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COMPREHENSIVE REVIEW ON PHYTO AND PHYSICO CHEMICAL CHARACTER AND THERAPEUTIC IMPLEMENTATION OF *ACACIA FERRUGINEA* GROWN IN SEMI-ARID ENVIRONMENT

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ABSTRACT

This study investigates the phytochemical, physicochemical, and fluorescence properties of *Acacia ferruginea,* a medicinally significant plant, to explore its potential in treating chronic inflammatory diseases. *Acacia ferruginea*, widely found in semi-arid environments, is traditionally known for its therapeutic applications. The research includes a detailed evaluation of its phytoconstituents, including alkaloids, flavonoids, tannins, and saponins, using standard analytical techniques. Physicochemical parameters, such as moisture content, ash values, and extractive values, were determined to assess the plant's quality and purity. Additionally, fluorescence analysis was conducted to establish its chemical fingerprint, providing insights into its stability and authenticity. The findings highlight the plant's significant anti-inflammatory properties, supported by its bioactive compounds, which could serve as natural therapeutic agents. This study emphasizes the importance of integrating traditional knowledge with scientific validation for developing sustainable and effective treatments for chronic inflammatory conditions, especially in resource-limited, semi-arid regions.

Keywords: chronic inflammatory diseases, alkaloids, flavonoids, tannins etc

INTRODUCTION

Acacia ferruginea DC, commonly known as Rusty Acacia, is a medium-sized leguminous tree native to the Indian subcontinent, thriving in dry deciduous forests and arid regions. This species is characterized by its rough, dark brown bark, bipinnate leaves, and fragrant yellow flowers that bloom in clusters. Its flat, brown pods contain seeds used for propagation. *Acacia ferruginea* plays a vital ecological role in nitrogen fixation, enhancing soil fertility, and providing habitat and nourishment for various wildlife. Economically, it is valued for its durable timber, commonly used in furniture and tools, and as a source of fuelwood. Traditionally, it holds significance in Ayurvedic medicine for treating skin diseases and wounds. Despite its resilience, overexploitation for its wood and medicinal uses poses a threat, highlighting the importance of conservation efforts to preserve this ecologically and economically significant species **[1]**.

The history of *Acacia ferruginea* DC, commonly known as Rusty Acacia, reflects its enduring significance in the ecological, economic, and cultural landscapes of the Indian subcontinent. This medium-sized leguminous tree is native to arid and semi-arid regions, where it has thrived for centuries as an integral component of traditional agroforestry systems. Its ability to withstand harsh climates and poor soils made it a reliable resource for ancient communities, who utilized its durable timber for constructing furniture, tools, and agricultural implements. The tree's wood was also a primary source of fuel and charcoal, particularly in rural areas where alternative energy sources were scarce **[2]**.

The historical importance of *Acacia ferruginea* lies not only in its diverse uses but also in its ability to support livelihoods and ecosystems, underscoring the need to preserve this vital species for future generations **[3, 4]**.

Figure 1: Pharmacological activities of *Acacia ferruginea*

The bark and seeds of *Acacia ferruginea* are rich in bioactive compounds that exhibit a wide range of pharmacological properties, making the plant highly valued in traditional and modern medicine. The bark contains tannins, flavonoids, saponins, alkaloids, and phenolic compounds, which contribute to its therapeutic potential. It has significant antimicrobial properties, effectively combating various bacterial and fungal pathogens by disrupting microbial cell membranes, a benefit attributed to its high tannin content. The bark also exhibits notable anti-inflammatory and analgesic effects, as it inhibits pro-inflammatory mediators such as prostaglandins, thereby reducing inflammation and alleviating pain. Additionally, the phenolic compounds present in the bark possess strong antioxidant activity, scavenging free radicals and protecting cells from oxidative damage, which helps prevent degenerative diseases. Its antidiabetic activity has also been observed, with extracts demonstrating the ability to lower blood glucose levels by enhancing insulin sensitivity and inhibiting carbohydrate-digesting enzymes.

In summary, the bark and seeds of *Acacia ferruginea* offer extensive pharmacological benefits due to their rich phytochemical profiles. Their antimicrobial, anti-inflammatory, antioxidant, antidiabetic, anthelmintic, antihyperlipidemic, and wound-healing properties highlight their importance in traditional medicinal systems and their potential for future drug development. This multifunctional nature makes *Acacia ferruginea* a valuable plant species for pharmaceutical exploration **[5, 6]**.

SECONDARY METABOLITES FOUND IN *ACACIA FERRUGINEA*

Acacia ferruginea DC, commonly known as Rusty Acacia, is a tree species recognized for its rich diversity of secondary metabolites, which play crucial roles in its ecological adaptability and medicinal applications **[7]**. Secondary metabolites are organic compounds not directly involved in the plant's growth or reproduction but are essential for defense, interaction with the environment, and therapeutic properties. The major classes of secondary metabolites found in *Acacia ferruginea* include phenolic compounds, alkaloids, terpenoids, saponins, steroids, and gums or resins, each contributing uniquely to its biological activity **[8]**.

Phenolic Compounds are among the most abundant secondary metabolites in *Acacia ferruginea*. These include tannins and flavonoids, primarily found in the bark. Tannins exhibit strong astringent properties, making them effective in treating wounds and gastrointestinal disorders such as diarrhoea. Their antioxidant activity helps combat oxidative stress, which is linked to various chronic diseases **[9]**.

Alkaloids in *Acacia ferruginea* contribute to its medicinal properties, particularly in antimicrobial and anti-inflammatory applications **[10]**. Alkaloids are nitrogen-containing compounds that often act as natural plant defense mechanisms against herbivores and pathogens.

Terpenoids are another vital group of secondary metabolites found in this tree. These compounds are hydrocarbons that serve as the building blocks for essential oils. Terpenoids contribute to the plant's aroma and play a deterrent role against herbivores and pathogens. Beyond their ecological functions, terpenoids have demonstrated significant pharmacological properties, including anti-inflammatory, antimicrobial, and antioxidant effects **[11]**.

Saponins, naturally occurring glycosides, are another class of secondary metabolites present in *Acacia ferruginea*. They exhibit a range of biological activities, including antimicrobial, antifungal, and hemolytic properties. Saponins are also known for their ability to reduce cholesterol levels and improve immune responses, making them valuable in medicinal applications. In plants, saponins serve as a line of defense against microbial pathogens and pests **[12]**.

Steroids, found in various parts of *Acacia ferruginea*, further enhance its medicinal potential. These compounds have been associated with anti-inflammatory, analgesic, and anti-cancer properties in pharmacological studies **[13]**. **Gums** act as stabilizers in food and pharmaceutical formulations, while resins often possess antimicrobial and anti-inflammatory properties. These exudates help the plant seal wounds and protect against microbial invasion, contributing to its survival in harsh environments **[14, 15]**. From treating wounds and skin conditions to combating infections and reducing inflammation, *Acacia ferruginea* has been a cornerstone in herbal remedies **[16]**.

In conclusion, the diverse range of secondary metabolites in *Acacia ferruginea*, including phenolic compounds, alkaloids, terpenoids, saponins, steroids, gums, and essential oils, reflects its versatility and significance as a medicinal and ecological resource **[17]**.

METHODS

Extraction

The extraction of *Acacia ferruginea* powder using a Soxhlet extractor involves isolating bioactive compounds through a systematic and efficient process. First, the dried bark or seeds are ground into a fine powder to maximize the surface area for extraction. A suitable solvent, such as ethanol or methanol, is chosen based on the target compounds, with polar solvents preferred for compounds like tannins and flavonoids. The powdered material is placed into a thimble and positioned in the main chamber of the Soxhlet apparatus, which is connected to a round-bottom flask containing the solvent and a condenser. Upon heating the solvent in the flask using a heating mantle or water bath, it vaporizes and travels to the condenser, where it cools and drips into the chamber containing the powder. The solvent repeatedly immerses the powder, dissolving the desired compounds, and then siphons back into the flask, carrying the extracted solutes. This cyclical process is maintained for several hours, typically 4–8 hours, until the solvent in the siphon becomes colorless, indicating the exhaustion of the extraction. The solvent containing the dissolved compounds is then evaporated using a rotary evaporator or a water bath, leaving behind the concentrated crude extract. The final extract is collected and stored in an airtight container for further analysis or use, ensuring the recovery of bioactive constituents in a pure and concentrated form. This method is widely recognized for its efficiency and ability to produce high-quality extracts from *Acacia ferruginea* **[18, 19]**.

Physicochemical studies

Physicochemical studies of *Acacia ferruginea* focus on analyzing its physical and chemical properties to evaluate its therapeutic potential and quality standards. These studies typically include parameters such as moisture content, ash value, extractive value, and pH, which provide insights into the plant's purity and stability. The phytochemical profile is assessed to identify bioactive compounds like flavonoids, tannins, alkaloids, and saponins, which contribute to its pharmacological properties **[20, 21]**.

Qualitative phytochemical studies

Qualitative phytochemical studies of *Acacia ferruginea* involve screening its extracts for bioactive compounds such as alkaloids, flavonoids, tannins, saponins, glycosides, and phenolic compounds. Standard chemical tests, including Mayer's and Wagner's tests for alkaloids or ferric chloride test for phenolics, are used. These studies provide insights into the plant's medicinal and pharmacological potential **[22]**.

Quantitative studies

The total content of terpenoids, alkaloids, and phenolics in the leaves and bark of *A. ferruginea* was quantified using standard methods **[23]**.

Quantification of alkaloids

A plant sample (5 g) was treated with 200 mL of 10% acetic acid in ethanol and allowed to stand for 4 hours. The mixture was then filtered and concentrated in a water bath for 15 minutes. Ammonium hydroxide was added drop by drop until precipitation was complete. The precipitate was washed with ammonium hydroxide, dried, and weighed. Calculations were then performed based on the obtained data **[24]**.

$$\%\text{Alkaloid} = W_a / W_b \times 100$$

W_a—weight of alkaloid; W_s—weight of sample.

Quantification of terpenoids

A dried plant extract (100 mg, denoted as Wa) was immersed in 9 mL of ethanol for 24 hours. The mixture was then extracted with 10 mL of petroleum ether using a separating funnel. The ether extract was transferred to pre-weighed beakers (denoted as Wb) and allowed to dry completely. Once the ether evaporated, the total terpenoid content was quantified as a percentage using the appropriate formula **[25]**.

$$\%\text{Terpenoid} = W_a - W_b/W_a \times 100$$

Fluorescence analysis

Fluorescence analysis of *Acacia ferruginea* are employed to analyze its bioactive compounds, particularly those with fluorescent properties, such as flavonoids, phenolic compounds, and alkaloids. The process typically involves preparing extracts from the plant material, such as bark or seeds, using solvents like ethanol, methanol, or water. These extracts are then subjected to fluorescence spectroscopy, where the samples are excited at specific wavelengths, and the emitted light is recorded. The fluorescence intensity and emission spectra provide insights into the presence and concentration of fluorescent phytochemicals **[26]**.

PHYSICOCHEMICAL EVALUATION OF *A. FERRUGINEA* BARK AND LEAVES

The physicochemical evaluation of the bark and leaves of *Acacia ferruginea* DC, commonly known as Rusty Acacia, is vital for understanding its chemical properties, quality, and potential for therapeutic applications. Both the bark and leaves of this species have been extensively used in traditional medicine, making their scientific evaluation important for standardization and validation. Key parameters include ash values, extractive values, moisture content, and phytochemical screening, all of which provide valuable insights into the plant's bioactive composition and purity **[27]**.

The **Bark** of *Acacia ferruginea* is a rich source of tannins, flavonoids, alkaloids, and glycosides, which contribute to its astringent, antimicrobial, and antioxidant properties. Physicochemical analysis begins with determining ash values, such as total ash, acid-insoluble ash, and water-soluble ash, which indicate the presence of inorganic materials and potential impurities like sand or soil. Low acid-insoluble ash values confirm minimal contamination, ensuring the material's purity. The **moisture content** of the bark is also measured, as lower levels are crucial for preventing microbial growth and ensuring better shelf life for medicinal preparations **[28]**.

Extractive values, which measure the solubility of bioactive compounds in solvents like water and ethanol, are crucial for understanding the bark's therapeutic potential. High aqueous extractive values suggest the presence of water-soluble compounds such as tannins and flavonoids, which are known for their antioxidant and wound-healing properties. Ethanol extractive values highlight the presence of moderately polar compounds, including alkaloids and phenolics, which contribute to anti-inflammatory and antimicrobial activities **[29]**.

The **Leaves** of *Acacia ferruginea* are equally significant and are rich in flavonoids, terpenoids, and saponins. Similar to the bark, the leaves are analysed for ash values to detect inorganic impurities and ensure their quality. Extractive values in water and ethanol reveal the presence of bioactive compounds, with water-soluble constituents like flavonoids and glycosides contributing to antioxidant and antimicrobial effects, while ethanol-soluble compounds indicate the presence of alkaloids and terpenoids with anti-inflammatory and immune-modulating activities **[30]**.

Additionally, **pH analysis** of the bark and leaf extracts is performed to determine their compatibility with medicinal formulations. A slightly acidic to neutral pH is generally favourable for maintaining the stability and bioavailability of the extracts. **Microscopic evaluation** of the powdered bark and leaves provides diagnostic features such as the presence of lignified fibres, tannin cells, and trichomes, which help authenticate the plant material and confirm its identity.

STUDY OF ANTI-INFLAMMATORY PROPERTY IN THE WHOLE PLANT OF *ACACIA FERRUGINEA*

Acacia ferruginea, a plant widely recognized in traditional medicine, has shown promising anti-inflammatory properties. This therapeutic potential is primarily attributed to its bioactive compounds, such as flavonoids, tannins, and phenolic acids, which possess strong antioxidant and anti-inflammatory activities. These compounds inhibit the production of pro-inflammatory mediators like cytokines, prostaglandins, and nitric oxide, which play key roles in inflammation. Studies have demonstrated that extracts of *Acacia ferruginea* can suppress the activity of enzymes such as cyclooxygenase (COX) and lipoxygenase (LOX), both of which are critical in the inflammatory process. Additionally, its antioxidant properties help neutralize free radicals, further reducing oxidative stress and inflammation in tissues **[31, 32]**.

Table 1: Study of anti-inflammatory property in the whole plant of *Acacia ferruginea* [33]

Plant sources	Mode of study	Chemicals utilized	Results
Leaves	**Invitro**	**Petroleum ether, chloroform, butanol and methanol**	**The butanol and methanol extracts of *Acacia ferruginea* leaves demonstrated exceptional antioxidant activity, effectively scavenging DPPH free radicals, hydrogen peroxide ions, and exhibiting strong reducing power. In the carrageenan-induced rat paw edema model, the methanol and petroleum ether extracts showed the highest inhibition of inflammation at 400 mg/kg, achieving 84.88% and 82.12% inhibition, respectively. Similarly, in the formalin-induced rat paw edema model, the chloroform and methanol extracts exhibited the greatest anti-inflammatory effects, with inhibition rates of 65.68% and 63.34% at the same dose. In both experimental models, the extracts were compared to the standard anti-inflammatory drug, Indomethacin® (40 mg/kg), highlighting their significant potential as natural anti-inflammatory agents.**
Flowers	**Invitro**	**80% Alcohol extract (EtOH–H2O). The ethyl acetate fraction was found to contain isoquercitrin**	**The yellow pigment (isoquercitrin (88) was found to contain positive results with respect to acute and chronic anti-inflammatory activity**
Seeds	**Invitro**	**Five protein fractions—albumin, globulin, prolamin, acidic glutelins, and basic glutelins—were extracted using a stepwise process. Proteins were initially extracted in NaCl and centrifuged. The supernatant was dialyzed with distilled water to separate albumins (ALB) and globulins (GLB), which were then freeze-dried and stored. Prolamins were extracted from the pellet by stirring it in 70% ethanol for 1 hour at 25°C, followed by centrifugation, dialysis, and freeze-drying. The remaining pellet was treated with 100 mM HCl to extract acidic glutelins, and after centrifugation, the supernatant was dialyzed and freeze-dried. Finally, the remaining pellet was stirred in 100 mM NaOH to extract basic glutelins, which were also dialyzed and freeze-dried.**	**GLB significantly reduced carrageenan-induced paw edema in a dose-dependent manner and lowered myeloperoxidase activity ($p < 0.05$). It also decreased neutrophil migration in the peritoneum caused by carrageenan but was ineffective against dextran-induced edema. Pre-treatment with GLB reduced abdominal constrictions caused by acetic acid and decreased paw-licking time during the first phase of the formalin test (69.1%). However, heating GLB at 100°C for 30 minutes eliminated its anti-edematogenic and hemagglutinating effects. These results suggest that *Acacia ferruginea* seeds contain proteins with promising anti-inflammatory and analgesic properties.**
Stem bark	**Invitro**	**Aqueous and ethanol**	**The extract at doses of 100 and 200 mg/kg significantly reduced edema caused by carrageenan and histamine. In the acetic acid-induced writhing model, it showed strong analgesic effects by significantly reducing the number of writhes compared to the untreated group. In the tail immersion test, the extract increased the reaction time to pain within 30 minutes of oral administration at both doses. Indomethacin® (10 mg/kg) was used as the reference drug in all tests.**

CARDIOVASCULAR DISEASE: Anti-inflammatory activities in *Acacia ferruginea*

The Activity of *A.ferruginea* hold potential benefits for cardiovascular health, as chronic inflammation is a major contributor to cardiovascular diseases (CVDs). The plant's bioactive compounds, such as flavonoids, tannins, and phenolic acids, have been shown to inhibit key inflammatory pathways by suppressing pro-inflammatory mediators like cytokines, prostaglandins, and nitric oxide. These mediators are directly linked to the development of atherosclerosis, endothelial dysfunction, and hypertension—conditions that increase the risk of CVDs **[34]**.

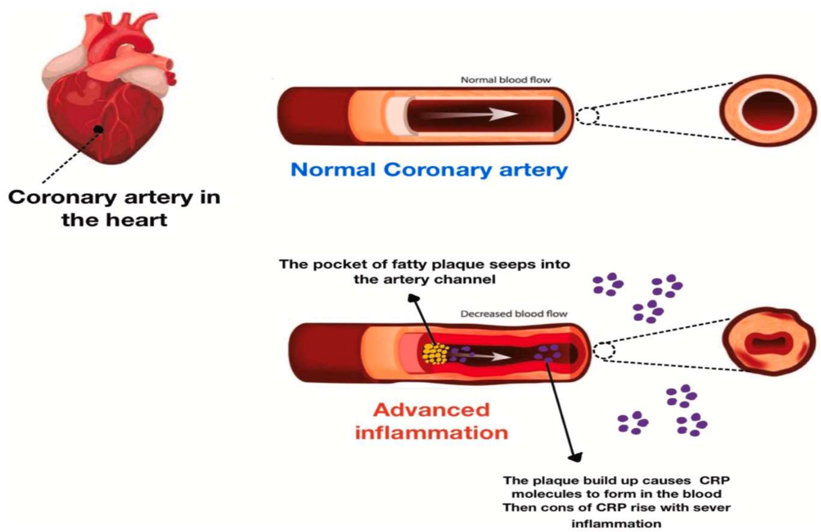

Figure 2: Inflammatory activity observed in the Heart related disorders

ANTI-INFLAMMATORY ACTIVITIES OF THE *ACACIA FERRUGINEA* RELATED TO DIABETES AND OBESITY

Persistent low-grade inflammation in these metabolic disorders contributes to insulin resistance, beta-cell dysfunction, and adipose tissue dysregulation, ultimately worsening the progression of diabetes and obesity-related complications. The bioactive compounds in *Acacia ferruginea*, such as flavonoids, tannins, and phenolic acids, have demonstrated the ability to inhibit pro-inflammatory mediators like cytokines (e.g., TNF-α, IL-6) and enzymes (e.g., COX and LOX) involved in inflammation. These compounds help reduce systemic inflammation and oxidative stress, two key drivers of insulin resistance and metabolic dysfunction. Additionally, *Acacia ferruginea*'s antioxidant properties protect pancreatic beta cells from oxidative damage, preserving their function and improving insulin secretion. In obesity, the plant's anti-inflammatory activity may help modulate inflammation in adipose tissue, reducing macrophage infiltration and the release of harmful adipokines. This can improve metabolic health and lower the risk of obesity-associated complications, such as cardiovascular disease and type 2 diabetes **[35]**.

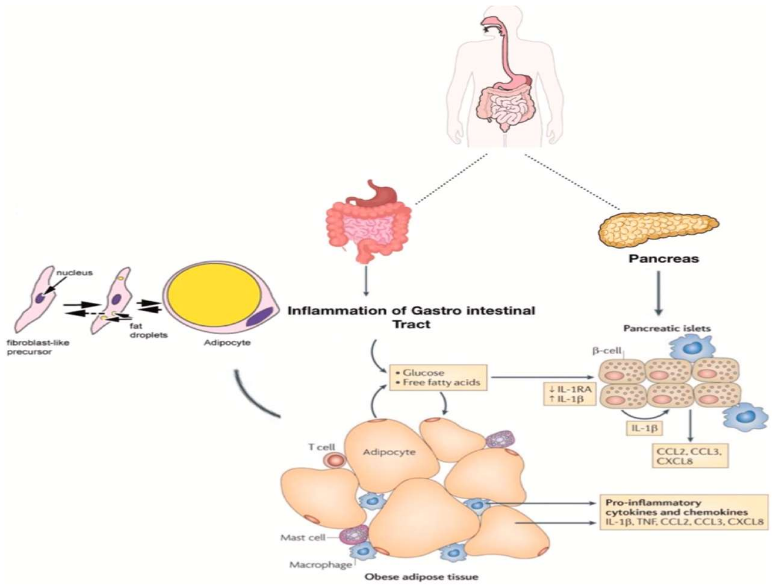

Figure 3: Representation of inflammatory in diabetes

CANCER: Anti-inflammation property of the whole plant

The properties of *Acacia ferruginea* hold significant promise in cancer prevention and management, as chronic inflammation is a well-established contributor to cancer initiation, progression, and metastasis. Persistent inflammation can lead to oxidative stress, DNA damage, and the activation of signalling pathways that promote tumour growth, angiogenesis, and immune evasion **[36]**.

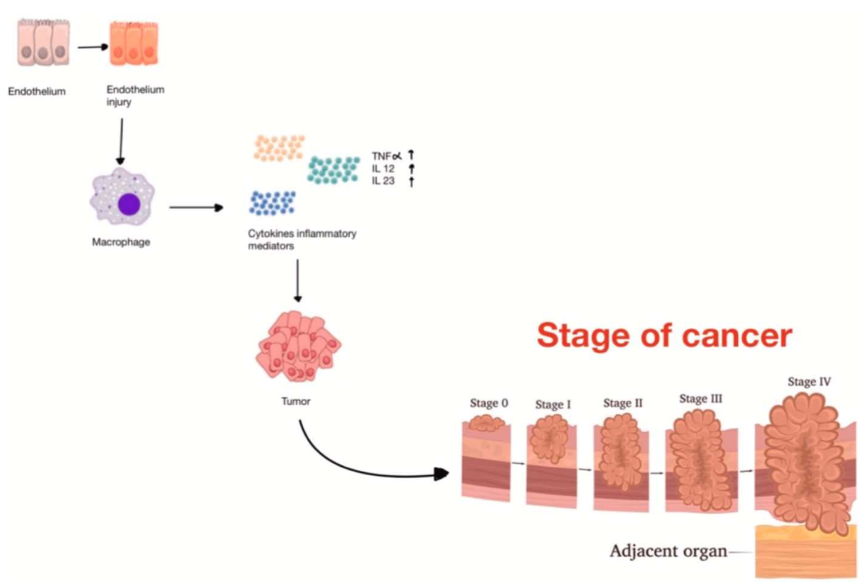

Figure 4: Schematized representation of inflammation in Cancer

CONCLUSION

In conclusion, this study highlights the significant potential of *Acacia ferruginea* as a natural therapeutic agent for managing chronic inflammatory diseases, particularly in semi-arid environments where the plant thrives. The phytochemical and physicochemical evaluations revealed the presence of bioactive compounds, such as flavonoids, tannins, and phenolic acids. Additionally, the fluorescence characteristics of the plant extracts offer insights into their chemical stability and potential for formulation in therapeutic applications. The findings demonstrate the ability of *Acacia ferruginea* to inhibit pro-inflammatory mediators, reduce oxidative stress, and modulate immune responses, making it a promising candidate for addressing conditions such as cardiovascular diseases, diabetes, obesity, and cancer. Furthermore, the adaptability of *Acacia ferruginea* to semi-arid regions underscores its ecological and medicinal importance, providing a sustainable resource for drug development. Future research should focus on clinical evaluations, standardization of extracts, and understanding the mechanisms of action to further validate the therapeutic efficacy of *Acacia ferruginea*. Overall, this study underscores the value of *Acacia ferruginea* as a versatile and eco-friendly solution for combating chronic inflammatory diseases.

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