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# A Review: Hepatoprotective Potential of Flavonoid-Rich Fraction from the Roots of *Lantana Camara* Against Paracetamol-Induced Liver Injury

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**Abstract**

Liver disorders continue to represent a significant global health challenge and contribute considerably to illness and death worldwide. Drug-induced liver damage, especially following excessive paracetamol intake, is a major clinical concern due to oxidative stress and injury to hepatocytes. In recent years, medicinal plants have attracted growing scientific interest as natural sources of hepatoprotective compounds because they contain a wide range of biologically active constituents.

*Lantana camara* is a common medicinal plant that contains numerous therapeutically important phytochemicals, including flavonoids, phenolic compounds, triterpenoids, and alkaloids. Among these, flavonoids exhibit strong antioxidant properties and may protect liver cells against oxidative damage.

The present review summarizes the available literature on the hepatoprotective capability of flavonoid-rich fractions obtained from the roots of *Lantana camara* against paracetamol induced liver injury. Particular attention has been given to the plant's phytochemical composition, the mechanism of paracetamol-mediated hepatic damage, and the contribution of flavonoids to protection against oxidative stress. The review also considers potential mechanisms by which flavonoids may act beneficially, such as reducing lipid oxidation, counteracting reactive oxygen species, and augmenting endogenous antioxidant defenses.

Available evidence suggests that flavonoid-rich root fractions of *Lantana camara* may serve as promising natural hepatoprotective agents. More scientific studies might help to establish their role for the prevention and therapeutic management of liver damage caused by drugs.

**Keywords:** *Lantana Camara*, Flavonoids, Hepatoprotection, Paracetamol-Induced Liver Damage, Oxidative Stress, Antioxidants

## 1. Introduction

### 1.1 Liver

The liver is one of the principal organs in the human system, the biggest internal gland. It is situated in the upper right-hand abdominal area, just behind the muscular diaphragm, and this organ responsible for over 500 critical body activities. The liver is vital for metabolism, protein synthesis, storage of nutrients, creation of bile, and detoxification of internal and external drugs. It is important in maintaining the balance of the body's metabolism, which is required for optimal health (Swati *et al*., 2020; Mahmood *et al*., 2014 [2]).

The liver's principal job is to metabolize and filter out chemicals, drugs, and environmental toxins. These functions are mediated mostly by hepatic enzyme systems, in particular cytochrome P450 enzymes. The liver is particularly vulnerable to toxic injury by medicines and other xenobiotics, as it is constantly exposed to chemicals absorbed via the gastrointestinal system (Anusha *et al*., 2011 [3]; S Vijayakumar *et al*., 2014).

### 1.2 Structure of the Liver

The liver represents the body's biggest gland as well as serves as one of the principal organs, responsible for maintaining normal physiological functions. It is a dark reddish-brown, wedge-shaped organ found in the upper right region within the abdominal cavity, immediately below the diaphragm. In healthy adults, this liver typically weighs between 1.2 and 1.8 kg. it lies superior to the gallbladder and occupies the right side of the stomach (Hall *et al*., 2021).

The liver receives blood circulating through two primary blood vessels, namely the portal vein and hepatic artery. The liver receives blood rich in absorbed nutrients through the portal vein, which transports it from the gastrointestinal tract for further processing and metabolism. Within the hepatic sinusoids, nutrients, oxygen, and metabolic substances are exchanged efficiently (Mescher *et al*., 2021).

The liver is surrounded by Glisson's capsule, delicate layer of fibrous connective tissue which provides structural support along with protection. Microscopically, this liver consists of multiple hepatic lobules, that serve as its organizational and functional components. Each lobule contains hepatocytes arranged radially around a centrally located vein. The porta hepatis act as the entrance and exit passage for the hepatic artery and portal vein, bile ducts, lymphatic vessels together with nerves. Externally, the liver is covered by a serous membrane derived from the peritoneum (Hall *et al*., 2021; Mescher *et al*., 2021).

### 1.3 Functions of the Liver

The primary functional units of the liver, referred as hepatocytes, are in charge of the organ's metabolic, synthetic, storage, and detoxifying processes. Over 500 vital physiological processes that support the preservation of proper bodily homeostasis are carried out by the liver. These processes can be mainly divided into three categories: transformation & clearing, storage & purification, and regulation & synthesis. Nutrient metabolism, bile production, plasma protein synthesis, drug and toxin detoxification, glycogen and vitamin and mineral storage, hormone modulation, and preservation of the body's general physiological balance are all critical functions of the liver (Adewusi *et al*., 2010) [7].

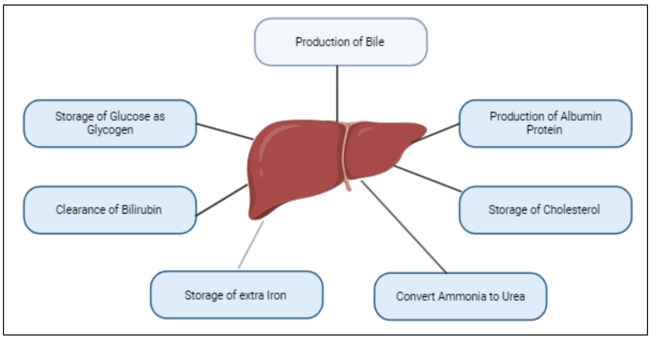


**Fig 1:** Function Liver

### 1.4 Liver Diseases

Liver disorders are among the leading factors associated with morbidity and mortality worldwide. They range from mild hepatic dysfunction to chronic liver failure and hepatocellular carcinoma and are caused by viral infections, alcohol abuse, metabolic disorders, autoimmune diseases, genetic abnormalities, and hepatotoxic drugs and chemicals (Asrani *et al.,* 2019; Robbins *et al*., 2022) [8, 9].

#### 1.4.1 Hepatitis

Hepatitis is characterized by inflammatory condition affecting the liver that has the potential to develop due to viral infections, excessive alcohol intake, autoimmune conditions, metabolic abnormalities, or exposure to certain drugs and toxins substances. If left untreated, chronic infections caused by hepatitis B virus (HBV) and hepatitis C virus (HCV) may gradually progress to hepatic liver fibrosis, hepatic cirrhosis as well as hepatocellular carcinoma. Common symptoms include jaundice, fatigue, nausea, abdominal pain, and elevated liver enzyme levels (World Health Organization, 2024) [10].

#### 1.4.2 Alcoholic Liver Disease (ALD)

Alcohol-related Liver Disease results from long-term heavy alcohol intake and includes hepatic steatosis, alcohol-induced hepatitis, hepatic fibrosis, and liver cirrhosis. Chronic alcohol intake promotes oxidative stress, inflammation, and hepatocellular injury, leading to irreversible liver damage (Robbin *et al*., 2022) [9].

#### 1.4.3 Fatty Liver Disease (Hepatic Steatosis)

Fatty Liver Disorder is defined through the abnormal deposition inside triglycerides within hepatocytes. It is commonly linked to chronic alcohol consumption or metabolic disorders such as obesity, insulin resistance, type II diabetes mellitus. Persistent steatosis may progress to steatohepatitis, fibrosis, cirrhosis, and hepatocellular carcinoma (Rinella *et al.,* 2023) [11].

In recent years, the designation metabolic dysfunction-associated hepatic steatotic disease (MASLD) has been proposed to substitute the term non-alcoholic fatty liver disease (NAFLD), underscoring the important impact of metabolic dysfunction in the progression of hepatic steatosis as the most common chronic liver disease in the world today, MASLD is becoming an important public health issue in India and in Chhattisgarh. (Rinella *et al.,* 2023 [11]; Pandey *et al.,* 2026).

#### 1.4.4 Cirrhosis

Cirrhosis represents the final advanced phase of chronic liver disease, marked associated with extensive fibrosis accompanied by the regenerative nodule formation, which progressively impair normal liver function. It commonly develops due to chronic hepatitis, alcohol abuse, metabolic disorders, autoimmune diseases, or hepatotoxic agents (Robbin *et al*., 2022) [9].

#### 1.4.5 Liver Cancer

The most common primary liver cancer is hepatocellular carcinoma (HCC), a severe liver disease that is usually associated with chronic hepatitis, cirrhosis, and metabolic liver diseases (Sung *et al.,* 2024) [12].

#### 1.4.6 Drug-Induced Hepatotoxicity

Drug-induced liver injury (DILI) is a prominent contributor to acute liver failure and is recognized as a substantial challenge in clinical practice as well as pharmaceutical research. As the primary organ responsible for the metabolism and detoxification of xenobiotics, the liver is particularly susceptible to damage caused by medications and other chemical agents. (Eswar Kumar *et al.,* 2013) [13].

Various drugs, including amoxicillin/clavulanate, isoniazid, and non-steroidal anti-inflammatory drugs (NSAIDs), have been associated with hepatic injury, with clinical manifestations ranging from asymptomatic elevation of liver enzymes to severe hepatic failure (Mischael *et al.,* 2014).

Drug-induced hepatotoxicity is regarded as one of the principal causes of acute liver failure across the world. Among drugs associated with hepatotoxicity paracetamol is one of the frequently prescribed common agents responsible for acute liver injury, particularly following overdose. Consequently, considerable research has focused on identifying hepatoprotective agents capable of reducing paracetamol-induced liver damage. (Jaeschke *et al.,* 2012; Hosack *et al*., 2023; Chidiac *et al*., 2023) [15, 16, 17].

Although several synthetic drugs have been investigated for the management for the therapeutic interventions of drug-induced liver injury, their long-term effectiveness and safety are not fully established. Therefore, increasing attention has been directed toward herbal hepatoprotective agents because of their antioxidant, anti-inflammatory, and cytoprotective properties. (EASL *et al.,* 2019; Li *et al.,* 2015).

### 1.5 Paracetamol Overview

Paracetamol (acetaminophen; N-acetyl-p-aminophenol) is one of the most commonly used non-prescription analgesic and fever-reducing agent drugs worldwide. It is widely recognized as prescribed for the management of relief of pain and discomfort the reduction of fever and is generally considered safe when administered within the recommended therapeutic dosage. Paracetamol overdose is one of the most well-studied forms of drug-induced liver injury because of the well-characterized mechanism of its hepatotoxicity and the important information it provides regarding oxidative stress-induced liver damage. (Yoon *et al*., 2020) [19].

After oral intake, paracetamol is readily absorbed via the gastrointestinal tract, and maximum plasma concentrations are usually reached during 30–60 minutes. The liver functions as the principal organ for its biochemical transformation. Around 55–60% of the administered dose is broken down through phase II glucuronide conjugation, whereas 30–35% undergoes phase II sulfate metabolism to generate harmless metabolites that are removed via urine. A minor proportion 5–10% is metabolized by oxidation via cytochrome P450 monooxygenase enzymes, mainly CYP2E1, CYP1A2, and CYP3A4, resulting in the formation of the highly reactive intermediate metabolite quinone imine metabolite.

In normal physiological circumstances, NAPQI is neutralized by conjugation with glutathione (GSH), leading to formation of non-toxic mercapturic acid conjugates. Therefore, liver toxicity is uncommon when paracetamol is administered within the recommended therapeutic dose. However, paracetamol overdose can overwhelm these detoxification mechanisms, leading to severe liver injury (Brunton *et al.,* 2018) [20].

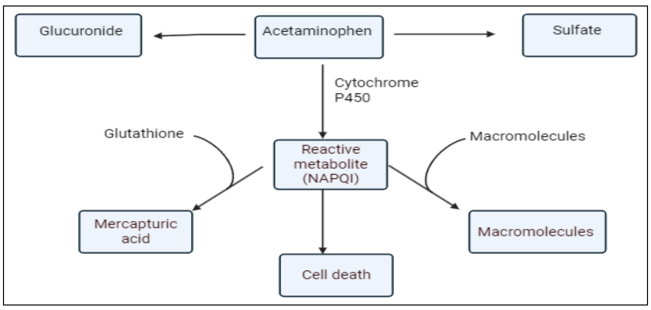


**Fig 2:** Metabolic Pathways of Paracetamol and Formation of NAPQI

#### 1.5.1 Mechanism of Paracetamol-Induced Hepatotoxicity

Paracetamol-induced liver injury is primarily mediated by excessive generation of N-acetyl-p-benzoquinone imine (NAPQI). During overdose, normal metabolic pathways become saturated, resulting in increased cytochrome P450-mediated metabolism and excessive NAPQI formation (Ramachandran *et al*., 2018) [21].

The accumulation of NAPQI depletes intracellular glutathione stores and promotes oxidative stress. Reactive oxygen species generated during this process contribute to lipid peroxidation, oxidative protein modification, DNA damage, and mitochondrial dysfunction. Persistent oxidative injury ultimately leads to hepatocellular necrosis and inflammatory responses that contribute to liver damage. (Jaeschke *et al*., 2012; Hinson JA *et al.,* 2010) [15, 22]

Mitochondrial dysfunction along with elevated oxidative stress induce a number of inflammatory pathways which exacerbate hepatocellular damage and cause acute liver injury. Severe hepatic necrosis may lead to acute liver failure (McGill *et al*., 2019) [23].

### 1.6 Hepatoprotective Agents

Hepatoprotective agents are substances capable of preventing liver injury and promoting restoration of normal hepatic structure and function. Their protective effects involve reduction of oxidative stress, inhibition of lipid peroxidation, stabilization of cellular membranes, enhancement of endogenous antioxidant defenses, and stimulation of hepatocyte regeneration (Prescott *et al*., 1979) [24].

Currently available hepatoprotective drugs include N-acetylcysteine, ursodeoxycholic acid, corticosteroids, and silymarin. Despite their therapeutic benefits, many of these agents are associated with adverse effects, limited efficacy, or high treatment costs, highlighting the need for safer alternatives from natural sources (Lee *et al*., 2004; Abenavoli *et al.,* 2018; Stickel *et al*., 2007 [27]).

Although several of these drugs have demonstrated therapeutic usefulness, the prolonged administration of synthetic hepatoprotective drugs is frequently associated with adverse effects, reduced efficacy over time, and increased treatment costs. poor efficacy, and costly treatment expenses. Thus, there is increasing interest in finding safer and more potent hepatoprotective compounds from medicinal plants. (EASL *et al.,* 2019; Li *et al*., 2015).

### 1.7 Herbal Hepatoprotective Agents

Medicinal plants have been utilized for centuries in traditional systems of medicine for the treatment of liver disorders. Herbal hepatoprotective agents contain numerous bioactive phytoconstituents, including flavonoids, phenolic acids, tannins, terpenoids, alkaloids, glycosides, and saponins, which contribute to their therapeutic activities (Flora *et al.,* 1998) [28].

Among the various bioactive phytoconstituents, flavonoids have gained significant scientific interest because of their potent antioxidant and hepatoprotective properties. Flavonoids neutralize reactive oxygen species, inhibit lipid peroxidation, preserve intracellular glutathione levels, and enhance endogenous antioxidant enzyme activity. In addition, they exhibit anti-inflammatory and membrane-stabilizing properties that contribute to hepatoprotection (Subramoniam *et al*., 1998; Cichoz-Lach *et al*., 2014) [30].

## 2. MASLD: A Major Liver Disease in Chhattisgarh

### 2.1 Introduction

Metabolic dysfunction-associated steatotic liver disease (MASLD) is acknowledged as the leading chronic liver disease globally and is regarded as a major public health concern in 2023, the term non-alcoholic fatty liver disease (NAFLD) was replaced by MASLD to better reflect the important role of metabolic dysfunction in the pathogenesis of hepatic steatosis (Rinella *et al.,* 2023) [11]. MASLD is a condition marked by fat accumulation in hepatocytes in individuals with cardiometabolic risk factors, including obesity, type 2 diabetes mellitus, dyslipidemia, hypertension, and insulin resistance. The clinical presentation of the disease is diverse, with cirrhosis, hepatocellular carcinoma, metabolic dysfunction-associated steatohepatitis (MASH), progressive fibrosis, and simple steatosis (Rinella *et al.,* 2023) [11].

Latest data suggests MASLD is becoming a health concern in Chhattisgarh. A survey of medical officers in Chhattisgarh found gaps in the knowledge, diagnosis, and application of MASLD recommendations, highlighting the importance of improved screening and management strategies (Kaushal *et al.,* 2026) [31]. This is further supported by a hospital-based study at Dr. Bhim Rao Ambedkar Memorial Hospital in Raipur that showed a significant burden of fatty liver disease among adults assessed using ultrasonography and elastography (Chaudhari *et al*., 2023) which adds to the increasing clinical significance of MASLD in the state.

**2.2 Liver Disease Burden in Chhattisgarh**

Liver problems are an important public health issue in Chhattisgarh. Among these, metabolic dysfunction-associated steatotic liver disease (MASLD), previously called non-alcoholic fatty liver disease (NAFLD), has become recognized due to the increasing prevalence of obesity, type 2 diabetes mellitus, dyslipidemia, and other metabolic risk factors (Rinella *et al*., 2023; Kaushal *et al*., 2026) [11, 31].

A hospital-based study carried out at Dr. Bhim Rao Ambedkar Memorial Hospital, Raipur revealed that most of the patients had Grade-I fatty liver and others had different degrees of liver fibrosis, this shows the increasing clinical burden of fatty liver disease in the state (Chaudhari *et al.,* 2023). If left untreated, MASLD may progress to metabolic dysfunction-associated steatohepatitis (MASH), fibrosis, cirrhosis, and hepatocellular carcinoma (HCC). (Rinella *et al*., 2023) [11].

**2.3 Epidemiology**

**2.3.1 Worldwide**

Metabolic dysfunction-associated steatotic liver disease (MASLD) is the most prevalent form of chronic hepatic disorder contributes substantially to disease burden and mortality across the world. MASLD affects around 25% of adults worldwide, mostly because obesity, insulin resistance, type 2 diabetes mellitus, dyslipidemia, and metabolic syndrome are becoming more common. (Rinella *et al*., 2023) [11].

**2.3.2 India**

In the past 20 years, rapid urbanization, unhealthy eating habits, sedentary lifestyle, obesity and diabetes have all contributed to a significant rise in the prevalence of MASLD in India. It is estimated that 25-30% of the Indian adult population is affected. (Kaushal *et al.,* 2026) [31].

**2.3.3 Chhattisgarh**

MASLD has emerged as an important liver disease in Chhattisgarh. The main causes for its rising prevalence of MASLD in Chhattisgarh is mainly connected with obesity, type 2 diabetes mellitus, and metabolic syndrome, and unhealthy lifestyle practices. Low awareness, inadequate screening, and delayed diagnosis are persistent problems; this emphasizes the need for early detection, lifestyle changes, and community-based preventive interventions (Kaushal *et al.,* 2026 [31]; Chaudhari *et al*., 2023).

**2.4 Major risk factors for MASLD**

- Obesity, especially visceral/central obesity.
- Insulin resistence.
- Type 2 Diabetes.
- Triglycerides, HDL, and LDL/VLDL serve as markers for dyslipidemia.
- High blood pressure.
- Sedentary lifestyle and absence of physical activity.
- Too much fat and processed carbohydrates is not healthy.
- Increasing age. (Rinella *et al.,* 2023 [11]; Kaushal *et al.,* 2026 [31]; Li *et al.,* 2015).

**2.5 MASLD pathophysiology**

Insulin resistance is thought to be the primary mechanism in the underlying mode of action of metabolic dysfunction-associated steatotic liver disease (MASLD). Hepatic steatosis, or excessive fat buildup inside hepatocytes, is caused by insulin resistance, which also enhances the hepatic influx of free fatty acids and facilitates triglyceride accumulation in hepatocytes. Lipotoxicity and mitochondrial dysfunction brought on by the accumulating lipids result in elevated production of reactive oxygen species (ROS). Hepatocytes are susceptible to injury caused by increased oxidative stress and lipid peroxidation, which weaken the liver's intrinsic antioxidant defense mechanisms. Sustained oxidative stress also activates inflammatory pathways, resulting in chronic liver inflammation and enhanced release of pro-inflammatory cytokines. Hepatic stellate cells are stimulated by ongoing liver damage, which results in collagen deposition and eventual fibrosis. (Li *et al*., 2015; Rinella *et al*., 2023 [11]).

**2.6 Diagnosis of MASLD**

Metabolic dysfunction-related fatty liver disorder is diagnosed using laboratory tests, imaging methods, metabolic risk assessment, physical examination, and clinical history. Initial evaluation often involves the use of serum lipid levels, serum glucose levels, hepatic function tests, and non-invasive fibrosis assessment instruments as the FIB-4 score. Imaging techniques, such as ultrasonic elastography (FibroScan) and abdominal ultrasonography, are crucial for evaluating liver fibrosis and identifying hepatic steatosis. Liver biopsy is still considered the most dependable diagnostic tool for confirming steatohepatitis and fibrosis when severe liver disease is suspected or diagnosis is uncertain. To stop the progression of the disease and enhance patient outcomes, early detection and prompt screening are critical (Rinella *et al*., 2023 [11]; Kaushal *et al.,* 2026 [31]; Chaudhari *et al*., 2023).

**2.7 Management of MASLD**

Lifestyle modification continues to be the primary therapeutic approach for the metabolic dysfunction-associated steatotic liver disease (MASLD), which includes eating a balanced diet, exercising frequently, and losing weight. It is also advised to manage associated metabolic disorders, including obesity, type 2 diabetes mellitus, dyslipidemia, and hypertension, should also be effectively managed. To improve clinical outcomes and stop the course of the disease, early screening with non-invasive fibrosis assessment techniques like the FIB-4 score and prompt referral of high-risk patients are crucial (Rinella *et al.,* 2023; Kaushal *et al.,* 2026) [11, 31].

**2.8 Need for Herbal Hepatoprotective Agents**

There are still few effective pharmacological treatments for preventing liver damage, and liver illnesses continue to remain an important global public health challenge. By encouraging lipid peroxidation, inflammation, and hepatocellular damage, Oxidative stress is one of the primary mechanisms involved in the progression of liver injury. Consequently, naturally occurring antioxidant compounds have received considerable scientific attention as potential hepatoprotective agents. The antioxidant potential of flavonoids is linked to their capacity to eliminate reactive oxygen species (ROS), suppress oxidative stress and lipid peroxidation, and reinforce the body's endogenous antioxidant defense system. Flavonoid-rich medicinal herbs are potential options for the management and prevention of liver damage because of these protective actions. (Li *et al*., 2015).

**2.9 Aim of the Review**

The hepatoprotective activity of many medicinal plants has been largely attributed to their flavonoid content, making flavonoid-rich fractions promising candidates for the prevention and management of liver disorders.

**2.10 Experimental Evidence (Preclinical Studies)**

Several preclinical investigations have demonstrated the hepatoprotective potential of *Lantana camara*, providing scientific evidence for its beneficial effects against liver injury. Antioxidant investigations have demonstrated that Extracts prepared from various parts of *Lantana camara* exhibit strong free radical scavenging properties, suggesting their effectiveness in minimizing oxidative stress. Since oxidative stress is a major contributor to paracetamol-induced liver injury, these findings suggest a possible protective role of *Lantana camara* against hepatic damage (Mahdi-Pour B *et al*., 2012) [33].

Furthermore, experimental studies have reported that *Lantana camara* extracts can ameliorate acetaminophen-induced liver injury by improving biochemical markers of liver function and reducing hepatic tissue damage. The observed protective effects are mainly attributed to the antioxidant properties of its phytoconstituents (Mahdi-Pour B *et al*., 2012) [33].

Although direct studies on flavonoid-rich fractions Obtained from the roots of *Lantana camara* are limited, the roots contain flavonoids along with other phenolic constituents that may contribute to their hepatoprotective activity. Therefore, further investigations are required to evaluate the efficacy of root-derived flavonoid-rich fractions against paracetamol-induced hepatotoxicity and to elucidate their underlying mechanisms of action (Stephen H *et al*., 2025) [34].

**2.11 Advantages of *Lantana Camara***

- *Lantana camara* roots are rich in Flavonoids and phenolic constituents with promising hepatoprotective properties.
- The plant exhibits significant antioxidant properties, which help reduce oxidative stress associated with paracetamol-induced liver injury.
- Flavonoids present in *Lantana camara* can scavenge Neutralize reactive free radicals, suppress lipid peroxidation, and safeguard hepatocytes against oxidative injury.
- The plant possesses anti-inflammatory activity that may help minimize liver inflammation and promote hepatic recovery.
- *Lantana camara* is widely available and serves as a cost-effective natural source of bioactive compounds for the development of hepatoprotective agents.

**2.12 Limitations of Current Research**

- Limited studies on root-derived flavonoid-rich fractions of *Lantana camara.*
- Insufficient evidence in paracetamol-induced hepatotoxicity models.
- Lack of standardization in extraction methods and dosage regimens.
- Limited phytochemical characterization of active flavonoid constituents.
- Incomplete understanding of the underlying hepatoprotective mechanisms.
- Absence of well-designed clinical studies in humans.

**3. Plant Profile**

**3.1 *Lantana Camara***

*Lantana camara* is a perennial medicinal shrub classified under the family Verbenaceae It is widely established throughout tropical and subtropical zones, including India, and has long been recognized for its medicinal importance. It is a perennial woody shrub with over 150 species that can be found in many different regions (Andhale C *et al.,* 2022).

**Fig 3:** Lantana camara plant

**Table 1:** Botanical Classification of Lantana camara (Andhale C *et al*., 2022)

| Taxonomic | Classification |
|---|---|
| Kingdom | Plantae |
| Super-division | Spercheophyta |
| Subkingdom | Tracheobionta |
| Division | Magnoliophyta |
| Class | Magnoliopsida |
| Order | Lamiales |
| Family | Verbenaceae |
| Genus | *Lantana* |
| Species | *Lantana camara linn.* |

**3.2 Common Names**
- English: Wild Sage, Red Sage
- Hindi: Raimuniya, Panchphuli
- Sanskrit: Vanacchedi

**3.3 Geographical Distribution**
*Lantana camara* originated in the tropical zones of Central and South America and is is currently widespread across warm tropical and subtropical zones, including India, Africa, Australia, and Southeast Asia. In India, it grows abundantly in forests, wastelands, roadsides, and hilly regions (Sharma *et al*., 1999).

**3.4 Botanical Description**
*Lantana camara* is a perennial, aromatic, erect or scrambling shrub belonging to the family Verbenaceae, attaining a height of about 2–4 meters. The stem is quadrangular in shape and may bear small prickles. The leaves are borne in opposite pairs, exhibit an ovate shape with a coarse texture, and release a characteristic fragrance when crushed. The flowers are compact and tubular, borne in compact flower heads, and occur diverse coloration, including yellow, orange, pink, red, and white. The fruits are small, fleshy drupes that turn black upon ripening (Kumar S *et al*., 2023).
**Parts used – Root** (Kumar S *et al*., 2023)

**Fig 4:** Root of Lantana camara

**3.5 Root Characteristics and Traditional Uses**
*Lantana camara L.* has well-developed, woody, cylindrical, and highly branching roots that produce a robust tap root system, which acts as a mechanical support to the plant and helps in the intake of water and essential nutrients from the soil. The roots are usually outwardly brown to dark brown in color and have a characteristic odor. Anatomical structure of roots includes a protective cork layer, cortex, vascular tissues, and medullary rays. These structures are involved in the storage and transport of nutrients and secondary metabolites (Singh *et al.,* 2013).
*Lantana camara* roots are utilized traditionally in several indigenous systems of medicine for the management of various diseases. Traditionally, root decoctions and extracts of *Lantana camara* have been employed for the management of fever, malaria, rheumatic conditions, skin diseases, gastrointestinal disorders, respiratory infections, and various inflammatory conditions. Root preparations are also utilized in some traditional techniques for the care of wounds and ulcers because of their antibacterial and wound-healing capabilities. *Lantana camara* roots have been used extensively as ethnomedicine, which indicates the presence of pharmacologically active ingredients that may be responsible for its therapeutic properties (Singh *et al.,* 2013).

**3.6 Phytochemical Constituents of Roots**
Phytochemical studies have demonstrated that the roots of *Lantana camara* Are rich in diverse secondary metabolites that contribute to their pharmacological and biological properties.
The major phytoconstituents identified from root extracts include.
- Flavonoid
- Triterpenoids
- Phenolic Compounds
- Tannins
- Saponins
- Alkaloids
- Glycosides
- essential oils.

Among the identified phytochemicals, flavonoids have received considerable scientific interest because of their strong antioxidant and hepatoprotective activities. Flavonoids are naturally occurring polyphenolic compounds capable of neutralizing reactive oxidant species (ROS) while stimulating the body's natural antioxidant defense network. These features may protect hepatocytes from oxidative stress-induced damage (Kalyankar *et al*., 2025).
Triterpenoids, lantadenes, have been identified in various parts of *Lantana camara*. Phenolic chemicals contribute to antioxidant potential due to their capacity to donate hydrogen atoms and neutralize reactive oxygen species (Kalyankar *et al*., 2025).
These bioactive ingredients support the traditional use of *Lantana camara* roots and give a scientific basis for exploring their hepatoprotective potential against chemically induced liver injury (Reddy *et al*., 2013).

**3.7 Flavonoids**
The flavonoids are one of the principal groups of naturally occurring polyphenolic compounds identified in plants. They are widely distributed throughout multiple plant parts, including leaves, flowers, fruits, stems, and roots. They are distributed in various parts of plants, including leaves, flowers, fruits, stems and roots. Flavonoids are recognized for their diverse pharmacological activities, such as antioxidant, anti-inflammatory, antimicrobial and hepatoprotective activities. These compounds protect cells by scavenging free radicals and suppressing oxidative stress, inhibit lipid peroxidation and enhance endogenous antioxidant defence mechanisms. Flavonoids have attracted much attention for these properties as promising therapeutic agents for the prevention and management of liver disorders, particularly drug-induced hepatotoxicity (Majee *et al*., 2023) [40].

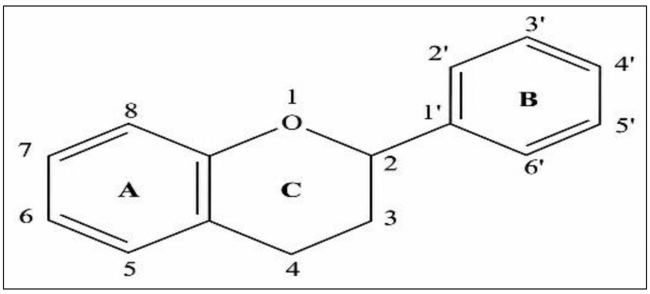

**Fig 5:** Basic Chemical Structure of Flavonoids

Flavonoids possess a characteristic C6–C3–C6 carbon backbone formed by two aromatic rings (A and B) interconnected via a heterocyclic ring (C). These structural features are responsible for their antioxidant and hepatoprotective properties (Majee *et al*., 2023) [40].

*Lantana camara* has been reported to possess several flavonoids including luteolin, quercetin, apigenin and kaempferol. Luteolin, a flavonoid that has attracted much scientific attention for its notable hepatoprotective, anti-inflammatory and antioxidant efficacy. Luteolin may be responsible for the hepatoprotective activity of flavonoid rich fraction of *Lantana camara.* Hence luteolin is discussed extensively in the next section. (Singh *et al*., 2013; Majee *et al*., 2023 [40]).

### 3.7.1 Luteolin: An Important Bioactive Flavonoid

Luteolin (3′,4′,5,7-tetrahydroxyflavone), is a naturally occurring bioactive flavonoid, has attracted great interest from scientists due to its potent anti-inflammatory, hepatoprotective, and antioxidant properties (Yao *et al*., 2023; Subramanya *et al*., 2018) [41, 42].

**Table 2:** Chemical Profile

| Parameter | Description |
|---|---|
| Chemical name | Luteolin (3′,4′,5,7-Tetrahydroxyflavone) |
| IUPAC Name | 2-(3,4-dihydroxyphenyl)-5,7-dihydroxy-4H-chromen-4-one |
| Molecular formula | $C_{15}H_{10}O_6$ |
| Molecular weight | 286.24 g/mol |
| Chemical class | Flavone (flavonoid) |

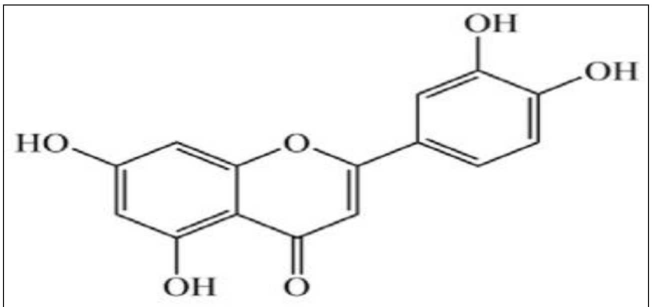


**Fig 6:** Chemical Structure of Luteolin

### 3.7.2 Mechanism of Hepatoprotective Action of Luteolin

N-acetyl-p-benzoquinone imine (NAPQI), a harmful metabolite generated during paracetamol overdose causes oxidative stress, depletion of glutathione (GSH) and hepatocellular injury. Luteolin has hepatoprotective effects by eliminating Reactive oxygen species (ROS) by elevating the levels of antioxidant enzymes, including superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx), as well as decreasing NF-κB mediated inflammatory responses. These anti-inflammatory and antioxidant properties combined protect hepatocytes from the damage to liver by paracetamol (Yao *et al*., 2023) [41].

Furthermore, research on phytochemicals isolated from plants with a protective activity against acetaminophen-induced hepatotoxicity has shown the hepatoprotective potential of luteolin. The results justify the inclusion of luteolin as an important bioactive flavonoid in the present review. (Subramanya *et al.,* 2018) [42].

### 3.8 Pharmacological Activities of *Lantana camara* root

*Lantana camara,* a medicinal plant of the family Verbenaceae, has been used for ages in traditional medicine for many maladies. It contains many bioactive phytoconstituents featuring flavonoids and phenolic compounds, triterpenoids, alkaloids, tannins, saponins, along with glycosides responsible for its varied pharmacological actions. *Lantana camara* was shown to contain antioxidant, anti-inflammatory, antibacterial, antidiabetic, wound healing, and hepatoprotective activities. Flavonoids are one of these substances and play a crucial role due to their strong antioxidant and free radical scavenging activity, therefore making the plant a good target for hepatoprotective studies (Tiwari *et al*., 2023) [43].

Several pharmacological studies have identified varied biological effects of *Lantana camara* root extracts, which are mainly ascribed to the presence of flavonoids and other phenolic compounds (Dogra *et al*., 2009) [44].

**a. Hepatoprotective Activity:** The antioxidant potential of Lantana camara roots is mainly attributed to the diverse bioactive phytoconstituents present in them. The flavonoids in particular may be protective of the hepatocytes from toxic insults by scavenging the free radicals, conserving the glutathione levels, decreasing the lipid peroxidation, and stabilizing the cellular membranes. The data suggest that root extracts of *Lantana camara* have the potential to act as a hepatoprotective agent against drug-induced liver injury (Ramírez *et al.,* 2025) [45].

The pharmacological activities of *Lantana camara* roots indicate therapeutic usefulness and further exploration of its bioactive ingredients, such as flavonoid-rich fractions, as a potential source of new hepatoprotective medicines (Ramírez *et al.,* 2025) [45].

**b. Antioxidant Activity:** Root extracts of *Lantana camara* exhibited strong free radical scavenging activity, thereby lowering oxidative stress and suppressing lipid peroxidation. Antioxidants help to reduce the cell damage caused by reactive oxygen species (Battase *et al.,* 2021) [46].

**c. Anti-inflammatory Activity:** The roots exhibit anti-inflammatory actions by suppressing inflammatory mediators and minimizing tissue inflammation. This activity could be the basis for its historic use to treat inflammatory disorders (Sharma *et al*., 1981) [47].

**d. Antimicrobial Activity:** The root extracts displayed inhibitory effects on many bacterial and fungal pathogens, indicating the potential utility in the management of diseases (Sharma *et al*., 1981) [47].

**e. Wound-Healing Activity:** Traditional use of *Lantana camara* roots in wound management has been supported by studies demonstrating enhanced tissue repair and antimicrobial effects (Ghisalberti *et al*., 2007).

**f. Antidiabetic Activity:** Some investigations have reported that root extracts may help regulate blood glucose levels through antioxidant mechanisms and modulation of carbohydrate metabolism (Kumar *et al*., 2013) [50].

## 4. Toxicity and Safety Concerns

Although *Lantana camara* possesses significant pharmacological and hepatoprotective properties, certain constituents such as lantadenes have been reported to exhibit hepatotoxic effects, particularly at higher doses. Toxicity has been mainly associated with crude plant extracts and foliage, whereas the safety profile of isolated bioactive fractions may differ. Therefore, proper standardization, dose optimization, and comprehensive toxicological evaluations are essential before considering the therapeutic application of flavonoid-rich fractions from *Lantana camara* roots (Sharma *et al*., 1981 [47]; Ghisalberti *et al*., 2000; Sharma *et al*., 2007 [49]).

## 5. Discussion

The principal mechanism underlying paracetamol-induced hepatotoxicity, a widely recognized model of one of the principal mechanisms underlying drug-induced hepatic injury is the formation of the toxic metabolite N-acetyl-p-benzoquinone imine. Excessive NAPQI leads to hepatocellular injury, lipid peroxidation, oxidative stress, and glutathione depletion (Jaeschke *et al*., 2012; Ramachandran & Jaeschke, 2018; Hinson *et al*., 2010) [15, 21, 22].

The roots of *Lantana camara* are enriched with diverse bioactive constituents particularly flavonoids as well as phenolic compounds that display considerable antioxidant and free radical-suppressing properties. These compounds may protect the liver by reducing oxidative stress, maintaining glutathione levels, and boosting the body's natural antioxidant defenses (Andhale *et al.,* 2022; Majee *et al.,* 2023 [40]; Panche *et al*., 2016 [51]).

*Lantana camara* roots seem to be a promising source of fractions high in flavonoids that may have hepatoprotective properties. Nevertheless, there is currently a dearth of thorough phytochemical characterization, standardization, and mechanism-based research. Furthermore, the existence of hazardous components such lantadenes emphasizes the necessity of purification and safety assessment prior to medicinal application (Ghisalberti *et al*., 2000; Sharma *et al*., 2007 [49]).

Despite the need for additional studies to confirm their efficacy and safety, the literature now available indicates that flavonoid-rich fractions from the roots of *Lantana camara* may have protective effects against oxidative liver injury.

## 6. Conclusions

This review emphasizes the hepatoprotective efficacy of flavonoid-rich fractions extracted from *Lantana camara* roots in limiting paracetamol-induced oxidative liver injury. The potent antioxidant, radical-scavenging, anti-inflammatory, and membrane-protective properties of flavonoids help to reduce oxidative stress, inhibit lipid peroxidation, preserve intracellular glutathione levels, and protect hepatocytes from cellular injury.

A promising natural source of hepatoprotective phytochemicals is the roots of *Lantana camara*, according to the literature that is currently accessible. However, there is still little information available about flavonoid-rich fractions obtained from roots, and more phytochemical characterization, standardization, mechanistic research, safety assessment, and clinical validation are required.

All things considered, flavonoid-rich fractions from *Lantana camara* roots hold great promise for the creation of herbal hepatoprotective medicines that are safe, efficient, and reasonably priced for the prevention and management of drug-induced hepatic disorders.

## 7. Future Scope

The main flavonoids found in the roots of *Lantana camara* should be isolated, purified, and characterized using sophisticated analytical methods in future studies. To guarantee consistency and reproducibility, flavonoid-rich fraction quality control and extraction process standardization are crucial.

The molecular processes behind hepatoprotection, in particular their impact on oxidative stress, inflammatory pathways, antioxidant defense systems, and hepatocellular protection, require more investigation. Purified flavonoid-rich fractions should also undergo a thorough safety investigation and toxicological assessment.

Clinical investigation is also required to verify the pharmacological and safety effectiveness of flavonoid-rich fractions produced from the roots of *Lantana camara* in patients with liver diseases. The creation of evidence-based herbal hepatoprotective compositions with enhanced safety and efficacy may be aided by such studies.

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