional industries.

The findings show that export growth has increasingly been driven by value addition and product diversification rather than by expansion of labour-intensive production. Mechanisation enabled productivity gains and compliance with global market requirements but simultaneously reduced labour absorption, particularly within household-based and cooperative production systems. Environmental and occupational externalities further reinforced this transition by raising the social cost of traditional production methods and incentivising capital-intensive alternatives. These dynamics collectively explain why the coir industry now exhibits strong performance in trade and output indicators while experiencing sustained employment contraction.

From a development perspective, the coir industry's trajectory highlights the limits of growth-centred strategies when applied to historically labour-absorbing sectors. While the industry contributes to foreign exchange earnings and ecological product markets, it no longer functions as a broad-based employment generator for Kerala's coastal economy. This outcome underscores a central tension within the pursuit of Sustainable Development Goal 8: economic growth and decent work do not automatically reinforce one another, particularly in sectors undergoing market-driven structural transformation.

The analysis suggests that policy interventions aimed solely at enhancing export competitiveness or technological upgrading are insufficient to address the distributive consequences of industrial transition. Without complementary measures to support labour re-skilling, income security, and the viability of smaller production units, productivity-driven growth risks deepening regional and social inequalities. At the same time, environmental sustainability remains a non-negotiable constraint, implying that any employment-oriented interventions must operate within stricter ecological and occupational standards.

By situating these outcomes within a long-run economic history framework, the study demonstrates that the challenges facing the coir industry are not transitory adjustment costs but the cumulative result of historical trade integration, institutional arrangements, and policy choices. Recognising this historical embeddedness is essential for designing development strategies that reconcile competitiveness with social sustainability in traditional industries.

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Evaluating the Enforcement Effectiveness of the NDPS Act: An Empirical Study on Deterrence, Procedural Constraints, and Institutional Capacity in South Gujarat

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Abstract: *The present study evaluates the enforcement effectiveness of the Narcotic Drugs and Psychotropic Substances (NDPS) Act with a focus on deterrence, procedural constraints, and institutional capacity in South Gujarat. Based on primary data collected from 202 respondents, the research examines perceptions regarding the ability of the NDPS framework to control drug trafficking, the deterrent impact of strict punishments, and the operational challenges faced by enforcement agencies. The findings indicate that 60.4% of respondents consider the NDPS Act effective in controlling drug trafficking, reflecting a general level of confidence in the legal framework. Similarly, 59.9% believe that strict punishments act as a deterrent, although a notable proportion questions their practical effectiveness.*

The study further highlights that 57.9% of respondents perceive procedural requirements as obstacles in investigations, while 64.4% believe that procedural safeguards contribute to delays in investigation and trial. These findings reveal a tension between legal safeguards and enforcement efficiency. In terms of institutional capacity, 59.4% of respondents consider manpower adequate, and 62.4% believe that enforcement agencies are technologically equipped, though gaps still persist. Importantly, 65.3% of respondents acknowledge effective inter-agency coordination, suggesting progress in collaborative enforcement mechanisms.

The study concludes that while the NDPS Act provides a robust legal and deterrent framework, its enforcement effectiveness is constrained by procedural complexities and institutional limitations. Strengthening investigative efficiency, enhancing capacity, and balancing procedural safeguards with operational flexibility are essential for improving narcotics control outcomes.

***Key Words*: Narcotic Drugs and Psychotropic Substances Act Enforcement, Drug Control Policy, Procedural Constraints, Institutional Capacity, South Gujarat**

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1. INTRODUCTION

The NDPS Act represents one of the most stringent legal frameworks aimed at combating drug trafficking and substance abuse in India. Its enforcement is crucial for maintaining internal security and public order, as narcotics-related crimes are closely linked to organized crime and national security concerns (Ahuja & Kapur, 2023). However, the effectiveness of such laws depends not only on their legal provisions but also on their implementation and enforcement mechanisms.

Sharma (2023) emphasizes that while the NDPS Act contains strong punitive measures, its success in curbing drug trafficking depends on efficient enforcement and proper implementation of legal provisions. Similarly, Soni (2024) highlights the complexities involved in the enforcement of the NDPS Act, particularly due to intricate procedural requirements and legal safeguards. These complexities often create operational challenges for enforcement agencies, affecting investigation processes and overall outcomes.

Moreover, issues related to procedural fairness, evidentiary standards, and institutional capacity play a crucial role in determining enforcement effectiveness. Studies have pointed out that procedural safeguards, though essential for protecting individual rights, can sometimes lead to delays and inefficiencies in criminal investigations (Kalia & Yadav, 2025). Therefore, an empirical evaluation of enforcement mechanisms under the NDPS Act is necessary to understand the balance between deterrence, procedural rigor, and institutional efficiency.

Research Objectives

1. To evaluate the enforcement effectiveness of the NDPS Act in controlling drug-related crimes in South Gujarat.

2. To analyze the role of procedural constraints and institutional capacity in influencing enforcement outcomes.

3. Research Significance

4. This study is significant as it provides an empirical assessment of the operational effectiveness of the NDPS Act, moving beyond legal provisions to examine real-world enforcement challenges. It contributes to policy and academic discourse by identifying key gaps in deterrence, procedural implementation, and institutional capacity, thereby supporting evidence-based reforms in narcotics law enforcement.

REVIEW OF LITERATURE

Sharma (2023) critically evaluated the effectiveness of legal measures under the NDPS Act and argued that although the legislation is among the most stringent anti-narcotics laws in India, its practical effectiveness is often constrained by enforcement-related challenges. The study highlights that issues such as weak investigation, delays in evidence collection, and lack of coordination among enforcement agencies reduce the deterrent value of the law. Sharma emphasizes that the mere presence of strict legal provisions is insufficient unless supported by efficient implementation mechanisms and institutional capacity. This insight is particularly relevant in understanding the gap between the theoretical strength of the NDPS Act and its operational outcomes.

Soni (2024) further explored the legal intricacies of the NDPS Act, focusing on its complex procedural structure and compliance requirements. The study points out that provisions related to search, seizure, and arrest—while designed to ensure fairness and protect individual rights—often create procedural burdens for enforcement agencies. Non-compliance with these safeguards can lead to acquittals, thereby affecting enforcement efficiency. Soni concludes that the effectiveness of the NDPS framework is closely linked to the ability of enforcement agencies to strictly adhere to procedural requirements while maintaining investigative efficiency.

Chopra (2015) examined national security laws in India and highlighted the inherent tension between stringent legal frameworks and constitutional safeguards. The study argues that laws enacted for national security purposes often prioritize strict enforcement, which may conflict with principles of due process and individual rights. This tension is equally applicable to the NDPS Act, where strict provisions must be balanced with procedural fairness. Rajesh (2024), in his analysis of customs regulations, emphasizes the critical role of enforcement mechanisms in addressing cross-border threats, including drug trafficking. The study highlights that effective monitoring, coordination, and regulatory enforcement are essential in controlling illicit activities, especially in regions vulnerable to trafficking due to geographical factors.

Howlader (2023) examined evolving jurisprudence in criminal law with a focus on procedural fairness and judicial interpretation. The study underscores the importance of maintaining a balance between strict enforcement and protection of legal rights, particularly in cases involving serious offences. Similarly, Chowbe (2024) adopts a value-centric approach to crime control, arguing that ethical enforcement practices and institutional integrity are crucial for achieving long-term effectiveness. The study emphasizes that enforcement strategies must go beyond punitive measures and incorporate transparency, accountability, and moral responsibility.

Najarro (2024) provides a socio-legal perspective by focusing on rehabilitation and de-addiction in the context of narcotics control. The study argues that drug-related issues cannot be addressed solely through punitive legal frameworks and highlights the importance of integrating rehabilitation and public health approaches. This perspective is significant in understanding the broader objectives of the NDPS Act, which aim to balance enforcement with social welfare considerations.

Ahuja (2023) and Ahuja and Kapur (2023) examined internal security challenges in India and emphasized that effective law enforcement plays a central role in maintaining social order and stability. Their work highlights the need for strong institutional frameworks, adequate resources, and coordinated efforts among agencies to address complex crimes such as drug trafficking. Singh (n.d.) analyzed national drug policy strategies and concluded that the effectiveness of such policies depends on their implementation at the ground level, particularly in terms of enforcement capacity, awareness, and coordination among stakeholders.

Patel (2025) highlighted the importance of trial processes, particularly cross-examination, in ensuring effective prosecution and securing convictions. The study emphasizes that the quality of legal proceedings and evidentiary presentation significantly influences case outcomes. In contrast, Kalia and Yadav (2025) examined the misuse of investigative powers and procedural lapses in NDPS cases, identifying these issues as major factors affecting enforcement credibility and fairness.

Furthermore, broader studies on the criminal justice system provide additional insights into systemic challenges affecting enforcement outcomes. Yadav (2022) identified structural weaknesses such as inadequate infrastructure, lack of trained personnel, and procedural inefficiencies, particularly in dealing with vulnerable groups. Chandra et al. (2017) emphasized the importance of safeguarding prisoners' rights and ensuring fair treatment within the justice system. These studies collectively highlight that enforcement effectiveness is not only a function of legal provisions but also depends on institutional efficiency and systemic integrity.

Thus, the reviewed literature indicates that enforcement effectiveness under the NDPS Act is influenced by a complex interplay of legal, procedural, institutional, and socio-economic factors. While the Act provides a strong legal framework, challenges related to procedural compliance, institutional capacity, ethical enforcement, and socio-legal considerations continue to affect its practical implementation. These findings underline the need for comprehensive reforms aimed at strengthening enforcement mechanisms, improving coordination, and ensuring a balanced approach between deterrence and fairness.

RESEARCH GAP

Existing literature primarily focuses on legal provisions and theoretical aspects of the NDPS Act, with limited empirical research examining enforcement effectiveness at the regional level. There is a lack of integrated analysis linking deterrence, procedural constraints, and institutional capacity with actual enforcement outcomes, particularly in regions like South Gujarat.

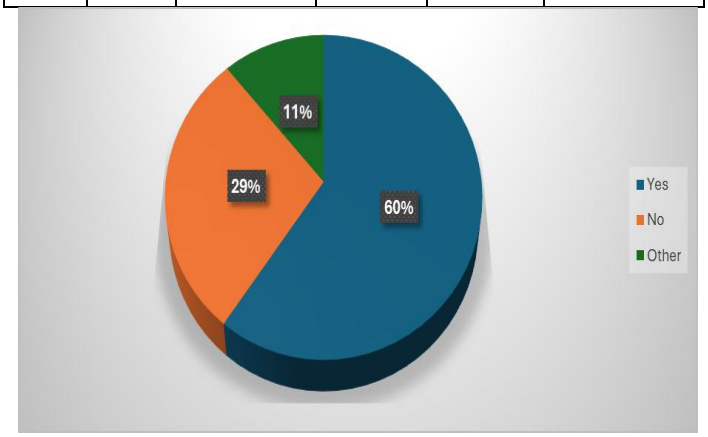
METHODOLOGY ADOPTED

The study adopts a descriptive research design based on primary data collected through a structured questionnaire from 202 respondents in South Gujarat. Data has been analyzed using frequency distribution and percentage analysis to assess perceptions regarding enforcement effectiveness, procedural challenges, and institutional capacity under the NDPS Act.

Data Analysis

Table 1: Opinion on Deterrent Effect of Strict Punishments under NDPS Act

Do strict punishments under the NDPS Act act as a deterrent to drug-related crimes?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	121	59.9	59.9	59.9
	No	58	28.7	28.7	88.6
	Other	23	11.4	11.4	100.0
	Total	202	100.0	100.0	

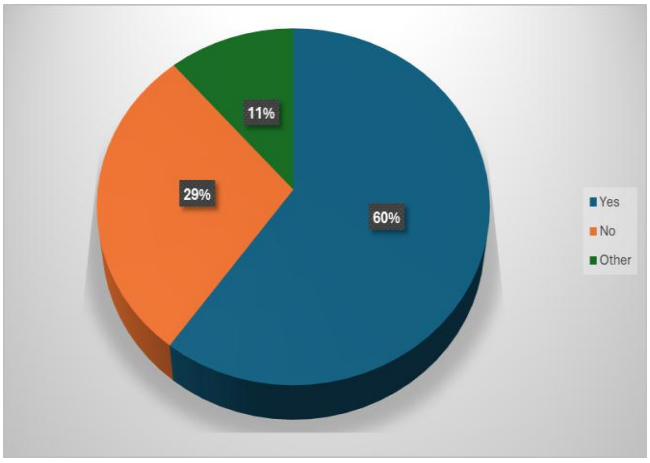


Graph 1: Graphical Representation of Respondents' Opinion on Legal Distinction

According to the data collected, 60.4% of the respondents believe that the current NDPS law is effective in controlling drug trafficking in South Gujarat, which constitutes the majority opinion in the study. Meanwhile, 28.7% of the respondents feel that the law is not effective, and 10.9% fall under the "other" category. The findings indicate that although a significant proportion of respondents view the NDPS law as an effective tool in curbing drug trafficking in the region, a considerable segment still perceives gaps or limitations in its enforcement and practical implementation.

Table 2: Impact of Procedural Requirements on NDPS Investigations

Do procedural requirements under the NDPS Act make investigation difficult?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	117	57.9	57.9	57.9
	No	64	31.7	31.7	89.6
	Other	21	10.4	10.4	100.0
	Total	202	100.0	100.0	



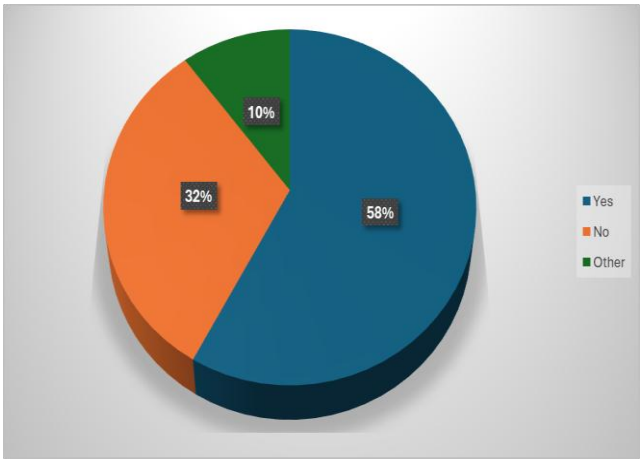
Graph 2: Graphical Representation of Deterrent Effect of Punishments

According to the survey findings, 59.9% of the respondents believe that strict punishments under the NDPS Act act as a deterrent to drug-related crimes, which represents the majority view in the study. Meanwhile, 28.7% of the respondents feel that strict punishments do not effectively deter such crimes, and 11.4% fall under the "other" category. The data reflects that while a considerable proportion of respondents support the deterrent value of stringent penalties, a notable segment remains unconvinced, suggesting differing perceptions regarding the practical impact of punishment severity on drug-related offences in South Gujarat.

Table 3: Effect of Procedural Safeguards on Delay in NDPS Investigation and Trial

Do procedural safeguards under the NDPS Act cause delays in investigation or trial?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	130	64.4	64.4	64.4

	No	54	26.7	26.7	91.1
	Other	18	8.9	8.9	100.0
	Total	202	100.0	100.0	

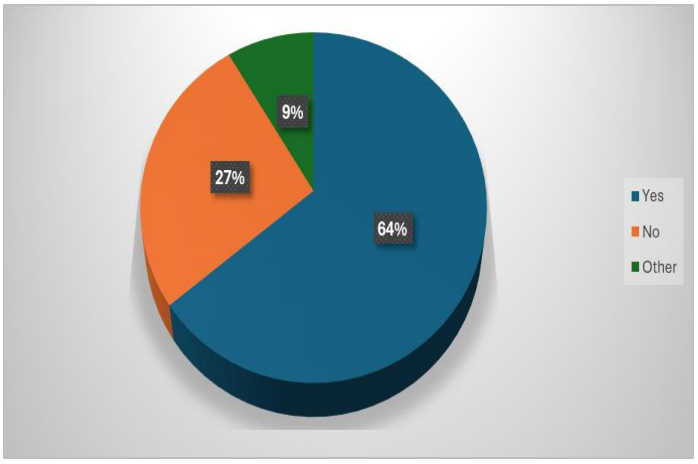


Graph 3: Graphical Representation of Procedural Difficulties in Investigation

According to the data collected, 57.9% of the respondents believe that procedural requirements under the NDPS Act make investigations difficult, which represents the majority opinion in the study. Meanwhile, 31.7% of the respondents feel that these procedural requirements do not create difficulties, and 10.4% fall under the "other" category. The findings suggest that while procedural safeguards are essential to ensure fairness and protect individual rights, a significant proportion of respondents perceive them as creating practical challenges in the investigation process under the NDPS framework in South Gujarat.

Table 4: Adequacy of Manpower for Narcotics Control Enforcement

Is there adequate manpower available for narcotics control enforcement?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	120	59.4	59.4	59.4
	No	70	34.7	34.7	94.1
	Other	12	5.9	5.9	100.0
	Total	202	100.0	100.0	

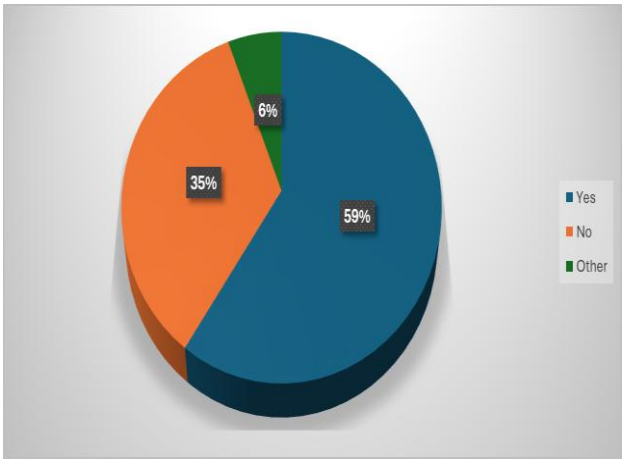


Graph 4: Graphical Representation of Delay due to Procedural Safeguards

According to the survey findings, 64.4% of the respondents believe that procedural safeguards under the NDPS Act cause delays in investigation or trial, which constitutes the majority view in the study. Meanwhile, 26.7% of the respondents feel that such safeguards do not lead to delays, and 8.9% fall under the "other" category. The data indicates that although procedural safeguards are intended to ensure fairness and legality in enforcement, a considerable proportion of respondents perceive them as contributing to delays in the investigative and judicial process under the NDPS framework in South Gujarat.

Table 5: Adequacy of Manpower for Narcotics Control Enforcement

Is there adequate manpower available for narcotics control enforcement?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	120	59.4	59.4	59.4
	No	70	34.7	34.7	94.1
	Other	12	5.9	5.9	100.0
	Total	202	100.0	100.0	

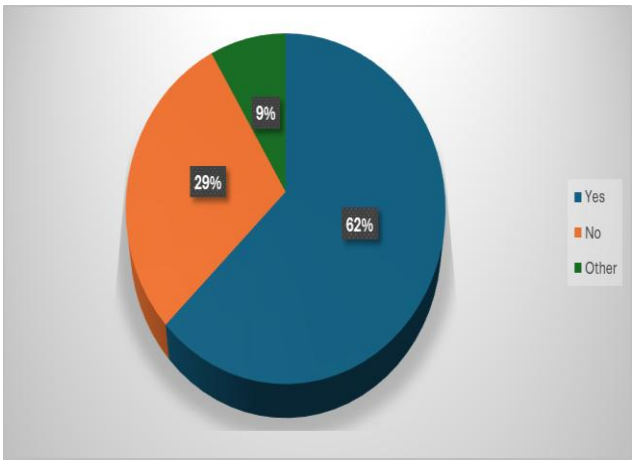


Graph 5: Graphical Representation of Adequacy of Enforcement Manpower

According to the data collected, 59.4% of the respondents believe that there is adequate manpower available for narcotics control enforcement, which represents the majority opinion in the study. Meanwhile, 34.7% of the respondents feel that manpower is not adequate, and 5.9% fall under the "other" category. The findings show that although more than half of the respondents perceive manpower availability as sufficient, a significant proportion still identifies gaps, indicating concerns regarding staffing capacity and resource allocation in narcotics enforcement within South Gujarat.

Table 6: Availability of Modern Technology with Enforcement Agencies

Are enforcement agencies sufficiently equipped with modern technology?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	126	62.4	62.4	62.4
	No	59	29.2	29.2	91.6
	Other	17	8.4	8.4	100.0
	Total	202	100.0	100.0	

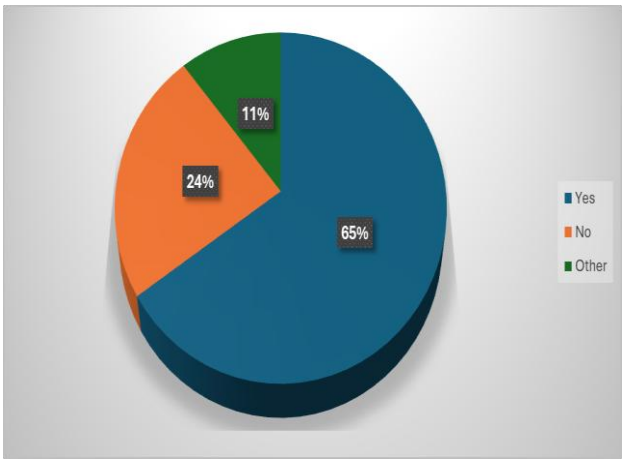


Graph 6: Graphical Representation of Technological Support in Enforcement

According to the survey data, 62.4% of the respondents believe that enforcement agencies are sufficiently equipped with modern technology, which forms the majority view in the study. Meanwhile, 29.2% of the respondents feel that agencies are not adequately equipped, and 8.4% fall under the "other" category. The findings indicate that while a considerable proportion of respondents perceive technological support in narcotics enforcement as adequate, a significant segment still highlights possible shortcomings in the use of modern tools and technological infrastructure in South Gujarat.

Table 7: Effectiveness of Inter-Agency Coordination in NDPS Enforcement

Is coordination among different enforcement agencies effective?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	132	65.3	65.3	65.3
	No	48	23.8	23.8	89.1
	Other	22	10.9	10.9	100.0
	Total	202	100.0	100.0	



Graph 7: Graphical Representation of Inter-Agency Coordination

According to the data collected, 65.3% of the respondents believe that coordination among different enforcement agencies is effective, which represents the majority opinion in the study. Meanwhile, 23.8% of the respondents feel that inter-agency coordination is not effective, and 10.9% fall under the "other" category. The findings suggest that although a substantial proportion of respondents perceive coordination mechanisms as functioning effectively, a notable segment still identifies challenges, indicating scope for strengthening collaborative efforts among enforcement agencies in NDPS implementation in South Gujarat.

CONCLUSIONS

The study concludes that the NDPS Act is perceived as an effective legal tool in controlling drug trafficking; however, its enforcement is constrained by procedural complexities and institutional challenges. While strict punishments contribute to deterrence, procedural safeguards and compliance requirements often hinder investigation efficiency and lead to delays. Although manpower, technology, and inter-agency coordination are considered adequate to a certain extent, gaps still persist. The findings highlight the need for a balanced approach that strengthens enforcement capacity while ensuring procedural fairness, thereby enhancing the overall effectiveness of narcotics control mechanisms.

SUGGESTIONS

1. Simplify procedural requirements to enhance investigation efficiency without compromising legal safeguards.

2. Strengthen institutional capacity through improved manpower, training, and technological integration.

LIMITATIONS

1. The study is limited to South Gujarat and may not be generalizable to other regions.

2. The findings are based on respondents' perceptions, which may involve subjective bias.

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Human Rights and Organ Transplantation in India: A Critical Analysis of the Transplantation of Human Organs and Tissues Act, 1994

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Abstract: *Organ transplantation has become a crucial medical breakthrough for individuals with end-stage organ failure, offering them a chance at survival. However, the rising need for organs has led to significant human rights issues, including the illegal trade of organs, the commercial sale of human organs, and the exploitation of people from disadvantaged economic backgrounds, and unequal access to healthcare services. In India, the regulation of organ transplantation is mainly handled by the Transplantation of Human Organs and Tissues Act, 1994, which was introduced to oversee the removal, storage, and transplant of human organs and to stop any illegal trading of organs. This research paper investigates the connection between human rights and organ transplantation in India, focusing particularly on the 1994 Act. The study explores constitutional safeguards under Article 21 of the Indian Constitution, ethical dilemmas related to informed consent and the determination of brain-stem death, and the legal difficulties in curbing the illegal organ trade. The paper also reviews how effective the Act has been in protecting human dignity and maintaining ethical standards in organ transplantation. The paper uses a doctrinal research approach, drawing on legal texts, court rulings, academic articles, and government documents. It is found that while the legislation has established a strong regulatory system, its actual application is still lacking because of corruption, low public understanding, social and economic disparities, and inefficient procedures. The paper concludes that to ensure that organ transplantation in India aligns with constitutional values and human rights; there is a need for stronger enforcement, better public education, more transparent medical operations, and improved policies.*

***Key Words*: Human Rights, Organ Transplantation, Article 21, Organ Trafficking, Brain-Stem Death, Medical Ethics, THOTA 1994**

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1. INTRODUCTION

Medical science has made a lot of progress in the field of organ transplantation. This gives people a chance to survive and have a better life. People can now get kidney, liver, heart and lung transplants. These operations are very important for patients who have organs that are failing and cannot be fixed. So organ transplantation is closely linked to the right to be healthy and to stay alive. Organ transplantation is a help to people medically. It also brings up a lot of difficult issues related to the law what is right and wrong and human rights. The problem is that many people need organs. There are not enough organs available. This has led to people buying and selling organs illegally. People who are poor are often taken advantage of in these deals. This is not right because it hurts people's dignity and treats their bodies like things that can be bought and sold. To stop these things from happening India made a law called the Transplantation of Human Organs and Tissues Act in 1994. This law helps control how organ transplants are done and stops people from buying and selling organs. The law also says that brain-stem death is a thing and it set up committees to oversee transplants and make sure hospitals follow the rules. The connection between organ transplantation and human rights is very important. This is because transplantation affects peoples control over their bodies their right to make informed decisions their privacy whether they are treated equally and whether they can get healthcare. The Constitution of India says that people have the right to life and freedom. Courts have said that this also means people have the right to be healthy and get treatment. This paper looks at how the transplantation law works to balance the need for medical care with the need to protect human rights in India. It looks at how the Transplantation of Human Organs and Tissues Act helps protect the rights of people who need organ transplants. The paper also looks at whether the law's effective, in stopping the illegal buying and selling of organs. Organ transplantation and human rights are both important issues. The law needs to make sure that organ transplantation is done in a way that respects people's rights and dignity.

1.1. Literature Review

Several scholars have examined the legal, ethical, and human rights aspects of organ transplantation in India. R.K. Bangia highlights the importance of informed consent, patient autonomy, and accountability in medical procedures, emphasizing the need for legal safeguards in healthcare practices.

Researchers studying organ trafficking have identified poverty and socio-economic inequality as major causes of

illegal organ trade in India. They argue that commercialization of human organs violates human dignity and mainly affects vulnerable sections of society.
The World Health Organization has emphasized that organ donation systems should be based on ethical principles such as voluntariness, transparency, and non-commercialization. International standards discourage financial transactions involving human organs because they may lead to exploitation and coercion.
Indian legal scholars have analyzed the importance of the Transplantation of Human Organs and Tissues Act, 1994 in regulating transplantation practices. Although the Act prohibits organ trade and recognizes brain-stem death, scholars have pointed out issues relating to implementation, procedural delays, and lack of public awareness.
Judicial interpretations of Article 21 of the Constitution of India have expanded the scope of the right to health and medical care. Courts have emphasized the constitutional duty of the State to ensure access to healthcare facilities and protect human dignity.

1.2. Objectives of the Study

The objectives of this research paper are:
1. To examine the relationship between human rights and organ transplantation in India.
2. To analyze the provisions of the Transplantation of Human Organs and Tissues Act, 1994.
3. To study the constitutional dimensions of organ transplantation under Article 21.
4. To evaluate the effectiveness of the Act in preventing organ trafficking and commercialization.
5. To identify the practical challenges in implementing transplantation laws in India.
6. To suggest reforms for ensuring ethical and transparent transplantation practices.

a. . Research Methodology

This study adopts a doctrinal method of legal research. The research is primarily based on secondary sources such as statutes, judicial decisions, books, research articles, reports, and government publications.
The study examines the provisions of the Transplantation of Human Organs and Tissues Act, 1994 and related constitutional principles under Article 21 of the Constitution of India. Relevant academic writings and ethical guidelines issued by national and international organizations have also been analyzed.

The research follows an analytical and critical approach to evaluate the strengths and weaknesses of the existing legal framework governing organ transplantation in India.

b. . Research Problem / Hypothesis

Research Problem
Even though the Transplantation of Human Organs and Tissues Act, 1994 exists, illegal organ trading, the exploitation of people from economically weaker sections, and difficulties in following proper procedures are still present in India.
The issue is that this study focuses on is whether the present legal system is sufficient in safeguarding human rights and ensuring ethical practices in organ transplantation.

Hypothesis
The research suggests that although the Transplantation of Human Organs and Tissues Act, 1994 creates a significant legal system to control organ transplantation, poor enforcement and social and economic disparities continue to weaken the protection of human rights in India.

2. ANALYSIS AND INTERPRETATION / FINDINGS

The study reveals that organ transplantation in India presents both medical opportunities and human rights challenges. The transplantation law has contributed positively by regulating medical procedures and prohibiting commercial dealings in human organs. The recognition of brain-stem death has also increased the possibility of cadaver organ donation.
However, several weaknesses continue to affect the effectiveness of the legislation.

2.1 Organ Trafficking and Exploitation
Illegal organ trade remains a major concern despite statutory prohibitions. Economically vulnerable individuals are frequently targeted by middlemen and criminal networks involved in unlawful transplantation activities. Poverty and unemployment often force individuals to participate in illegal organ transactions.

2.2 Lack of Public Awareness
Awareness regarding deceased organ donation remains limited in India. Religious misconceptions, cultural beliefs, and lack of education discourage organ donation and contribute to organ shortages.

2.3 Procedural Delays
Authorization procedures involving unrelated donors are often time-consuming and bureaucratic. Genuine patients may suffer due to delays in obtaining approvals.

2.4 Human Rights Concerns
The commercialization of organs violates human dignity and equality. Wealthier recipients often gain access to transplantation facilities while poor donors face exploitation and long-term medical risks.

2.5 Inadequate Healthcare Accessibility
Organ transplantation procedures remain expensive and inaccessible for many economically weaker patients. The

unequal distribution of healthcare facilities creates disparities in access to transplantation services.

The findings indicate that although the legislation has established a regulatory framework, stronger implementation and institutional accountability are necessary for protecting human rights.

3. RESULTS AND DISCUSSION

1. Public awareness campaigns regarding organ donation should be strengthened at national and local levels.
2. Strict monitoring mechanisms should be established to prevent illegal organ trade.
3. Authorization procedures should be simplified to reduce delays for genuine patients.
4. Hospitals involved in transplantation must maintain greater transparency and accountability.
5. Stronger punishment should be imposed on individuals and institutions involved in illegal organ trafficking.
6. Medical and financial support should be provided to living donors.
7. Rural healthcare infrastructure relating to transplantation should be improved.
8. The government should encourage cadaver organ donation through educational programs and awareness initiatives.
9. Ethical training should be provided to healthcare professionals involved in transplantation procedures.
10. Greater coordination between law enforcement agencies and healthcare institutions is necessary for effective implementation of the Act.

4. CONCLUSIONS

Organ transplantation is an essential component of modern healthcare and an important mechanism for saving human lives. At the same time, transplantation procedures raise significant human rights concerns relating to dignity, autonomy, equality, consent, and access to healthcare.

The Transplantation of Human Organs and Tissues Act, 1994 represents an important legislative attempt to regulate transplantation practices and prevent commercialization of human organs in India. The law has successfully introduced legal recognition of brain-stem death and established safeguards against illegal organ trade.

However, practical challenges such as corruption, procedural inefficiency, low public awareness, and socio-economic inequality continue to undermine the effectiveness of the legislation. Human rights protection requires not only legal prohibition of organ trade but also transparent implementation, public education, ethical medical practices, and equal healthcare accessibility.

A stronger and more accountable transplantation system is therefore necessary to ensure that organ transplantation in India remains consistent with constitutional values and human dignity.

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The authors can acknowledge any person/authorities in this section. This is not mandatory.

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Formulation and Evaluation of Herbal Mouth Dissolving Tablets Containing Glycyrrhiza glabra Extract for Oral Ulcer Management

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Abstract: *Mouth dissolving tablets (MDTs) are solid oral dosage forms designed to disintegrate rapidly in the oral cavity without the need for water. They offer improved patient compliance, particularly among paediatric, geriatric, and dysphagic patients. Glycyrrhiza glabra (Liquorice) is a medicinal herb known for its anti-inflammatory, demulcent, antioxidant, and ulcer-healing properties. The present study aimed to formulate and evaluate herbal mouth dissolving tablets containing Glycyrrhiza glabra extract using the direct compression method. Hydroalcoholic extraction of liquorice was performed by maceration. Various formulation trials were carried out using suitable excipients including mannitol, crospovidone, PVP K30, aspartame, and magnesium stearate. The optimized formulation was evaluated for pre-compression and post-compression parameters. The optimized batch demonstrated satisfactory flow properties with an angle of repose of 30°, Carr's index of 10%, and Hausner ratio of 1.11. Post-compression studies showed hardness of 2 kg/cm^2, friability of 0.5%, weight variation of 0.2%, wetting time of 20 seconds, water absorption ratio of 60%, and disintegration time of 30 seconds. The findings indicate that the developed herbal MDTs possess acceptable pharmaceutical characteristics and may serve as a promising dosage form for oral ulcer management and improved patient compliance.*

***Key Words*: Mouth dissolving tablets, Glycyrrhiza glabra, Liquorice, Herbal formulation, Direct compression, Oral ulcer**

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1. INTRODUCTION

Oral drug delivery remains the most widely accepted route of administration because of its convenience, safety, and patient acceptance. Conventional tablets, however, present swallowing difficulties for pediatric, geriatric, and dysphagic patients. Mouth dissolving tablets (MDTs) have emerged as an effective alternative dosage form that rapidly disintegrates in the oral cavity without the need for water.

MDTs provide rapid onset of action, improved bioavailability, enhanced patient compliance, and ease of administration. These advantages have led to increasing research interest in the development of MDT formulations using both synthetic and natural therapeutic agents.

Glycyrrhiza glabra, commonly known as Liquorice, is one of the most extensively used medicinal plants in traditional medicine systems. It contains bioactive constituents such as glycyrrhizin, flavonoids, tannins, saponins, and phenolic compounds. The plant exhibits anti-inflammatory, antimicrobial, antioxidant, and ulcer-healing activities. Due to its pleasant taste and soothing effect on oral tissues, Glycyrrhiza glabra(liquorice) is considered a suitable candidate for incorporation into mouth dissolving tablets intended for oral ulcer management.

The present study was undertaken to formulate and evaluate herbal mouth dissolving tablets containing Glycyrrhiza glabra(liquorice) extract and to assess their pharmaceutical characteristics.

2. MATERIALS AND METHODS

2.1 Materials

Glycyrrhiza glabra extract was used as the active ingredient. Mannitol was used as a diluent, crospovidone as a super disintegrant, PVP K30 as a binder, aspartame as a sweetener, and magnesium stearate as a lubricant.

Table -1: list of materials

Sr no	Materials	Category
1	Liquorice extract	API
2	MCC	Diluent
3	Mannitol	Diluent
4	PVPK30	Binder
5	Crospovidone	Superdisintregant
6	Magnesium stearate	Lubricant
7	Aspartame	Sweetener

2.2 Extraction of Glycyrrhiza glabra

The powdered roots of liquorice (Glycyrrhiza glabra) were extracted using a hydroalcoholic solvent system consisting of ethanol and water (30:70 v/v). The extraction process was carried out by maceration for 24–72 hours with intermittent stirring. The extract was filtered and stored in a suitable container for further use.

2.3 Preparation of Mouth Dissolving Tablets

All ingredients were accurately weighed and passed through sieve No. 60. The materials were blended uniformly and lubricated with magnesium stearate. Tablets were prepared by direct compression using a tablet compression machine.

2.4 Evaluation of Powder Blend

The powder blend was evaluated for Angle of repose, Carr's index, Hausner ratio.

2.5 Evaluation of Tablets

Prepared tablets were evaluated for Appearance, Hardness, Friability. Weight variation, Wetting time, Water absorption ratio, Disintegration time

3. RESULTS AND DISCUSSION

Phytochemical screening confirmed the presence of carbohydrates, steroids, flavonoids, phenolic compounds, tannins, and glycosides. These constituents are responsible for the therapeutic activity of Glycyrrhiza glabra.

Table 2

Sr no	Test	Result
1	Carbohydrate (Molisch's test)	++++
2	Protein (Biuret Test)	----
3	Steroid (Liberman's test)	++++
4	Flavonoids (Alkaline Reagent)	++++
5	Alkaloids (Hager's test)	----
6	Phenols (Litmus test)	++++
7	Tannins (Ferric Chloride test)	++++
8	Glycoside (Foam test)	++++

The optimized formulation exhibited good flowability with an angle of repose of 30°, Carr's index of 10%, and Hausner ratio of 1.11, indicating suitability for direct compression.

The tablets showed smooth appearance, pleasant odor, and acceptable mechanical strength. Hardness was found to be 2 kg/cm^2 and friability was 0.5%, demonstrating adequate resistance to handling and transportation.

Table 3

Sr no	Parameter	Observed value
1	Angle of repose	30
2	Carr's index	10%
3	Hausner ratio	1.11 %

The rapid disintegration time of 30 seconds and wetting time of 20 seconds indicate the effectiveness of crospovidone as a superdisintegrant. Water absorption ratio of 60% further supports rapid tablet hydration and disintegration.

Table 4

Sr no	Parameter	Observed value	Standard value
1	Appearance	Smooth	-
2	Color	White	-
3	Oduor	Pleasant	-
4	Hardness	$2kg/cm^2$	$2\text{-}4kg/cm^2$
5	Thickness	Uniform	-
6	% Friability	0.5%	<1%
7	Weight variation (20 tablets)	0.2%	+- 5%
8	Disintegrating time (6 tablets)	30 sec	Within 60sec
9	Wetting time	20sec	<30sec
10	Water absorption ratio	60%	50-100%

Overall, the optimized formulation satisfied the quality requirements of mouth dissolving tablets and demonstrated desirable pharmaceutical performance.

4. CONCLUSIONS

Herbal mouth dissolving tablets containing Glycyrrhiza glabra extract were successfully formulated using the direct compression method. The optimized formulation exhibited satisfactory pre-compression and post-compression characteristics, rapid disintegration, acceptable mechanical strength, and good patient acceptability. The study demonstrates the potential of Glycyrrhiza glabra as a suitable herbal ingredient for MDT development and oral ulcer management.

ACKNOWLEDGEMENT (Optional)

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Towards a Transparent E-FIR Regime: Legal and Procedural Challenges in India's Digital Criminal Justice

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Abstract: This paper examines the legal uncertainty surrounding the First Information Report (FIR) within India's criminal justice system, particularly under the Criminal Procedure Code (CrPC) and the recent Bharatiya Nagarik Suraksha Sanhita (BNSS) Act 2023. While the BNSS Act seeks to modernize legal procedures, it fails to address existing ambiguities in the CrPC, further complicating the FIR process.

The study employs quantitative research to assess public perception of the e-FIR system through surveys conducted in Ahmedabad, Dhrangadhra, and Gogha—cities in Gujarat noted for significant mobile and internet penetration. Findings indicate that although the e-FIR system may enhance accessibility and transparency, the lack of clear legal guidelines continues to obstruct fairness and due process.

The paper also highlighting persistent challenges in legal clarity. It concludes that comprehensive legal reform is essential to streamline FIR reporting, protect individual rights, and ensure greater accountability in India's criminal justice framework.

***Key Words*: Legal Certainty, Criminal Procedure Code, BNSS Act, E-FIR, Pre independence, Post independence, Reporting**

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1. INTRODUCTION

This In the digital age, public access to swift and transparent justice mechanisms is increasingly reliant on the integration of technology into legal systems. One such advancement is the Electronic First Information Report (E-FIR), which enables citizens to lodge complaints online without visiting a police station physically. This study aims to explore public perspectives on the E-FIR system, with a focus on the need for proper information dissemination, timely updates, and a robust tracking mechanism for registered complaints. In particular, the study investigates the demand for a unique identification system that allows complainants to trace their reports in real-time.

1.1. Evolution of Efir Regime

The genesis of the procedure for criminal complaint in India can be traced back to the CrPC 1861, which brought about the introduction of a written criminal complaint. It was followed by subsequent amendments in 1872, 1882 and 1898 which further strengthened the documentation particularly for cognizable offences under Section 154. The CrPC of 1973 further set the guidelines for the procedure of filing FIRs, which was further streamlined in 2013, with additional protection for women and people with disabilities. The need to record and sign complaints correctly including sensitive matters by female officers is prescribed under section 154. Section 173 of the BNSS Act permits complaints to be made online and also requires to accommodate women and disabled people. It also allows for preliminary investigations by senior approval on certain offenses.

The New Criminal Law Amendment which has been brought by the Union Ministry has posed several challenges like the completion of Criminal Trial in 3 Years which as said by the current CJI will become mere words if the means to achieve it are not provided .

1.2 Rational for Research Area

Gujarat was chosen as the study area due to its notable progress in digital literacy and internet accessibility. By 2036, it is projected that 82% of Gujarat's population will be digitally literate, and 8 out of 10 individuals will use mobile phones—figures that reflect the state's readiness for digital initiatives like E-FIR. Gujarat also ranks 10th nationally in internet penetration, making it an ideal region to assess the feasibility and reception of such systems.

For acquiring a varied and comprehensive grasp of the phenomenon of digital engagement in the context of various developmental settings, three regions were chosen: Ahmedabad (an urban metropolitan city), Bahnagar (a developing city), and Gogha (a rural city, under-developed taluka). Together these areas provide a representative sample to determine public opinion among the urban, semi-urban and rural population.

The study aims to understand the public readiness for the E-FIR system, need for periodic updates after registration and the preference for a clear tracking system. It also assesses the existing E-FIR mechanism, its acceptance by the public, sense of accountability among law enforcers and general awareness about the concept of E-FIR.

2. RESEARCH METHODOLOGY

In the digital era, access to efficient and transparent justice increasingly depends on the integration of technology into legal systems. One such initiative is the Electronic First Information Report (E-FIR), which enables citizens to report cognizable offences online without visiting a police station.

The legal framework governing criminal complaint registration originated with the Code of Criminal Procedure, 1861 (CrPC) and was subsequently refined through the Codes of 1872, 1882, 1898, and the Code of Criminal Procedure, 1973 (CrPC). The latter established the statutory procedure for registering a First Information Report (FIR), while the Criminal Law (Amendment) Act, 2013 strengthened safeguards for women and persons with disabilities.

The enactment of the Bharatiya Nagarik Suraksha Sanhita, 2023 (BNSS) marks a significant step towards digital criminal justice by recognising electronic reporting of cognizable offences under Section 173. The framework is supported by the Crime and Criminal Tracking Network and Systems (CCTNS); however, challenges relating to infrastructure, authentication, and implementation continue to affect its effectiveness. As noted by the Chief Justice of India (CJI), the objectives of the new criminal laws can only be achieved through adequate institutional and technological support.

Table -1: Sample Size

Study Area	Category	Sampling Technique	Number of Respondents (n)	Purpose
Ahmedabad	Urban	Cluster Sampling	20	To assess public perception in a metropolitan setting with high digital access
Bahnagar (Dhrangadhra)	Semi-urban	Cluster Sampling	15	To evaluate acceptance of E-FIR in a developing urban area
Gogha	Rural	Cluster Sampling	15	To examine awareness and feasibility of E-FIR in a rural setting
Total	—	—	**50**	Representative sample of Gujarat

2.1. Research Objectives

The present study examines public perception regarding the implementation of the E-FIR system in India. The specific objectives of the study are:

1. To examine public awareness and perception of the E-FIR system in India.
2. To analyse citizens' willingness to register First Information Reports (FIRs) through the E-FIR system without visiting police stations.
3. To assess public demand for transparency, authentication, and complaint-tracking mechanisms in the E-FIR process.
4. To examine public opinion regarding the inclusion of a wider range of offences within the scope of online FIR registration.
5. To identify preferred international E-FIR models and the features that may strengthen India's E-FIR framework.

2.2. Research Questions

The study seeks to answer the following research questions:

1. What is the level of public awareness regarding the E-FIR system in India?
2. Are citizens willing to utilise the E-FIR system instead of visiting police stations?
3. Do citizens perceive a need for authentication and follow-up mechanisms in the E-FIR process?
4. Is the existing E-FIR framework perceived as transparent and accessible?
5. Which features of international E-FIR models are preferred by citizens for adoption in India?

2.3. Research Design

The study adopts a descriptive quantitative research design to examine public perception regarding the E-FIR system. Primary data were collected through a structured questionnaire administered using Google Forms, while secondary data were obtained from books, journal articles, government reports, newspaper articles, and publications of national and international organisations.

2.4 Sampling Procedure

The study employed the cluster sampling technique. The study area comprised three regions of Gujarat representing different levels of urbanisation:

- Ahmedabad (Urban)
- Dhrangadhra/Bahnagar (Semi-urban)
- Gogha (Rural)

A total of 50 respondents participated in the survey over a period of 10 days.

2.5 Research Instrument

The questionnaire was pilot-tested before final administration. It contained questions relating to public awareness, willingness to use the E-FIR system, transparency, authentication mechanisms, complaint-tracking facilities, and suggested improvements to the existing framework.

2.4. Limitations of the Study

1. The study is limited to 50 respondents from selected regions of Gujarat and may not represent the views of the entire population of India.
2. The findings are based on respondents' perceptions and may be influenced by individual experiences and awareness levels.
3. The study focuses on public opinion regarding the E-FIR framework rather than its actual implementation by law enforcement agencies.
4. As the E-FIR framework under the BNSS is relatively recent, future legislative or technological developments may influence the applicability of the findings.

3. RESULTS AND DISCUSSION

3.1 Results

I. Till what Extent will the inclusivity of Electronic Communication Extend

Form the survey it was found that '56%' people were willing to report the E-FIR instead of going to police station if provided with the option .

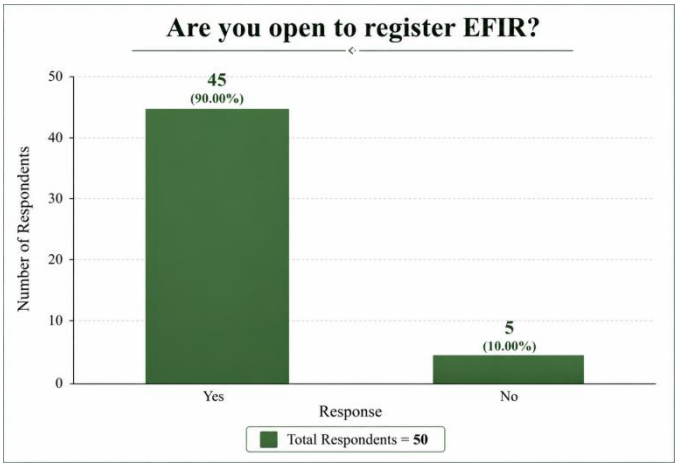

Figure 1 *: Shows willingness of people to register E-fir.*

70% percent of the people opined that the current system is futile and needs to be strengthened. There is still much ambiguity as to how the system can work in practice because grievances are so diverse. There remains doubt as to whether the police will enroll complaints from these various platforms and whether they will register as to plying justice. The off line reporting system has also revealed the reluctance of the police to record complaints and register FIRs as revealed by the IPF Survey.

II. Limited Scope of Inclusion for online Reporting

Further in the states in India where E - Complaint is taken is for non Heinous Crimes i.e .with the punishment of less than 3 Years so further the ambiguity remains on wither the scope of taking the Fir for offences of more than 3 years will be inculcated or not and if so the Complainant information will be taken as a complaint or a FIR .As per the survey '75%' people felt the need of more inclusiveness of crimes that can be reported online .

III. Lack of Authentication Process

As per the survey '65% 'people were willing to have an authentication process so as to get a timely update to their online E –FIR .The system which prevails in the states which at present has the online complaint system fail to contain any systematic authentication system so as to increase the authenticity of the complaint and nor is the issue brought in light or dealt with in the new BNSS .

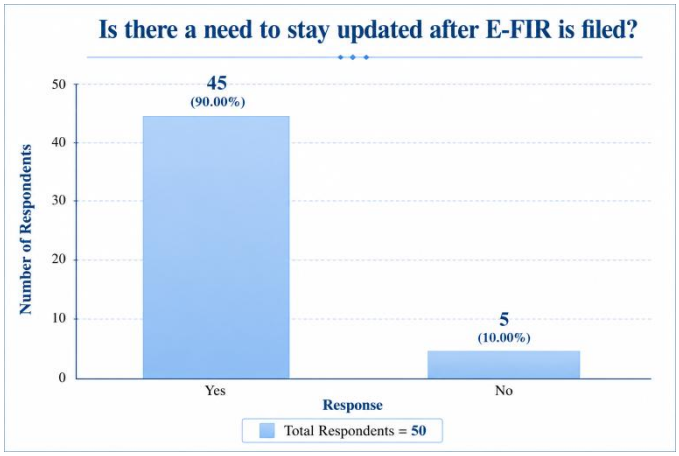

Figure 1.5 need of authentication and follow-up mechanism

Whereas in Countries like the United Kingdom , New Zealand and Hon Kong they have a verification system linking verification before starting and few have a specific time limit for a single complaint to be registered therefore increasing the authentication for speedy and robust Justice system .In the UK they have more crimes option to file online and 10 mins system of code delivery , in New zeland it is 30 min time limit , in Honking there is 1 hour time to complain and in end itself a code for follow-up is provided and lastly in Saudi Arabia application based with limited crimes system is there .

When given to choose from the 4 countries , the system UK was preferred most by 45% , Honkong by 25% , Saudi Arabia 10 % and Newzeland 10 % .

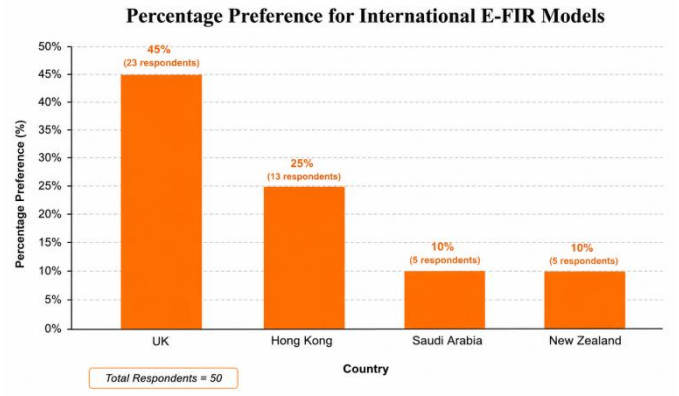

***Figure 2**: Shows most favored mechanisms*

IV. Lack of Data and Awareness

'50% 'people of the survey were of the opinion that the present system lacks transparencey. There is no data that before the BNSS how much complaints came from online e reporting and how much were disposed off or considered by the police. The NCRB has also not recorded any data relating to the same. The need for accountability is therefore required for the new BNSS.

20% said that they were not aware of the concept of E-FIR , and 12% were willing to get more understanding on it was seen in the survey.

3.2 Discussion

Digital complaint filing has been made possible under Section 2(i) and the procedure mentioned in Section 173(2) of the BNSS. To bring justice into the modern age, the law allows FIRs to be submitted via emails, messages, video files and other electronic means. At the same time, many practical challenges remain as the system is equipped.

Concerns exist because there is no clear approach to verify who sent an FIR online. If we fail to verify reports, there is a higher chance of false complaints which may overpower law enforcement and interfere with due process. While the UK, New Zealand and Hong Kong use reliable methods for verifying complaints, the BNSS does not include them.

In addition, though there is the CCTNS, various states in India remain reluctant about using advanced cloud-based infrastructure due to uncertainties related to security and unequal government funding. Because of this, the growth and speed of handling online complaints are limited.

Submitting electronic complaints often has no effect and the complainant is required to travel to the police station for the FIR to be recorded. Owing to fully take advantage of its e-complaint systems, India requires strong verification methods, sufficient infrastructure spending and clear guidelines by the government. Lack of these means leads to law reform failing to reach or help people in courts.

4. CONCLUSIONS

All things considered, upholding legal certainty is the key factor in handling the procedural issues of India's criminal justice system. There have been some concerns on the application and interpretation of the law in the BNSS Act and other related Acts under the Criminal Procedure Code (CrPC), which some parts of the Act are still unclear. As a result of the unclear aspects of these laws, justice and clarity in their application are put at risk, proving it is essential to reform these areas.

The study reveals that there is a push towards the digital space as a justice solution today. 65% of people who participated in the study believed in applying authentication systems to ensure the timely posting of E-FIRs and 75% wanted more crimes to be made reportable via online means. On the other hand, most people did not want to use the web based FIR system and went to the police station. Over half of those who participated in the survey said that there is a lack of transparency in the complaints system. 45% of the sample group favoured the E-FIR model of the UK, 25% liked the model of Hong Kong and 20% did not know that E-FIR exists.

These numbers also indicate that the public is ready to change, provided there are suitable standards and clear

systems as well. Indian laws should be updated so that justice becomes accessible to all, earlier, in a transparent and technologically-appropriate manner.

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BIOGRAPHIES

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Neatly type every portion of the manuscript with single line spacing (a minimum of 6 mm between lines) and Narrow Margin (0.5" inch, 1.27 cm margins on all sides, including figure legends, table footnotes and references.

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Introduction: Heading Cambria Font, Size 11, Description: Cambria Font, Size 10

Materials and methods: Heading Cambria Font, Size 11, Description: Cambria Font, Size 10

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The introduction should not be an extensive literature review although it should provide sufficient background information for the reader to understand and evaluate the results of the present study without referring to previous publications on the same topic.

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When data are summarized in the Results section, give numeric results not only as derivatives (for example, percentages) but also as the absolute derivatives were calculated, and specify the statistical methods used to analyze them. Restrict tables and figures to those needed to explain the its support. Use graphs as an alternative to tables with many entries; do not duplicate data in graphs and tables. "Where scientifically appropriate, such as age and sex should be included. Include summary of key findings, Strengths (study question, study design, data collection, analysis and interpretation); what this study adds to the available evidence, effects on patient care and health Controversies raised by this study; and Future research directions. Do not repeat in detail data or other material given in the

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Shah DP, Jani GK, Modification and Characterization of Gellan Gum, Pharmaceutical Technology, 2009; 33(7): 48-58.

Books and other Monographs

Author(s) of Book (Surname initials). Title of Book. Edition. Publisher; Place of publication; Year of publication.

Personal author(s)

Eisen HN. Immunology: an introduction to molecular and cellular principles of the immune response. 5th Edition. New York: Harper and Row; 1974.

Chapter or Article in a book

Author(s) of Chapter (Surname initials). Title of Chapter. In: Editor(s) name, Editors. Title of Book. Place of publication: Publisher; Year of publication, Page numbers.

Kelly HW and Sorknes CA. Asthma, Dipiro JT, Talbert RL, Yee GC, Matzke TR, Wells BG, Posey LM, Pharmacotherapy- A Pathophysiological Aproch, Sixth Edition, The McGraw-Hill; 2005.504

Patent

Larsen CE, Trip R, Johnson CR, inventors; Novoste Corporation, assignee. Methods for procedures related to the electrophysiology of the heart. US patent 5529 067. 1995.

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