

Scientific Formulation and Evaluation of Polyherbal Chain Oil Using Medicinal Plant Extracts

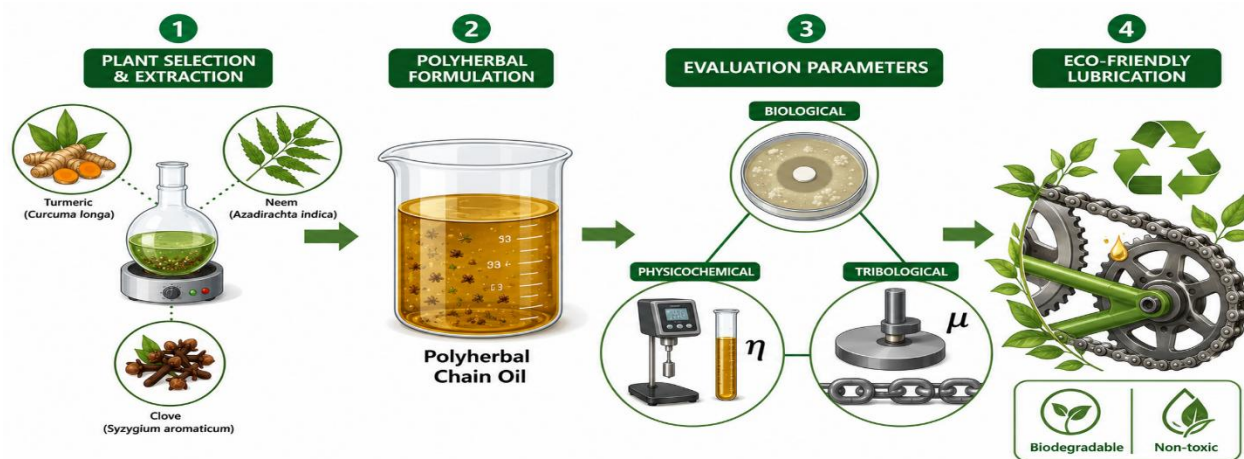
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Abstract-- The growing demand for sustainable and high-performance lubricants has spurred research into bio-based alternatives. Modern engineering chain lubricants typically rely on petroleum-derived oils, which pose significant environmental hazards upon leakage. Polyherbal chain oil a novel, synergistic blend of medicinal plant extracts and bio-based carrier oils offers a promising solution by combining superior tribological performance with biodegradability, multifunctional bioactivity, and environmental safety. This review synthesizes recent advances across phytochemistry, pharmaceutical formulation science, and green tribology. Key functional ingredients, such as curcuminoids from *Curcuma longa*, eugenol from clove, and alkaloids from *Vitex negundo*, are discussed in terms of their lubricating and stabilizing mechanisms. A systematic framework for formulation and evaluation is presented, covering standardization using

HPTLC and HPLC; physicochemical parameters (viscosity, acid value, rheology); biological assays (antimicrobial, antioxidant, anti-inflammatory); and tribological testing (coefficient of friction, wear scar analysis). Additionally, the alignment of polyherbal oils with regulatory frameworks (e.g., OECD 301 biodegradability criteria, WHO guidelines on contaminants) and emerging challenges including stability, scalability, and raw material standardization are critically addressed. By bridging traditional knowledge with contemporary industrial demands, polyherbal chain oil advances a new class of eco-friendly, functionally active lubricants.

Keywords-- Polyherbal formulation, chain oil, medicinal plant extract, bio-lubricant, standardization, green tribology, HPTLC, biodegradability.



I. INTRODUCTION

Polyherbal formulations defined as therapeutic preparations combining multiple medicinal plants or their extracts have been a cornerstone of traditional medicine systems such as Ayurveda, Traditional Chinese Medicine (TCM), and Siddha for millennia [1, 2]. The underlying principle is synergism: the combination of herbs enhances efficacy, reduces toxicity, and targets multiple pathological pathways simultaneously [3].

Historically, medicated oils (e.g., sesame, coconut, castor) infused with potent botanicals have been used for topical pain relief, joint lubrication, and wound healing [4]. In Snehana (Ayurvedic oleation therapy), oil functions not only as a carrier but also as an active therapeutic agent, deeply penetrating tissues, lubricating joints, and flushing metabolic wastes [5]. Concurrently, the industrial lubricant sector is seeking alternatives to petroleum-based oils.



Mineral oil chain lubricants, used extensively in sawmills, agricultural machinery, bicycles, and food processing equipment, are persistent pollutants that contaminate soil and groundwater upon leakage [6]. Biodegradable lubricants derived from vegetable oils (e.g., canola, soy, rapeseed) have emerged, yet they often suffer from low oxidative stability, poor anti-wear properties, and lack of multifunctionality [7]. Recent commercial products such as NZERO BIO Bicycle Chain Oil and ELM Biotechbased™ Bar & Chain Oil demonstrate the viability of bio-based chain lubricants, but these are primarily formulated from refined vegetable oils rather than extract-rich polyherbal complexes [8, 9]. The concept of polyherbal chain oil represents a convergence of these two trajectories: medicinal plant extracts and essential oils are incorporated into a vegetable oil base to produce a chain lubricant that is both tribologically efficient and functionally active. Beyond lubrication, the phytoconstituents confer antioxidant, antimicrobial, and anti-corrosion properties, which protect metal chains from oxidation, microbial growth, and friction-induced degradation [10]. This review aims to provide a comprehensive framework for the scientific formulation and evaluation of polyherbal chain oils, addressing phytochemical selection, formulation strategies, analytical standardization, evaluation protocols, and regulatory pathways.

II. PHYTOCHEMISTRY AND BIOACTIVE COMPOUNDS

Understanding the chemical composition of medicinal plant extracts is fundamental to rational formulation.

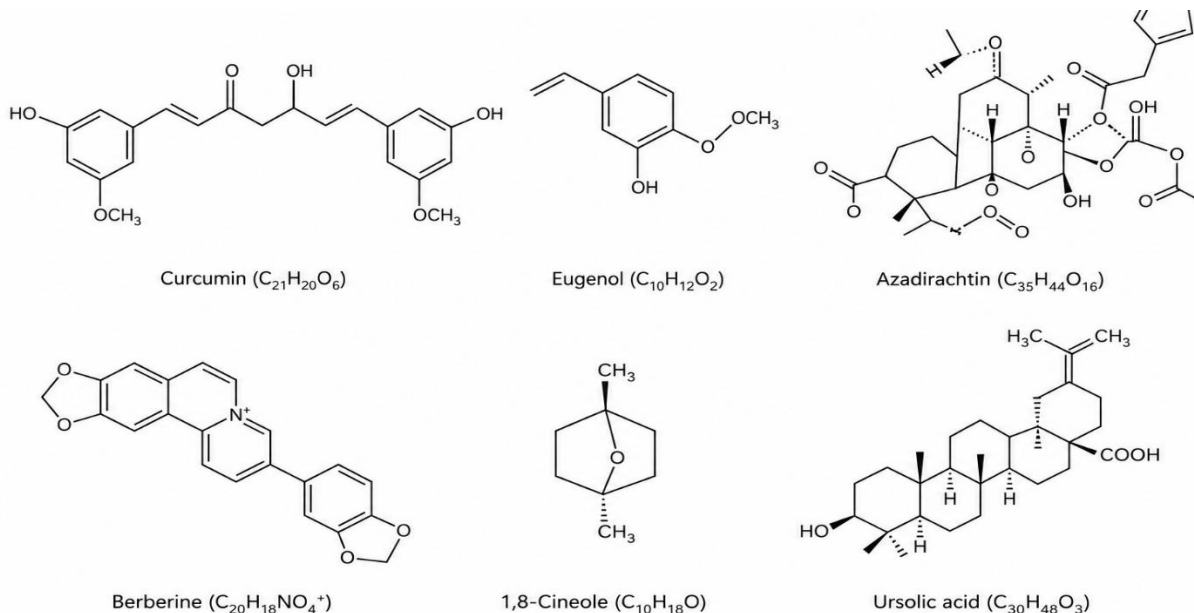
Medicinal plants produce a diverse array of secondary metabolites that serve both therapeutic and functional roles.

2.1. Major Classes of Bioactive Phytoconstituents

Plants used in traditional oil formulations are rich in several classes of compounds with proven lubricant-relevant activities: Terpenes and essential oils: Monoterpenes (e.g., eucalyptol, thymol), sesquiterpenes (e.g., β -caryophyllene), and triterpenes exhibit low viscosity, high volatility, and antimicrobial activity. Essential oils from turmeric (*Curcuma longa*) and red ginger (*Zingiber officinale* var. *rubrum*) demonstrate moderate activity against multidrug-resistant *Streptococcus aureus* and *Candida albicans* [11]. Phenolics and flavonoids: These include curcuminoids, gallic acid, quercetin, and catechins. They are potent antioxidants that inhibit lipid peroxidation and oxidation of the base oil, thereby extending lubricant service life. Total Phenolic Content (TPC) in polyherbal formulations measured via UV-Vis spectrophotometry correlates with free-radical scavenging activity [11].

Alkaloids: Compounds such as berberine, piperine, and vincamine possess anti-inflammatory and antimicrobial properties. Recent studies on polyherbal oils for rheumatoid arthritis have identified alkaloids in combination with flavonoids and terpenes as key contributors to bioactivity [12].

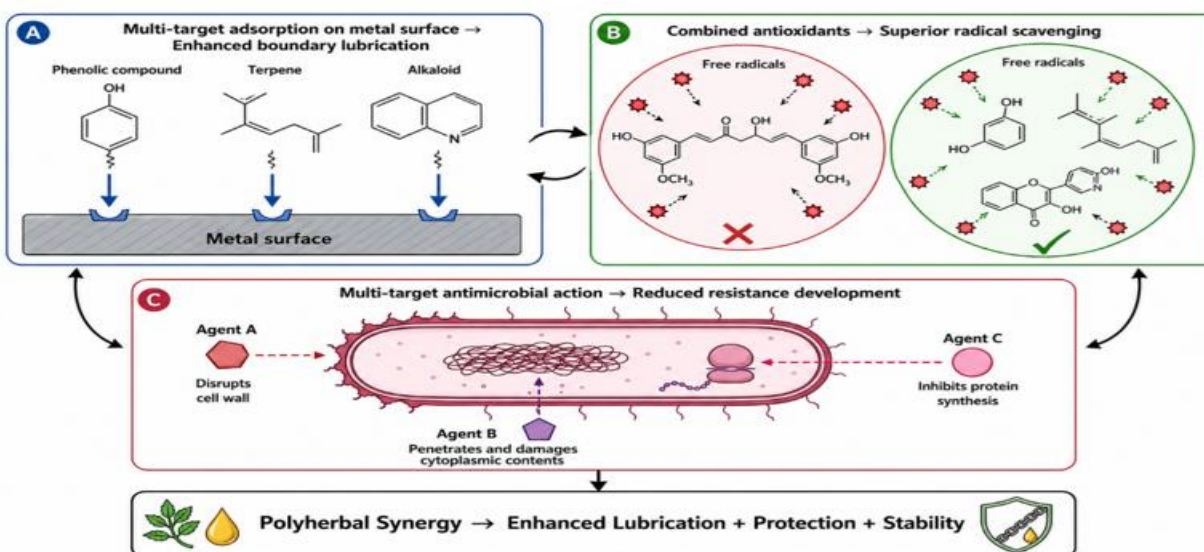
Fixed oils and fatty acids: Carrier oils (sesame, coconut, castor) are rich in unsaturated fatty acids (oleic, linoleic, linolenic) that provide base lubricity and skin penetration enhancement.



2.2. Synergistic Mechanisms

Synergism is the defining feature of polyherbal formulations. A number of studies have demonstrated that combining plant extracts or essential oils yields activity greater than the sum of individual components [3]. For example, eugenol from clove, cinnamaldehyde from cinnamon, and berberine from Berberis have been combined in a microemulsion system to exert enhanced antibacterial activity against *Staphylococcus epidermidis* [13].

In a Design of Experiments (DOE) optimization study, the combination of 51 crude extracts and 15 essential oils predicted optimal synergistic ratios, validated through Checkerboard MIC assays and Σ FICI calculations [3]. Such synergy can arise through: (a) multi-target effects on microbial cells or oxidation pathways; (b) increased bioavailability of one compound by another; (c) stabilization of active constituents; and (d) modulation of the physical properties (e.g., viscosity, spreadability) of the final oil [10, 14].



2.3. Key Functional Ingredients for Polyherbal Chain Oil

Drawing from both traditional use and modern tribological studies, the following botanicals are of particular interest for chain oil formulation:

Plant (Common Name)	Active Constituents	Lubricant/Functional Role	References
Azadirachta indica (Neem)	Azadirachtin, nimbin, fatty acids	Antimicrobial, antioxidant, corrosion inhibition	[15]
Curcuma longa (Turmeric)	Curcumin, turmerone	High viscosity base, antioxidant, anti-wear additive	[16]
Syzygium aromaticum (Clove)	Eugenol, β -caryophyllene	Viscosity modifier, antimicrobial, anti-inflammatory	[13, 17]
Ocimum sanctum (Tulsi)	Eugenol, ursolic acid, carvacrol	Antioxidant, antimicrobial, thermal stabilizer	[12]
Vitex negundo (Nirgundi)	Flavonoids, terpenoids, alkaloids	Anti-inflammatory, bio-lubricant carrier	[12]
Eucalyptus globulus	1,8-Cineole, limonene	Low-viscosity penetrant, antimicrobial, cleaning action	[18]
Moringa oleifera	Oleic acid, behenic acid, flavonoids	High-viscosity base oil, excellent thermal stability, non-toxic biolubricant	[19]

III. SCIENTIFIC FORMULATION OF POLYHERBAL CHAIN OIL

Formulation of a polyherbal chain oil involves selection of carrier oils, extraction of active botanicals, blending, and optimization.

3.1. Carrier Oils (Base Fluids)

The base oil determines the fundamental lubricating properties—viscosity, tackiness, film strength, and thermal stability.

Vegetable oils such as sesame oil, coconut oil, castor oil, and Moringa oil are preferred for their inherent biodegradability and low toxicity [20]. Moringa oil, in particular, has been utilized to synthesize high-viscosity lubricant esters with good thermal stability and negligible aquatic toxicity [19]. Castor oil contributes tackiness and anti-wear properties due to its high ricinoleic acid content.

3.2. Preparation Methods

Traditional and modern preparation techniques are detailed in Table 1.

Table 1.

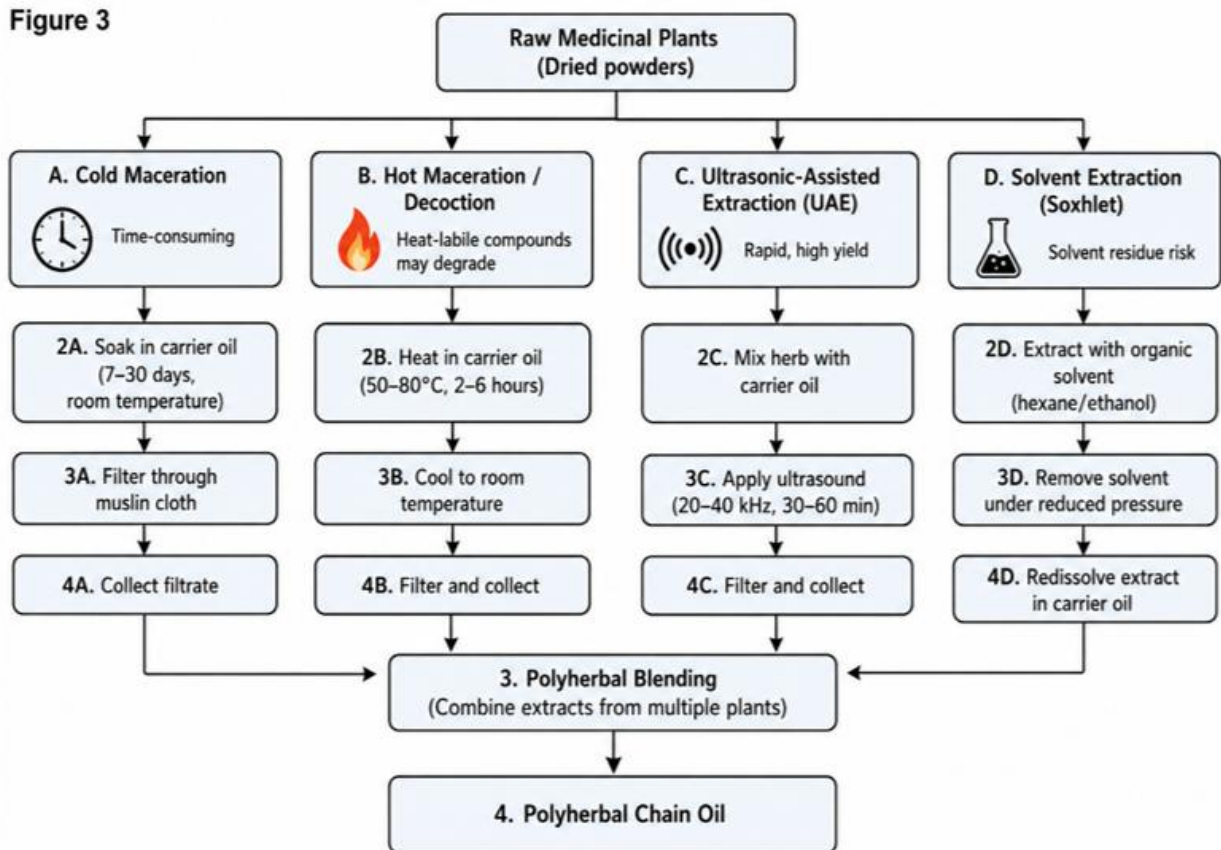
Preparation methods for polyherbal oils.

Method	Procedure	Advantages	Limitations
Cold maceration	Dried herb powders are soaked in carrier oil for 7–30 days at room temperature, and then filtered.	Preserves thermolabile compounds; simple, low-cost	Time-consuming; lower extraction efficiency
Hot maceration / Decoction	Herbs are heated in oil (50–80 °C) for several hours, then cooled and filtered.	Higher yield; reduces microbial load	Risk of degrading heat-sensitive actives
Infusion (Snehana method)	Aqueous herbal decoctions, herbal pastes, and milk extracts are combined with oil and simmered for many hours, as in traditional Mahamasha Thailam preparation.	Profound penetration; highly concentrated extract	Laborious; energy-intensive
Ultrasonic-assisted extraction (UAE)	Ultrasound waves (20–40 kHz) are applied to herb-oil mixture for 30–60 min.	Rapid, high extraction yield; preserves actives	Requires specialized equipment
Soxhlet extraction	Organic solvents (e.g., hexane, ethanol) are used to extract phytoconstituents, then solvent is removed and extract redissolved in base oil.	Very high yield of lipophilic compounds	Solvent residue concerns; not “green”

Optimized extraction parameters have been reported: for *Ocimum lamiifolium*, an extraction time of 4.5 h, particle size 1.375 mm, and solute-to-solvent ratio 0.28 w/v yielded

12.4% oil [10]. Such parameters should be adapted for each plant species.

Figure 3

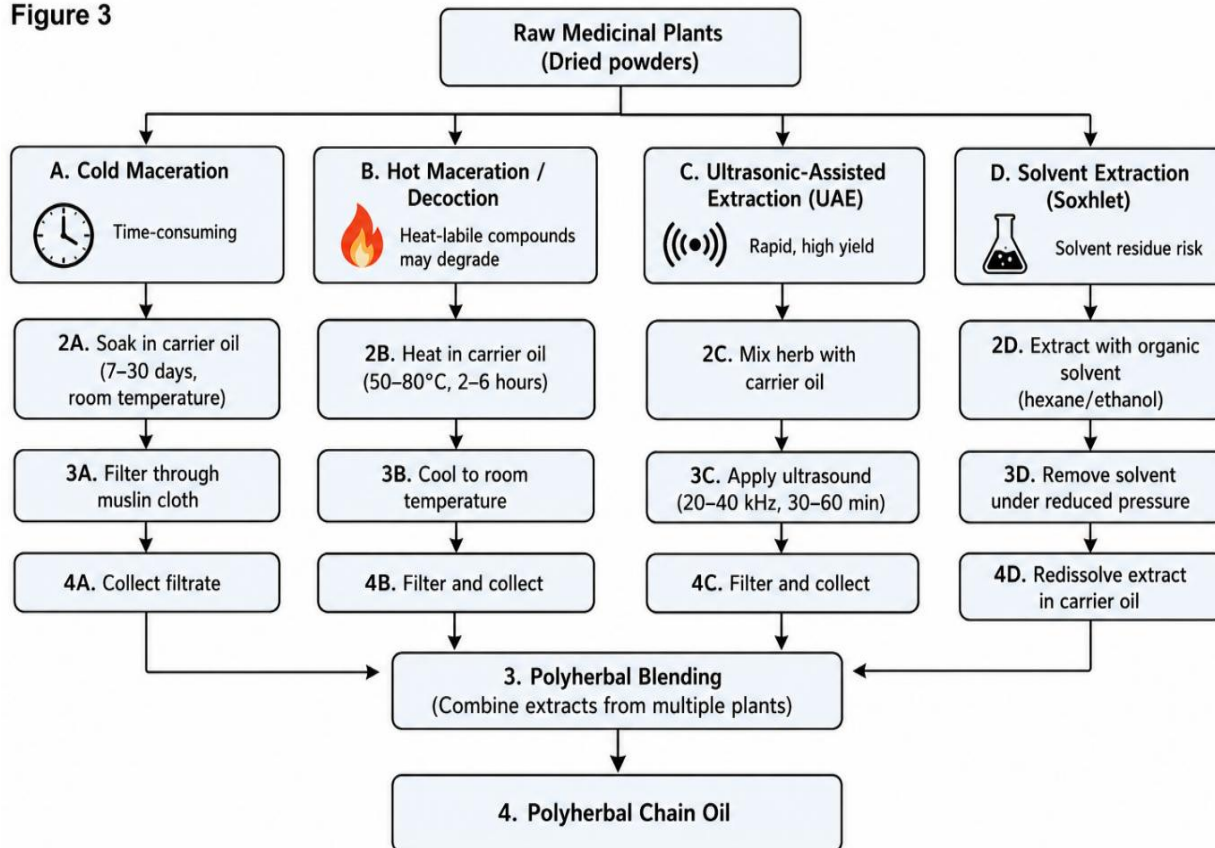


3.3. Blending and Optimization

Once individual extracts are obtained, they are blended with the carrier oil(s) and any additional excipients (e.g., natural antioxidants like vitamin E, tackifiers, corrosion inhibitors).

Statistically designed experiments (DOE) using response surface methodology (RSM) or simplex lattice designs can optimize the blending ratio to achieve desired viscosity, antimicrobial activity, and stability [3, 10].

Figure 3



For example, a combination of *Vitex negundo* leaves, *Nyctanthes arbor-tristis*, *Withania somnifera*, and carrier oils (sesame, castor, coconut) resulted in a yellowish-green oil with pH 5–6 and optimal spreadability [12].

IV. EVALUATION PARAMETERS

Comprehensive evaluation of polyherbal chain oil requires assessment of physicochemical, biological, and tribological properties.

4.1. Physicochemical and Organoleptic Evaluation

Standard tests adapted from pharmaceutical and lubricant sciences are summarized in Table 2.

Table 2.
Physicochemical evaluation parameters for polyherbal chain oil.

Parameter	Test method	Significance for chain oil
Organoleptic (color, odor, clarity)	Visual inspection, olfactory	Batch-to-batch consistency, detection of degradation
pH (of oil-water extract)	pH meter (1% emulsion in water)	Acidity indicates free fatty acids; affects corrosion potential
Specific gravity / Density	Pycnometer or densitometer	Consistency, dosing; affects film formation
Refractive index	Refractometer	Purity, adulteration detection
Viscosity (kinematic, dynamic)	Brookfield viscometer, capillary viscometer at 40 °C	Determines film thickness, energy loss, and lubricant pumpability. Target range: 40–200 cSt at 40 °C
Viscosity index	Calculated from viscosities at 40 °C and 100 °C	Indicates stability over temperature range
Acid value (AV)	Titration with KOH	Measures free fatty acids; high AV indicates oxidation or hydrolysis
Saponification value (SV)	Titration with KOH after hydrolysis	Average molecular weight of esters; indicates type of oil
Iodine value (IV)	Titration with iodine chloride / Wij's method	Degree of unsaturation; influences oxidative stability
Peroxide value (PV)	Iodometric titration	Primary oxidation product; indicates rancidity
Unsaponifiable matter	Solvent extraction after saponification	Presence of non-glyceride components (e.g., sterols, hydrocarbons)

These parameters have been applied in recent polyherbal oil studies. For instance, a standardized polyherbal formulation (Megni) showed compliance with Ayurvedic pharmacopoeial standards, with consistent batch-to-batch properties and acceptable acid, saponification, iodine, and ester values [21].

4.2. Biological and Functional Activity Evaluation

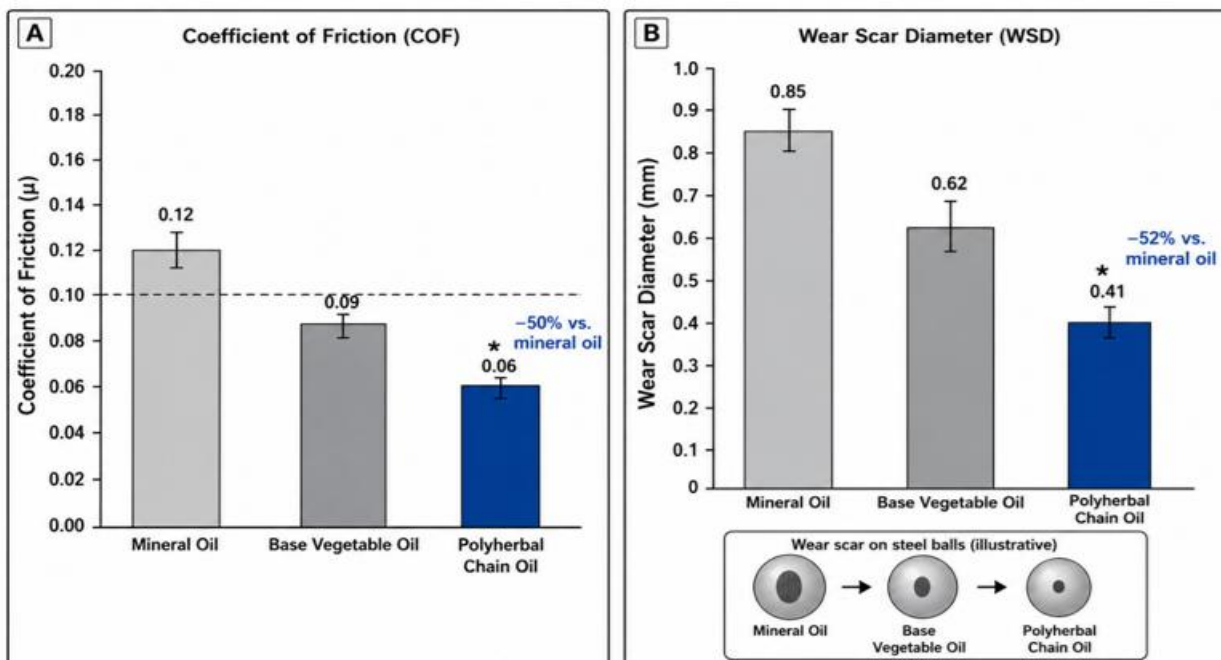
Polyherbal chain oils offer unique functional benefits beyond lubrication. Antimicrobial activity is critical to prevent microbial growth in stored oil and on chain surfaces. The microdilution method (minimum inhibitory concentration, MIC) and disk diffusion assay are standard.

Polyherbal essential oil formulations have demonstrated moderate activity against multidrug-resistant *S. aureus* and *C. albicans*, with some formulations showing higher antifungal (71.67% inhibition) than antibacterial activity [11]. A biolubricant derived from *O. lamiifolium* showed activity against *E. coli*, *B. subtilis*, *S. typhimurium*, and *S. aureus*, with highest potency against *S. aureus* and *E. coli* [10]. Antioxidant activity prolongs oil life by inhibiting autoxidation. DPPH (2,2-diphenyl-1-picrylhydrazyl), ABTS (2,2-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)), and FRAP (ferric reducing antioxidant power) assays quantify radical scavenging. The polyherbal oil Megni showed membrane-stabilizing capacity, with 78.48% inhibition of HRBC hemolysis and 91.78% inhibition of protein denaturation [21]. Anti-inflammatory activity may be relevant if the oil contacts skin (e.g., in manual chain maintenance). Protein denaturation inhibition and HRBC membrane stabilization assays are used. The Vitex-based polyherbal oil exhibited no skin irritation and good physical stability over 90 days under ICH conditions ($40 \pm 2^\circ\text{C}$, $75 \pm 5\% \text{RH}$) [12, 22]. Corrosion inhibition can be assessed by immersing metal coupons (e.g., mild steel, stainless steel) in the oil under controlled conditions and measuring weight loss or using electrochemical impedance spectroscopy (EIS). No direct studies on polyherbal chain oil have been published, but neem oil and curcumin-containing formulations are known to inhibit rust formation.

4.4. Stability Studies

4.3. Tribological Evaluation

Tribological performance determines the lubricant's ability to reduce friction, wear, and energy consumption. Coefficient of friction (COF): Measured using a pin-on-disk tribometer or four-ball tester under defined loads, speeds, and temperatures. Wear scar diameter (WSD): The four-ball extreme pressure (EP) test measures anti-wear properties; smaller WSD indicates better protection. Friction torque and power loss: Can be assessed on a chain-on-block rig or actual chain drive test bench. Film strength and tackiness: The ability of the oil to adhere to fast-moving chain surfaces ("oil fling-off") is evaluated by high-speed rotation tests. Commercial bio-based bar and chain oils incorporate tackifiers derived from vegetable oils to prevent sling-off [9]. Bio-based chain oils have demonstrated lubricity superior to conventional mineral oils; ELM Biotechbased™ Bar & Chain Oil is reported to surpass the lubricity of most conventional oils [9]. Although not polyherbal, these results provide proof of concept for vegetable-oil-based chain lubricants. The incorporation of medicinal plant extracts is expected to further enhance anti-wear and EP properties through the formation of boundary lubricating films by polar phytoconstituents (phospholipids, fatty acids, terpenes) on metal surfaces.



Accelerated stability studies are conducted following ICH guidelines: samples stored at $40 \pm 2^\circ\text{C} / 75 \pm 5\% \text{RH}$ for 3–6 months, with periodic testing of appearance, pH, viscosity, acid value, peroxide value, and antimicrobial activity. A polyherbal skin cream exhibited no alterations in pH (~6), viscosity, or appearance throughout a three-month accelerated stability study [22]. Similar protocols apply to chain oils.

V. QUALITY CONTROL AND STANDARDIZATION

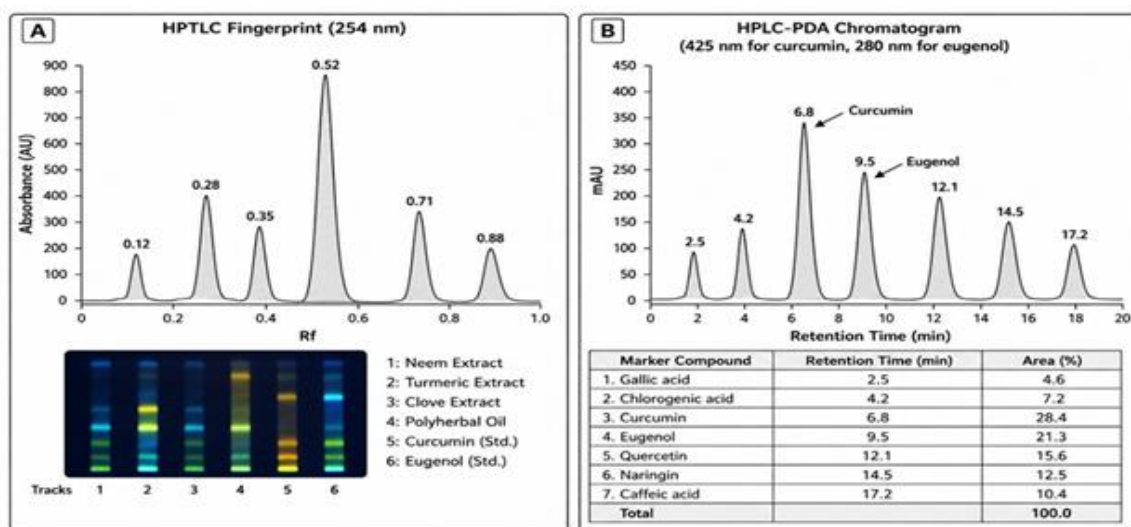
Standardization is the most critical challenge for polyherbal products. Without reproducible quality, batch-to-batch variation renders safety and efficacy data meaningless.

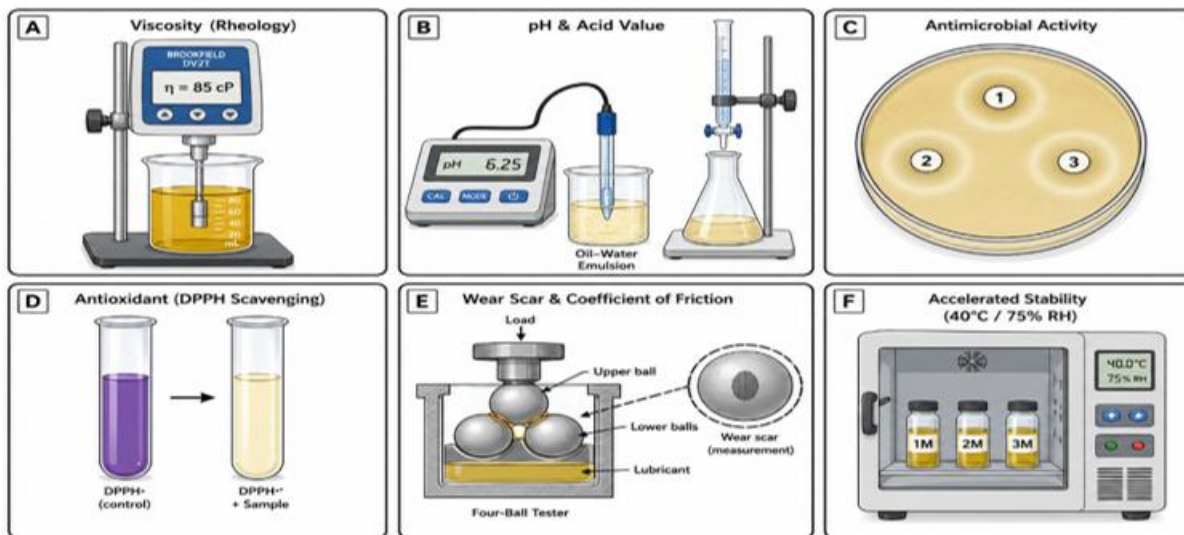
5.1. Analytical Techniques for Quality Control

Multiple chromatographic and spectroscopic techniques are employed for authentication, quantification of marker compounds, and detection of adulterants [23, 24]. HPTLC (High-Performance Thin-Layer Chromatography): Provides a chemical fingerprint of the polyherbal oil. A validated HPTLC method for quantifying piperine in Marichadi Tailam (coconut oil-based) used a mobile phase of toluene: ethyl acetate: diethyl amine (7:2:1) and detection at 340 nm, yielding 99.32% recovery of piperine [25]. HPTLC has also been used for authentication of *Sphaeranthus indicus* and for

comparative profiling of aromatic medicinal herbs [26, 27]. HPLC (High-Performance Liquid Chromatography): Quantifies individual marker compounds (e.g., curcumin, eugenol, berberine) with high sensitivity and reproducibility. GC-MS (Gas Chromatography-Mass Spectrometry): Essential for analyzing volatile terpenes and fatty acid methyl esters (FAMES). In one polyherbal oil study, GC-MS/MS identified over 32 phytochemicals, including eugenol, isocaryophyllene, elemicin, and squalene [10]. LC-MS/MS (Liquid Chromatography-Tandem Mass Spectrometry): Used for non-volatile and thermo-labile compounds (flavonoids, alkaloids) in crude extracts. NMR (Nuclear Magnetic Resonance): Provides structural elucidation of unknown compounds and can detect adulteration. FTIR (Fourier Transform Infrared Spectroscopy): Rapidly identifies functional groups (e.g., hydroxyl, carbonyl) and can detect interactions between extract and base oil (e.g., hydrogen bonding with lactic acid) [10]. A tiered quality control protocol is proposed:

Authentication of raw herbs: Macroscopic, microscopic, and DNA barcoding. Extract fingerprinting: HPTLC fingerprint with complementary solvent systems to ensure batch-to-batch consistency [26]. Quantification of at least two marker compounds: Using validated HPLC or GC-MS methods. Physicochemical testing: As per Table 2. Heavy metals and microbial load: Compliant with WHO guidelines [21].





5.2. Regulatory Reference Standards

In India, polyherbal oils must comply with the Ayurvedic Pharmacopoeia of India (API), the Siddha Pharmacopoeia, and the Unani Pharmacopoeia. WHO guidelines on contaminants and residues provide a baseline for international acceptance [28]. For bio-lubricant registration in the EU, the OECD 301 series biodegradability tests (>60% degradation within 28 days) and the EU Ecolabel criteria for lubricants (e.g., low aquatic toxicity, renewable content >50%) apply [8].

VI. SAFETY AND TOXICITY EVALUATION

Safety evaluation is essential before commercial release, particularly for oils that may contact skin or be released into the environment. Acute dermal irritation/corrosion: Tested on animal models (e.g., rabbit) or reconstructed human epidermis (OECD 439). The Vitex-based polyherbal oil showed no skin irritation in preliminary testing [12]. Sensitization: Murine Local Lymph Node Assay (LLNA) or human repeat insult patch test (HRIPT). Oral toxicity (if accidental ingestion): OECD 420/423 acute oral toxicity. Aquatic toxicity: *Daphnia magna* acute immobilization test (OECD 202) and algal growth inhibition test (OECD 201). Moringa esters have been found non-toxic to aquatic environments, suggesting vegetable-oil-based lubricants are generally safe [19]. Brine shrimp lethality assay (BSLA): Used as an initial screening for cytotoxicity; a polyherbal capsule formulation passed BSLA, indicating low toxicity [3].

VII. INDUSTRIAL, ENVIRONMENTAL, AND REGULATORY PERSPECTIVES

The substitution of mineral chain oils with polyherbal versions addresses multiple environmental and worker safety concerns. Mineral oil lubricants are responsible for approximately 50% of all lubricants entering the environment through total loss applications (e.g., chainsaw and bicycle chains) [6, 8]. Biodegradability: Vegetable-oil-based chain oils, such as NZERO BIO (herbal composition) and Renewable Lubricants Bio-Pro Bar & Chain Oil, are ultimately biodegradable, meeting EPA's Environmentally Preferable Purchasing criteria [8, 9]. Oxidative stability: The primary drawback of vegetable oils is limited oxidative stability due to unsaturated fatty acids. Incorporating antioxidant-rich medicinal plant extracts (e.g., curcumin, flavonoids) significantly extends service life [16, 19]. Regulatory approval: "Kyzyl may" polyherbal oil from Kazakhstan, comprising seven medicinal plant extracts, has undergone preclinical and clinical testing and obtained pharmacopoeial certificates for medical use [29]. This demonstrates that polyherbal oils can achieve registration if properly standardized. Manufacturing scalability: Traditional maceration methods are impractical for large-scale production. Ultrasonic-assisted and Soxhlet extraction with solvent recovery systems, followed by blending and homogenization, represent scalable processes.

VIII. CHALLENGES AND FUTURE PERSPECTIVES

Despite its promise, polyherbal chain oil faces several scientific and industrial challenges.

8.1. Raw Material Standardization

Batch-to-batch variation in medicinal plant phytochemistry influenced by genotype, growing conditions, harvest time, and post-harvest processing remains the primary obstacle. Development of phytochemical reference fingerprints using HPTLC and its integration into pharmacopoeial monographs is needed [26, 27].

8.2. Stability of Active Constituents

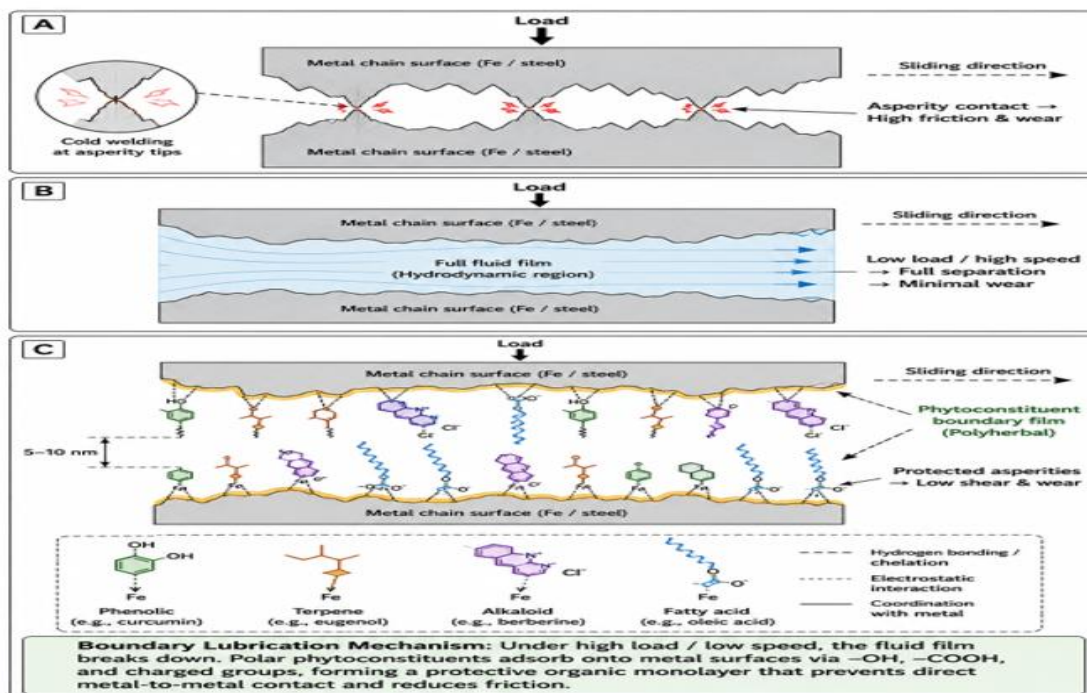
Many bioactive phytoconstituents are susceptible to thermal, oxidative, and photolytic degradation during long-term storage and under high-shear, high-temperature lubrication conditions.

8.4. Cost-Effectiveness and Scalability

Nanoencapsulation (e.g., liposomes, solid lipid nanoparticles) of labile extracts before blending into the base oil could improve stability while maintaining lubricity. Microemulsion systems have been successfully used to stabilize clove oil, cinnamaldehyde, and berberine [13].

8.3. Tribological Mechanism Studies

The tribological mechanisms of polyherbal oils are not well understood. Polar functional groups in phytoconstituents (e.g., -OH of phenolics, -COOH of fatty acids) likely adsorb onto metal surfaces, forming a protective boundary film. Advanced surface characterization—X-ray photoelectron spectroscopy (XPS) and atomic force microscopy (AFM)—on lubricated metal surfaces could elucidate these interactions.



Medicinal plant extracts are more expensive than refined vegetable oils. Low-cost, high-yield extraction technologies (supercritical fluid extraction, UAE) and the use of agro-industrial residues (e.g., deodorizer distillates) as sources of bioactive compounds are promising directions [30]. Life cycle assessment (LCA) studies are required to quantify the environmental payback.

8.5. Future Research Directions

In silico screening of phytochemical libraries for lubricant property prediction (e.g., viscosity, adsorption energy) using molecular dynamics simulations and machine learning.

Field trials of polyherbal chain oils on actual machinery (chainsaws, bicycles, industrial conveyors) to measure wear reduction, energy efficiency, and oil consumption under real operating conditions.

Formal product registration under EU Ecolabel, USDA BioPreferred®, and national pharmacopoeias as “functional lubricants” rather than therapeutics, leveraging existing bio-lubricant frameworks.

IX. CONCLUSION

Polyherbal chain oil represents an innovative convergence of traditional phytomedicine and modern green tribology. By integrating medicinal plant extracts—rich in terpenes, phenolics, flavonoids, and alkaloids—into bio-based carrier oils, this new class of lubricant offers multi-functionality: tribological efficiency, antimicrobial protection, antioxidant stability, corrosion inhibition, and complete biodegradability. A rigorous formulation and evaluation framework has been established, encompassing phytochemical fingerprinting (HPTLC, HPLC, GC-MS), physicochemical testing (viscosity, acid value, peroxide value), biological assays (antimicrobial, antioxidant, anti-inflammatory), tribological benchmarking (COF, WSD), and stability studies. Challenges remain, particularly in raw material standardization, active constituent stability, and cost-effective scaling. However, with ongoing advances in analytical chemistry, process engineering, and regulatory science, polyherbal chain oils are well positioned to displace petroleum-based lubricants in a wide range of chain-drive applications. The integration of traditional knowledge with industrial innovation thus opens a sustainable pathway for lubricants that are both high-performing and environmentally responsible.

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