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A REVIEW ON THE IMMUNOMODULATORY AND HEPATOPROTECTIVE EFFECTS OF BUCHANANIA LANZAN SEED EXTRACT

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ABSTRACT

Liver diseases are becoming a serious health problem all over the world and are responsible for a large number of deaths every year. Factors such as alcohol consumption, unhealthy lifestyle, viral infections, excessive use of medicines, and environmental pollution can damage the liver and disturb its normal functions. Since many synthetic drugs used for liver disorders may cause side effects after long-term use, researchers and healthcare professionals are now showing greater interest in medicinal plants as safer and more natural alternatives. Among these medicinal plants, Buchanania lanzan, commonly known as chironji, has gained significant attention because of its traditional medicinal value and therapeutic potential. For many years, different parts of this plant have been used in traditional Indian medicine for the treatment of various diseases. Among all parts, the seeds are considered especially important because they are rich in nutrients and several bioactive compounds such as flavonoids, phenols, tannins, saponins, and fatty acids. These natural compounds are well known for their antioxidant and protective properties, which help the body fight against harmful free radicals and oxidative stress. Since oxidative stress is closely linked with liver damage and weakened immunity, the antioxidant activity of Buchanania lanzan plays an important role in maintaining overall health. In this review paper, we discussed how different extracts of Buchanania lanzan show antioxidant, anti-inflammatory, immunomodulatory, and hepatoprotective activities. Studies suggest that the plant helps strengthen the immune system, reduce inflammation, and protect liver cells from toxin-induced damage by improving liver enzyme levels and restoring normal liver function. Because of these beneficial effects, Buchanania lanzan may become a promising natural medicine for liver and immune-related disorders. However, despite its encouraging medicinal potential, more detailed experimental and clinical studies are still required to confirm its safety, effectiveness, and future pharmaceutical applications.

KEYWORDS: Buchanania lanzan; Chironji; Immunomodulatory activity; Hepatoprotective effect; Antioxidant activity; Phytochemicals; Herbal medicine; Liver protection.

1. INTRODUCTION

Liver diseases are one of the major health problems worldwide and are responsible for a large number of illnesses and deaths every year. The liver is a vital organ that performs many important functions in the body, such as metabolism, detoxification of harmful substances, protein synthesis, bile production, and regulation of immune functions.[1] When the liver becomes damaged, these functions are affected, which can lead to serious health complications including fibrosis, cirrhosis, liver failure, and hepatocellular carcinoma (HCC). In recent years, cases of chronic liver diseases have increased rapidly due to unhealthy lifestyle habits, excessive alcohol consumption, viral infections, exposure to environmental toxins, and drug-induced liver damage. Globally, liver diseases account for approximately two million deaths annually.[2] Among the most common liver disorders are alcoholic liver disease (ALD), non-alcoholic fatty liver disease (NAFLD), viral hepatitis, drug-induced liver injury (DILI), autoimmune hepatitis, and liver cancer. NAFLD has emerged as one of the most prevalent chronic liver diseases worldwide, mainly due

to increasing obesity, diabetes, and metabolic syndrome. Viral hepatitis caused by hepatitis B virus (HBV) and hepatitis C virus (HCV) remains a significant cause of chronic liver damage and hepatocellular carcinoma, particularly in developing countries. Several etiological factors contribute to liver injury.[3] Excessive alcohol consumption is one of the primary causes of hepatic damage, leading to fatty liver, alcoholic hepatitis, fibrosis, and cirrhosis. Viral infections such as hepatitis B, C, and E viruses can induce chronic inflammation and progressive liver dysfunction. In addition, prolonged use or overdose of certain drugs, including paracetamol, anti-tubercular drugs, and chemotherapeutic agents, may result in hepatotoxicity. Environmental toxins, industrial chemicals, pesticides, heavy metals, and aflatoxins also contribute significantly to liver injury. Metabolic disorders, obesity, and diabetes further aggravate hepatic dysfunction through lipid accumulation and oxidative stress. Oxidative stress and inflammation play crucial roles in the pathogenesis and progression of liver diseases. Oxidative stress occurs when the production of reactive oxygen species (ROS) exceeds the antioxidant defense capacity of the body.[4] Excess ROS can damage cellular lipids, proteins, and DNA, resulting in hepatocyte injury and mitochondrial dysfunction. Lipid peroxidation caused by oxidative stress disrupts cell membrane integrity and promotes necrosis or apoptosis of liver cells. Inflammation is another important factor involved in liver injury. Hepatic damage activates Kupffer cells and other immune cells, leading to the release of pro-inflammatory cytokines such as tumor necrosis factor-alpha (TNF-α), interleukin-1 beta (IL-1β), and interleukin-6 (IL-6). Persistent inflammation contributes to fibrosis, cirrhosis, and eventually liver cancer. Therefore, controlling oxidative stress and inflammatory responses has become an important therapeutic strategy for the prevention and treatment of liver diseases. Natural products and medicinal plants possessing antioxidant and anti-inflammatory properties have gained significant attention for their hepatoprotective potential. Among these, *Buchanania lanzan* has emerged as a promising medicinal plant due to its rich phytochemical profile and various pharmacological activities.[5]

Table 1: Causes of Liver Diseases.[6,7]

S. No.	Category of Liver Disease	Causes/Examples	Effects on Liver
1	Alcohol-related liver disease	Excessive alcohol consumption	Fatty liver, alcoholic hepatitis, cirrhosis
2	Viral hepatitis	Hepatitis A, B, C, D, and E viruses	Chronic inflammation, fibrosis, liver cancer
3	Drug-induced liver injury (DILI)	Paracetamol overdose, anti-tubercular drugs, antibiotics, chemotherapy	Hepatotoxicity and liver cell damage
4	Non-alcoholic fatty liver disease (NAFLD)	Obesity, diabetes, metabolic syndrome	Fat accumulation and liver inflammation
5	Genetic and metabolic disorders	Wilson's disease, hemochromatosis, α1-antitrypsin deficiency	Impaired liver metabolism and fibrosis
6	Infectious diseases	Bacterial and parasitic infections	Hepatic inflammation and dysfunction
7	Lifestyle-related factors	Poor diet, smoking, sedentary lifestyle	Increased risk of fatty liver disease
8	Oxidative stress and inflammation	Excess reactive oxygen species (ROS) and cytokine production	Cellular damage, fibrosis, cirrhosis

The immune system plays a crucial role in protecting the body against infections, toxins, and abnormal cellular activities. It consists of complex networks of immune cells, cytokines, signaling molecules, and defense mechanisms that work together to maintain immune balance.[8] However, dysregulation of immune responses may contribute to chronic inflammation, autoimmune disorders, and tissue damage, including liver injury. Oxidative stress and inflammatory mediators are considered major factors involved in the progression of hepatic diseases and immune dysfunctions. Therefore, agents possessing both immunomodulatory and antioxidant properties have gained significant attention for their potential therapeutic applications in the prevention and management of liver-related disorders.[9]

2. LITERATURE REVIEW

In recent years, herbal medicine has emerged as an important area of pharmaceutical and biomedical research due to its wide therapeutic potential, natural origin, affordability, and comparatively lower side effects. Medicinal plants contain diverse bioactive compounds such as flavonoids, phenolics, alkaloids, tannins, terpenoids, and glycosides, which exhibit antioxidant, anti-inflammatory, immunomodulatory, and hepatoprotective activities. Traditional systems of medicine, including Ayurveda, Siddha, and Unani, have long utilized plant-based remedies for the treatment of liver and immune-related diseases. Scientific validation of these medicinal plants has further strengthened their

importance in modern drug discovery and development.[10]

3. Buchanania lanzan

Buchanania lanzan is an important medicinal and nutritional plant widely recognized in traditional Indian medicine for its therapeutic potential. It belongs to the family Anacardiaceae, which also includes economically significant plants such as mango and cashew. The plant is commonly known as Chironji or Charoli, and its seeds are highly valued for their nutritional richness and medicinal applications.[11] Due to its broad pharmacological activities, Buchanania lanzan has gained increasing attention in phytopharmaceutical and ethnomedicinal research. The plant is a medium-sized deciduous tree predominantly distributed throughout the tropical and subtropical regions of India. It is commonly found in states such as Madhya Pradesh, Rajasthan, Chhattisgarh, Jharkhand, Uttar Pradesh, and parts of South India. In addition to India, the plant is also distributed in Nepal, Sri Lanka, and Southeast Asian regions. It grows well in dry deciduous forests and is considered an important forest resource for tribal and rural communities. Traditionally, different parts of Buchanania lanzan, including seeds, bark, leaves, roots, and gum, have been used in Ayurvedic and folk medicine systems for the treatment of various diseases. The seeds are commonly used as a nutritive tonic and are believed to improve strength and immunity.[12] Bark extracts have been traditionally used for the management of diarrhea, dysentery, skin disorders, and inflammatory conditions. Leaves and roots are also used in wound healing and treatment of infections. Tribal communities have extensively utilized this plant for gastrointestinal disorders, fever, respiratory ailments, and reproductive health management. Nutritionally, Chironji seeds are considered highly valuable because they are rich in proteins, healthy fats, carbohydrates, vitamins, minerals, and essential amino acids. The seeds also contain significant amounts of antioxidants and bioactive phytochemicals such as flavonoids, tannins, phenolic compounds, and saponins, which contribute to their medicinal properties.[13] Due to these constituents, the plant exhibits several pharmacological activities including antioxidant, anti-inflammatory, antimicrobial, antidiabetic, hepatoprotective, and immunomodulatory effects. The ethnopharmacological importance of Buchanania lanzan has encouraged researchers to explore its therapeutic potential through modern scientific studies. Recent investigations have focused on isolating bioactive compounds and evaluating their pharmacological actions for the development of herbal formulations and phytopharmaceutical products. Therefore, Buchanania lanzan represents a promising medicinal plant with significant nutritional, therapeutic, and commercial value in contemporary healthcare research.[14]

4. Botanical Profile of Buchanania lanzan

4.1 Taxonomy[15]

Table no. 2: Botanical Profile of Buchanania lanzan.

Category	Details
Kingdom	Plantae
Division	Magnoliophyta
Class	Magnoliopsida
Order	Sapindales
Family	Anacardiaceae
Genus	*Buchanania*
Species	*Buchanania lanzan* Spreng.

5. Ethnomedicinal Uses

Buchanania lanzan has been extensively utilized in traditional systems of medicine such as Ayurveda, Unani, and folk medicine for the management of various ailments. Different parts of the plant including seeds, bark, leaves, roots, and gum possess significant therapeutic value due to the presence of bioactive phytoconstituents.[16]

Traditionally, the seeds are used as a nutritive tonic and are considered beneficial in treating general weakness, malnutrition, and reproductive disorders. The seed paste is commonly applied to skin diseases, wounds, and inflammatory conditions because of its antimicrobial and anti-inflammatory activities. The bark is traditionally employed for the treatment of diarrhea, dysentery, and fever owing to its astringent properties.[17] Leaves of the

plant are used in folk medicine for wound healing and ulcer management. Decoctions prepared from leaves and bark are administered in cases of rheumatism and body pain. Tribal communities also utilize different plant parts for the treatment of respiratory disorders such as cough, asthma, and bronchitis. The gum exudate obtained from the bark exhibits demulcent properties and is used in digestive disorders. In several rural regions, chironji seeds are regarded as an immunity-enhancing functional food because of their rich nutritional composition. Recent pharmacological investigations support many of these traditional claims and indicate that the plant possesses antioxidant, hepatoprotective, antimicrobial, anti-inflammatory, antidiabetic, and immunomodulatory activities.[18] Thus, the extensive ethnomedicinal applications of *Buchanania lanzan* highlight its importance as a valuable medicinal plant with considerable therapeutic potential for future herbal drug development. The plant is traditionally valued for its nutritional and medicinal properties. Different parts of the plant, particularly the seeds, bark, leaves, and roots, have been used in folk medicine for treating skin disorders, digestive problems, inflammation, fever, and various systemic ailments. The seeds are rich in proteins, fatty acids, vitamins, minerals, and several phytoconstituents including flavonoids, phenolic compounds, tannins, and saponins. Previous pharmacological studies have reported antioxidant, antimicrobial, anti-inflammatory, antidiabetic, immunomodulatory, and hepatoprotective activities of *Buchanania lanzan* extracts, indicating its potential as a promising medicinal plant. The present review aims to comprehensively summarize and critically discuss the available scientific literature regarding the immunomodulatory and hepatoprotective effects of *Buchanania lanzan* seed extract.[19,20] The review also focuses on its phytochemical composition, possible mechanisms of action, and therapeutic significance in the management of immune-related and liver disorders. Furthermore, this article highlights current research gaps and future perspectives for the development of *Buchanania lanzan*-based herbal formulations and pharmaceutical applications.[21]

Table 3: Short Review of *Buchanania lanzan* and Its Reported Pharmacological Uses.

S. No.	Review Paper / Study	*Buchanania lanzan* Reported Activity	Uses (Reported Diseases/Conditions)	Reference
1	*Pharmacological studies on Buchanania lanzan Spreng.-A focus on wound healing with particular reference to anti-biofilm properties*	Antioxidant, antimicrobial, wound healing activity	Wound healing, skin infections, bacterial infections, inflammation	[22]
2	*Evaluation of the immunomodulatory activity of hydroalcoholic extracts of Buchanania lanzan fruits*	Immunomodulatory and anti-inflammatory activity	Immune disorders, inflammation, oxidative stress-related conditions	[23]
3	*A Comprehensive Review of Phytoconstituents, Medicinal Properties, and Nanoformulations*	Antioxidant, antimicrobial, anti-inflammatory activity	Liver disorders, infections, inflammatory diseases, pharmaceutical applications	[24]
4	*Review on Buchanania Lanzan Phytochemistry, Traditional Used and Pharmacological Potential*	Phytochemical and therapeutic potential	Diabetes, ulcers, inflammation, microbial diseases	[25]
5	*A Review on Phytochemical Constituents and Pharmacological Activities of Buchanania lanzan*	Anti-inflammatory, antioxidant, antidiabetic activity	Diabetes, ulcers, oxidative stress, inflammatory disorders	[26]
6	*Attenuation of reactive O of No_2 expression in RAW 264.7 by bark extract of Buchanania lanzan*	Antioxidant and anti-inflammatory activity	Oxidative stress, inflammatory disorders, immune dysfunction	[27]
7	*Buchanania lanzan is a Pharmacognostic Miracle Herb*	Hepatoprotective, antiulcer, antidiabetic activity	Liver disorders, gastric ulcers, diabetes, inflammation	[28]
8	*An Updated Review on Phyto-Pharmacological and Pharmacognostical Profile of Buchanania lanzan*	Pharmacognostic and medicinal importance	Skin diseases, diarrhea, ulcers, inflammatory diseases	[29]
9	*In-vivo diuretic and antiulcer activity in fruits of Buchanania lanzan*	Antiulcer and diuretic activity	Gastric ulcers, urinary disorders, inflammation	[30]
10	*A Review on Hepatoprotective and Immunomodulatory Herbal Plants*	Herbal hepatoprotective and immunomodulatory potential	Hepatitis, liver injury, immune dysfunctions	[31]

6. IMMUNE SYSTEM AND LIVER FUNCTION

6.1. Relationship Between Liver and Immunity

The liver is not only a metabolic organ but also an important immunological organ that plays a central role in maintaining body homeostasis. It continuously receives blood from the gastrointestinal tract through the portal vein, exposing it to dietary antigens, microbial products, toxins, and pathogens. Because of this unique anatomical position, the liver acts as the first line of immune defense against harmful substances entering the body. The liver contains a large number of immune cells, including Kupffer cells, macrophages, dendritic cells, natural killer (NK) cells, and T lymphocytes. These immune cells help identify and eliminate pathogens while maintaining immune tolerance toward harmless antigens.[32] Hepatocytes and liver sinusoidal endothelial cells also contribute to immune regulation by producing cytokines and signaling molecules.[33]

6.2. Cytokines, Macrophages, Kupffer Cells, and Inflammatory Mediators

Cytokines are small signaling proteins that regulate immune responses and inflammation in the liver. They can be classified as pro-inflammatory cytokines, such as tumor necrosis factor-alpha (TNF-α), interleukin-1β (IL-1β), and interleukin-6 (IL-6), or anti-inflammatory cytokines, such as interleukin-10 (IL-10) and transforming growth factor-beta (TGF-β). A proper balance between these cytokines is necessary for maintaining liver homeostasis. Kupffer cells are specialized resident macrophages located in the liver sinusoids. They are responsible for removing pathogens, damaged cells, and toxins from the bloodstream through phagocytosis. Upon activation, Kupffer cells release cytokines and chemokines that recruit additional immune cells to sites of injury or infection. Although this process is protective, excessive activation of Kupffer cells can contribute to chronic inflammation and liver damage.[34,35] Macrophages and dendritic cells also participate in antigen presentation and activation of adaptive immune responses. During liver injury, inflammatory mediators such as reactive oxygen species (ROS), nitric oxide (NO), and chemokines are released, leading to oxidative stress and tissue damage. Persistent inflammatory signaling may activate hepatic stellate cells, resulting in fibrosis and scar tissue formation.[36]

6.3. Immune Dysregulation in Hepatic Diseases

Immune dysregulation plays a significant role in the development and progression of hepatic diseases. Under healthy conditions, the liver maintains a balance between immune activation and immune tolerance. However, chronic infections, alcohol abuse, metabolic disorders, drug toxicity, and viral hepatitis can disrupt this balance, leading to excessive inflammation. In chronic liver diseases, continuous activation of Kupffer cells and immune pathways increases the production of pro-inflammatory cytokines such as TNF-α, IL-6, and interferon-gamma (IFN-γ). This persistent inflammatory environment promotes hepatocyte injury, fibrosis, and cirrhosis. In advanced stages, chronic inflammation may contribute to hepatocellular carcinoma (HCC).[37,38] Immune dysfunction also weakens the liver's ability to fight infections, making patients more susceptible to bacterial and viral complications. Additionally, altered immune responses can lead to autoimmune liver diseases, including autoimmune hepatitis and primary biliary cholangitis.[39]

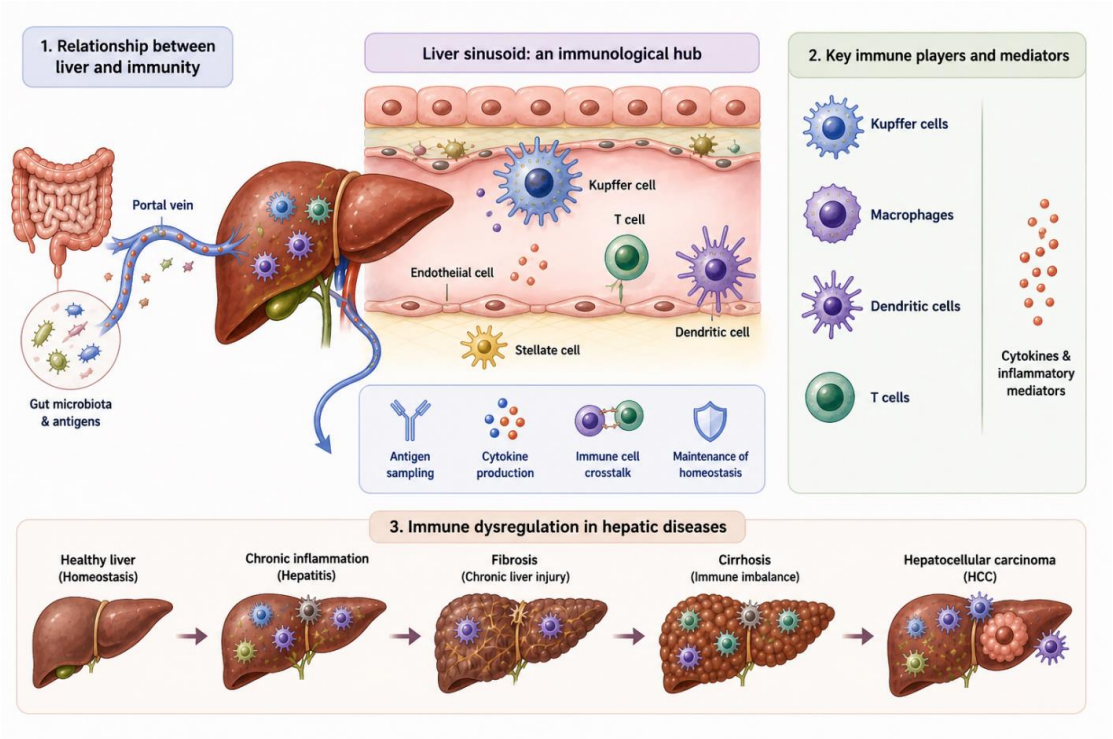


Figure 1: Relationship between liver and immunity.

6.4. Importance of Herbal Medicines

Herbal medicines have been used traditionally for the treatment of liver disorders for many centuries. Many medicinal plants possess hepatoprotective, antioxidant, and anti-inflammatory properties. Traditional systems such as Ayurveda and Unani widely use herbs for liver health management. Plant-based therapies are considered safer and have fewer side effects compared to synthetic drugs. Herbal medicines help in reducing oxidative stress and improving liver function.

Natural compounds from plants can support liver regeneration and detoxification processes.

Several herbs contain bioactive phytochemicals such as flavonoids, alkaloids, and phenolics.

Modern research is focusing on scientifically validating traditional herbal remedies.

Phytopharmaceutical research is exploring novel drug formulations from medicinal plants.

Herbal medicine continues to gain importance as a promising alternative approach for liver disease treatment.[40,41]

7. Pharmacological Activities of Buchanania lanzan

Buchanania lanzan, commonly known as chironji, is an important medicinal plant belonging to the family Anacardiaceae. Different parts of the plant such as seeds, bark, leaves, roots, and fruits are traditionally used in Ayurveda and folk medicine for the treatment of various diseases. The plant contains several bioactive phytoconstituents including flavonoids, tannins, saponins, phenolic compounds, triterpenoids, glycosides, and steroids, which are responsible for its diverse pharmacological activities. Recent scientific studies have validated many of its traditional medicinal uses and demonstrated its therapeutic potential in the management of inflammation, oxidative stress, microbial infections, wounds, and liver disorders.[42,43]

7.1. Antioxidant Activity

Oxidative stress plays an important role in the development of chronic diseases such as liver disorders, diabetes, cancer, cardiovascular diseases, and neurodegenerative conditions. Extracts of *Buchanania lanzan* have shown significant antioxidant activity due to the presence of polyphenols and flavonoids. Various in vitro assays such as DPPH and FRAP methods have confirmed the free radical scavenging potential of seed and bark extracts. Studies reported that methanolic and alcoholic extracts of the seeds possess strong reducing power and effectively neutralize reactive oxygen species (ROS). This antioxidant effect helps protect cellular components from oxidative damage and supports the traditional use of the plant in maintaining health and immunity.[44,45]

7.2. Anti-inflammatory Activity

Inflammation is a protective biological response, but chronic inflammation contributes to many pathological conditions including arthritis, liver injury, diabetes, and cardiovascular diseases. Methanolic extracts of *Buchanania lanzan* kernels demonstrated significant anti-inflammatory activity in experimental animal models such as carrageenan-induced paw edema and formaldehyde-induced arthritis.[46] The anti-inflammatory effect may be attributed to the inhibition of inflammatory mediators and the presence of bioactive compounds such as tannins, triterpenoids, and flavonoids. Bark extracts were also found to suppress reactive oxygen and nitrogen species as well as inducible nitric oxide synthase (iNOS), thereby reducing inflammatory responses.[47]

7.3. Antimicrobial Activity

The increasing resistance of microorganisms to conventional antibiotics has encouraged the search for plant-based antimicrobial agents. Extracts of *Buchanania lanzan* roots, bark, and seeds exhibit antibacterial and antifungal activities against several pathogenic microorganisms. Studies revealed that methanolic root extracts inhibited the growth of both Gram-positive and Gram-negative bacteria.[48] The plant also showed anti-biofilm activity, which is important in controlling persistent microbial infections. Essential oil extracted from the seeds demonstrated antimicrobial activity due to the presence of volatile phytochemicals identified through GC-MS analysis.[49]

7.4. Wound Healing Activity

Traditional healers have long used *Buchanania lanzan* leaves and roots for the treatment of wounds and skin infections. Scientific investigations confirmed that topical application of root extract ointment significantly enhanced wound contraction and increased tensile strength in excision and incision wound models.[50] The wound healing activity is associated with its antimicrobial, antioxidant, and anti-inflammatory properties, which accelerate tissue regeneration and collagen synthesis. The plant's ability to reduce microbial load and biofilm formation further supports its effectiveness in wound management.[51]

7.5. Hepatoprotective Activity

Liver damage caused by drugs, alcohol, toxins, and oxidative stress is a major global health issue. *Buchanania lanzan* possesses hepatoprotective potential mainly because of its antioxidant and anti-inflammatory properties.[52] The bark and seed extracts help reduce oxidative stress in liver tissues and protect hepatocytes from damage caused by free radicals and toxic chemicals. Polyphenolic compounds present in the plant are believed to stabilize liver cell membranes and improve antioxidant defense mechanisms. These findings indicate that the plant may be useful in the prevention and management of liver disorders.[53]

7.6. Immunomodulatory Activity

Some studies suggest that the fruits and seeds of *Buchanania lanzan* possess immunostimulatory properties. The phytochemicals present in the plant may enhance immune responses by improving macrophage activity and reducing oxidative stress. Traditional medicine systems also use the plant for improving general health and resistance against diseases.[54]

7.7. Antidiabetic Activity

The seeds and bark extracts of *Buchanania lanzan* have shown potential antidiabetic effects in preliminary studies. The antioxidant constituents may help reduce oxidative stress associated with diabetes and improve glucose metabolism. Flavonoids and phenolic compounds present in the plant are believed to contribute to its antihyperglycemic activity. However, more clinical and experimental studies are required to establish its exact mechanism of action.[55]

7.8. Antiulcer Activity

Traditional medicinal systems describe the use of *Buchanania lanzan* in gastrointestinal disorders. The plant's antioxidant and anti-inflammatory properties may help protect the gastric mucosa from ulcer formation. Polyphenolic compounds may reduce gastric irritation and oxidative injury, thereby promoting mucosal healing.[56]

Table: Pharmacological Activities of *Buchanania lanzan*

S.No.	Pharmacological Activity	Plant Part Used	Reference
1	Antioxidant activity	Seeds, bark	[57]
2	Anti-inflammatory activity	Kernel, bark	[58]
3	Antimicrobial activity	Roots, seeds	[59]
4	Wound healing activity	Roots, leaves	[60]
5	Hepatoprotective activity	Bark, seeds	[61]
6	Immunomodulatory activity	Fruits, seeds	[62]
7	Antidiabetic activity	Seeds, bark	[63]
8	Antiulcer activity	Bark, leaves	[64]
9	Anti-biofilm activity	Roots	[65]
10	Free radical scavenging activity	Seeds	[66]

Limitations in Current Toxicological Data

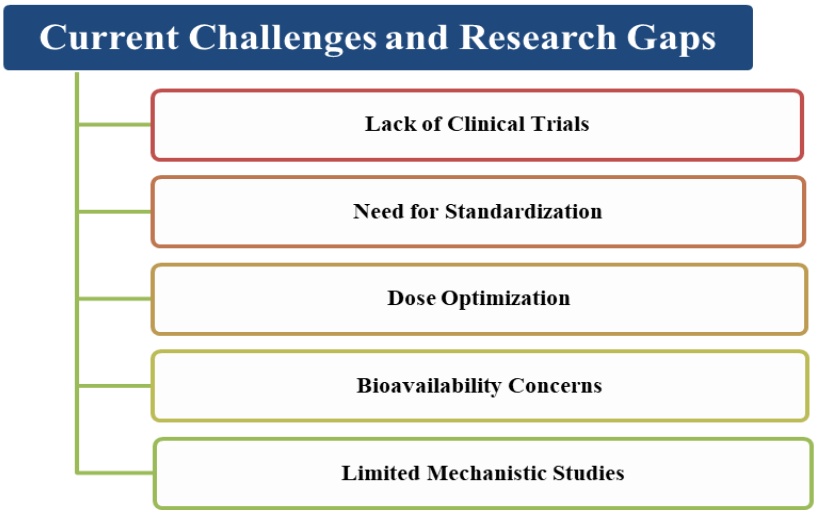
Although *Buchanania lanzan* has shown promising pharmacological and therapeutic activities, the currently available toxicological data are still limited and insufficient for establishing its complete safety profile. Most of the published studies mainly focus on its traditional uses, phytochemical constituents, and pharmacological activities, while detailed toxicity investigations remain inadequate. One of the major limitations is the lack of comprehensive acute, sub-acute, and chronic toxicity studies. Most experimental studies have been conducted only on animal models for short durations, and very few studies have evaluated the long-term safety of repeated administration of *Buchanania lanzan* extracts.[67] Therefore, the possible toxic effects associated with prolonged use are still not clearly understood. Another important limitation is the absence of well-designed clinical toxicological studies in humans. Despite its extensive use in traditional medicine, scientific evidence regarding its safety in human subjects is very limited. Information related to safe dosage range, toxicity threshold, contraindications, and adverse reactions is still lacking. This creates difficulty in developing standardized herbal formulations for therapeutic applications. The toxicity profile of different plant parts such as seeds, bark, leaves, roots, and gum has also not been fully explored. Different extracts may contain varying concentrations of phytochemicals, which can influence their safety and biological activity. In addition, extraction methods, solvents, geographical variations, and environmental conditions may affect the chemical composition of the plant, leading to inconsistency in toxicological findings.[68]

Current literature also lacks detailed studies on genotoxicity, mutagenicity, reproductive toxicity, teratogenicity, and carcinogenicity of *Buchanania lanzan*. Only limited experimental evidence is available regarding its protective effects against oxidative stress and genotoxic damage, but systematic toxicity evaluation is still required. Another challenge is the absence of standardized protocols for toxicity assessment.[69] Many studies use different extraction procedures, animal models, doses, and experimental conditions, making comparison between studies difficult. Furthermore, data regarding herb–drug interactions and the safety of combining *Buchanania lanzan* with conventional medicines are not adequately available. Therefore, future research should focus on detailed toxicological investigations, including long-term animal studies, clinical safety evaluations, dose standardization, and molecular toxicity assessments. Such studies are essential to establish the safety, efficacy, and therapeutic reliability of *Buchanania lanzan* for pharmaceutical and clinical applications.[70]

Current Challenges and Research Gaps

Despite the significant medicinal and pharmacological potential of *Buchanania lanzan*, several challenges and research gaps still limit its therapeutic development and clinical application. Although many experimental studies have demonstrated its antioxidant, anti-inflammatory, antimicrobial, hepatoprotective, and wound healing

properties, most of the available evidence is based on in vitro and animal studies. Comprehensive scientific validation and clinical translation are still lacking.



13. Future Perspectives

Buchanania lanzan has gained considerable attention because of its diverse pharmacological properties and traditional medicinal importance. Although several experimental studies have demonstrated its therapeutic potential, further scientific research is still required to fully explore its clinical applications. Future studies should focus on advanced formulation approaches, clinical validation, isolation of active constituents, and development of effective herbal therapies for liver diseases and other disorders.[71]

Nanoformulations and Targeted Delivery: One of the promising future approaches is the development of nanoformulations of *Buchanania lanzan* extracts and phytoconstituents. Nanotechnology-based drug delivery systems such as nanoparticles, liposomes, nanoemulsions, and phytosomes can improve the solubility, stability, and bioavailability of plant-derived compounds. These systems may also enhance targeted delivery of active constituents directly to diseased tissues, especially the liver, thereby increasing therapeutic effectiveness and reducing side effects. Nanoformulations can further protect sensitive phytochemicals from degradation and improve their controlled release in the body.[72,73]

CONCLUSION

Buchanania lanzan is an important medicinal plant widely recognized for its nutritional and therapeutic properties. The plant, particularly its seed extract, has shown significant hepatoprotective and immunomodulatory potential in various experimental studies. Its protective effects against liver damage are mainly associated with its antioxidant and anti-inflammatory activities, which help reduce oxidative stress, inflammation, and cellular injury in hepatic tissues. In addition, the plant has demonstrated the ability to support immune function by enhancing the body's natural defense mechanisms. The pharmacological activities of *Buchanania lanzan* are largely attributed to the presence of diverse phytochemicals such as flavonoids, phenolic compounds, tannins, glycosides, saponins, and triterpenoids. These bioactive constituents contribute to free radical scavenging activity, membrane stabilization, anti-inflammatory responses, and overall cellular protection. The rich phytochemical composition of the plant supports its traditional use in the treatment of various diseases and highlights its potential as a natural therapeutic agent. Among different plant parts, the seed extract has gained considerable attention due to its nutritional value and broad spectrum of biological activities. The therapeutic promise of *Buchanania lanzan* seed extract suggests its possible application in the development of herbal hepatoprotective formulations and supportive therapies for liver disorders. However, despite encouraging experimental finds in this review paper focus in detailed pharmacological investigations and well-designed clinical studies are still needed to confirm its safety, efficacy, mechanism of action, dose optimization, and long-term therapeutic benefits. Future scientific research will help establish *Buchanania lanzan* as a reliable and standardized medicinal plant for clinical and pharmaceutical applications.

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