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Review Paper

Phytochemistry and Mechanism-Based Pharmacological Potential of *Luffa acutangula* (L.) Roxb.: A Comprehensive Review

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ABSTRACT

Luffa acutangula (L.) Roxb., commonly known as ridge gourd, is an important member of the Cucurbitaceae family widely recognized for its nutritional and medicinal significance. This review provides a comprehensive and up-to-date synthesis of recent advances (2024–2026) in the botanical characteristics, phytochemical composition, pharmacological activities, and safety evaluation of *L. acutangula*. The plant is rich in diverse bioactive compounds, including flavonoids, phenolic acids, triterpenoids, saponins, and phytosterols, which collectively contribute to its broad therapeutic potential. Mechanistic studies indicate that these phytoconstituents exert biological effects through modulation of key molecular pathways such as Nrf2-mediated antioxidant defense, NF- κ B-regulated inflammatory responses, and PI3K/Akt signaling involved in glucose metabolism. Experimental evidence from in vitro and in vivo studies demonstrates significant antioxidant, anti-inflammatory, antidiabetic, hepatoprotective, antihyperlipidemic, and antimicrobial activities. Toxicological evaluations suggest a favorable safety profile, with high LD₅₀ values (>2000 mg/kg) and minimal adverse effects at therapeutic doses. Despite promising preclinical findings, the clinical translation of *L. acutangula* remains limited due to the lack of standardized extracts, insufficient molecular-level investigations, and absence of well-designed clinical trials. Future research should focus on bioactive compound isolation, mechanistic validation using advanced omics technologies, and development of novel drug delivery systems, including nanotechnology-based approaches. Overall, *L. acutangula* represents a promising candidate for the development of functional foods and plant-based therapeutics, warranting further investigation to establish its clinical efficacy and safety.

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INTRODUCTION

Natural products continue to play a pivotal role in modern drug discovery and development, particularly as the demand for safer, plant-derived therapeutic agents increases¹. Within this context, the Cucurbitaceae family has attracted considerable attention due to its rich repository of bioactive compounds and diverse pharmacological activities. Among its members, *Luffa acutangula* (L.) Roxb., commonly known as ridge gourd, has emerged as a plant of significant nutritional and medicinal relevance. Native to tropical and subtropical regions, it is widely cultivated across South and Southeast Asia, as well as parts of Africa, where it is consumed as a vegetable and utilized in traditional medicine systems^{2,3}.

Historically, *L. acutangula* has been integrated into traditional healing practices such as Ayurveda and folk medicine for the management of various ailments, including jaundice, diabetes, inflammatory disorders, gastrointestinal disturbances, and dermatological conditions⁴. Different plant parts—fruits, leaves, seeds, and roots—are employed either individually or in combination, reflecting a broad therapeutic spectrum. While these uses are deeply rooted in ethnomedicinal knowledge, recent scientific investigations have begun to systematically evaluate and validate these claims, thereby bridging the gap between traditional practices and evidence-based medicine^{5,6}.

Phytochemical investigations conducted over the past few years have revealed that *L. acutangula* possesses a complex and diverse chemical composition. Advanced analytical techniques such as gas chromatography–mass spectrometry (GC–MS), liquid chromatography–mass spectrometry (LC–MS), and high-performance liquid chromatography (HPLC) have enabled the identification of numerous secondary metabolites, including flavonoids, phenolic acids, triterpenoids,

saponins, alkaloids, and sterols. These compounds are widely recognized for their biological activities and are believed to underlie the therapeutic potential of the plant. For instance, phenolic compounds and flavonoids contribute significantly to antioxidant activity, while triterpenoids and saponins are associated with anti-inflammatory and metabolic regulatory effects^{5,7}. In addition to secondary metabolites, *L. acutangula* is also a valuable source of essential nutrients, including vitamins, minerals, dietary fiber, and amino acids. The fruit, in particular, is low in calories yet rich in micronutrients, making it suitable for incorporation into functional diets aimed at preventing chronic diseases. Recent nutritional analyses emphasize its potential role as a functional food that not only provides basic nourishment but also confers health benefits beyond conventional dietary value³. This dual role—nutritional and therapeutic—positions *L. acutangula* at the interface of food science and pharmacology⁸.

The growing body of pharmacological evidence further supports the medicinal significance of *L. acutangula*. Recent in vitro and in vivo studies have demonstrated a wide range of biological activities, including antioxidant, anti-inflammatory, antidiabetic, hepatoprotective, antihyperlipidemic, and antimicrobial effects. These activities are often attributed to the synergistic interactions of multiple phytoconstituents rather than a single active compound. For example, antioxidant activity is primarily linked to the presence of phenolic compounds that scavenge reactive oxygen species (ROS), thereby reducing oxidative stress—a key factor in the pathogenesis of chronic diseases. Similarly, antidiabetic effects are associated with the modulation of glucose metabolism, enhancement of insulin sensitivity, and inhibition of carbohydrate-digesting enzymes^{2,5}.



Recent studies have also highlighted the influence of extraction methods and processing conditions on the phytochemical profile and bioactivity of *L. acutangula*. Solvent polarity, extraction techniques, and thermal processing can significantly affect the yield and stability of bioactive compounds. For instance, methanolic and ethyl acetate extracts have been reported to exhibit higher antioxidant and lipid-lowering activities compared to aqueous extracts. Moreover, thermal treatments can lead to either degradation or enhancement of certain phytochemicals, depending on the processing parameters⁹. These findings underscore the importance of optimizing extraction and processing conditions to maximize therapeutic efficacy.

Compared to other members of the Cucurbitaceae family, *L. acutangula* stands out due to its relatively diverse phytochemical composition and broad spectrum of pharmacological activities. While plants such as *Momordica charantia* and *Cucurbita pepo* have been extensively studied, *L. acutangula* remains relatively underexplored, particularly in terms of its molecular mechanisms of action and clinical applications. This presents an opportunity for further research aimed at isolating specific bioactive compounds, elucidating their mechanisms, and evaluating their safety and efficacy in human populations^{2,6}.

Despite promising preclinical findings, several challenges hinder the translation of *L. acutangula* into mainstream therapeutic applications. These include the lack of standardized extraction protocols, limited clinical trials, and insufficient toxicological data. Additionally, variations in phytochemical composition due to geographical, environmental, and genetic factors complicate the reproducibility of results. Addressing these challenges requires a multidisciplinary approach that integrates phytochemistry, pharmacology, biotechnology, and clinical research.

In light of these considerations, the present review aims to provide a comprehensive and up-to-date overview of the phytochemical composition and pharmacological properties of *Luffa acutangula*, with a particular emphasis on recent advances reported between 2024 and 2026. By synthesizing current knowledge and identifying existing research gaps, this review seeks to contribute to the growing interest in plant-based therapeutics and to support future investigations into the development of novel drugs and functional foods derived from this promising plant species.

2. Botanical Description and Distribution

Luffa acutangula (L.) Roxb. belongs to the family Cucurbitaceae, a group of plants widely recognized for their economic and medicinal importance. Commonly known as ridge gourd or angled luffa, this species is a fast-growing, annual climbing vine characterized by elongated, ridged fruits and tendrilled stems that enable it to spread over supporting structures. Morphologically, the plant exhibits palmately lobed leaves, yellow unisexual flowers, and cylindrical fruits with distinct longitudinal ridges. The seeds are typically black, flattened, and embedded within a fibrous pulp that becomes more prominent upon maturation^{2,5}.

The species is predominantly distributed across tropical and subtropical regions, with extensive cultivation in countries such as India, China, Indonesia, Thailand, and other parts of Southeast Asia. It is also grown in several African regions, where it adapts well to warm climates with moderate rainfall and well-drained soils. The widespread distribution of *L. acutangula* reflects its adaptability to diverse agro-climatic conditions and its importance as both a food crop and a medicinal resource^{3,6}.

Different parts of the plant are utilized for various purposes, highlighting its multifunctional value.



The immature fruits are commonly consumed as a vegetable due to their nutritional content and mild flavor, while the leaves, seeds, and roots are traditionally used in herbal medicine. These plant parts have been associated with therapeutic applications in the management of metabolic disorders, liver conditions, and inflammatory diseases. Recent studies have emphasized that the bioactive compounds present in these tissues contribute significantly to their pharmacological properties^{5,7}.

The plant thrives under tropical climatic conditions, requiring adequate sunlight, warm temperatures, and sufficient moisture for optimal growth. Its cultivation is relatively straightforward, which has contributed to its widespread use in both subsistence and commercial agriculture. Beyond its dietary role, *L. acutangula* is increasingly recognized for its potential in nutraceutical and pharmaceutical applications, driven by growing scientific evidence supporting its bioactivity^{2,3}.

3. Taxonomy and Microscopic Anatomy

3.1 Taxonomic Classification

Luffa acutangula (L.) Roxb. is taxonomically classified within the Cucurbitaceae family, a large group of flowering plants known for their climbing habit and economically important fruits. Its systematic classification is as follows:

- **Kingdom:** Plantae
- **Clade:** Angiosperms
- **Clade:** Eudicots
- **Order:** Cucurbitales
- **Family:** Cucurbitaceae
- **Genus:** *Luffa*
- **Species:** *Luffa acutangula* (L.) Roxb.

The genus *Luffa* comprises several species, among which *L. acutangula* and *Luffa cylindrica* are the most widely cultivated. Within the family, *L. acutangula* is distinguished by its characteristic

ridged fruits, climbing growth habit, and specific floral morphology. Recent taxonomic studies within Cucurbitaceae have utilized molecular phylogenetic approaches, confirming the placement of *Luffa* species within a well-defined clade and highlighting their evolutionary relationships with other economically important genera^{2,6,7}.

3.2 Microscopic Anatomy

Microscopic evaluation of *L. acutangula* provides valuable insights into its structural organization and supports pharmacognostic identification, which is essential for quality control in herbal drug development.

3.2.1 Leaf Anatomy

The leaf of *L. acutangula* typically exhibits a **dorsiventral structure**, with distinct upper (adaxial) and lower (abaxial) epidermal layers. The epidermis is composed of a single layer of compactly arranged cells covered by a thin cuticle. **Stomata are predominantly present on the abaxial surface**, indicating a hypostomatic leaf type, which is common among Cucurbitaceae members.

The mesophyll is differentiated into:

- **Palisade parenchyma** (rich in chloroplasts, responsible for photosynthesis)
- **Spongy parenchyma** (loosely arranged cells facilitating gas exchange)

Vascular bundles are collateral and surrounded by parenchymatous sheath cells. The presence of **trichomes (unicellular or multicellular hair-like structures)** has also been reported, which may play a role in defense and transpiration regulation^{2,5}.

3.2.2 Stem Anatomy

The stem shows typical features of a **dicotyledonous climbing plant**. In transverse section, it consists of:



- An outer **epidermis** with cuticle
- A **collenchymatous hypodermis**, providing mechanical support
- A **parenchymatous cortex**
- **Vascular bundles arranged in a ring**, which are bicollateral—a characteristic feature of Cucurbitaceae

The vascular bundles consist of:

- External and internal phloem
- Xylem elements (vessels, tracheids)

A well-developed **pith region** occupies the central part of the stem. The presence of bicollateral vascular bundles is a key diagnostic anatomical feature for identifying members of this family^{6,7}.

3.2.3 Root Anatomy

The root exhibits a typical **dicot root structure** with:

- A multilayered **epidermis (epiblema)**
- A wide **cortex composed of parenchymatous cells**
- A distinct **endodermis with Casparian strips**
- A well-defined **pericycle**

The vascular system is radial, with alternating xylem and phloem strands. Secondary growth may occur due to the activity of vascular cambium, leading to increased girth. These features support efficient water and nutrient transport and contribute to the plant's adaptability to various soil conditions².

3.2.4 Fruit and Seed Anatomy

The fruit of *L. acutangula* shows a **multilayered pericarp**, consisting of:

- **Exocarp**: outer protective layer
- **Mesocarp**: fleshy region rich in nutrients
- **Endocarp**: inner fibrous network, especially prominent in mature fruits

The seeds are characterized by:

- A **hard seed coat (testa)**

- Presence of **endosperm and well-developed embryo**

Microscopic studies reveal that the fibrous network in mature fruits is composed mainly of **cellulose-rich vascular tissues**, which contribute to its traditional use as a natural sponge. Additionally, seed tissues contain storage compounds such as proteins and lipids, which are relevant for both nutritional and pharmacological applications^{3,5}.

3.3 Pharmacognostic Significance

The anatomical characteristics of *L. acutangula*, particularly the presence of bicollateral vascular bundles, trichomes, and distinct mesophyll organization, are important diagnostic markers. These features are widely used in pharmacognostic standardization to ensure the authenticity and quality of plant-derived raw materials. With increasing interest in herbal formulations, such microscopic parameters play a crucial role in preventing adulteration and ensuring reproducibility in phytopharmaceutical research⁶.

4. Phytochemistry of *Luffa acutangula*

4.1 Overview of Phytochemical Profile

Recent investigations into *Luffa acutangula* (L.) Roxb. reveal a chemically diverse profile comprising both primary and secondary metabolites that contribute to its nutritional and therapeutic properties. Advances in chromatographic and spectrometric techniques—such as GC–MS, LC–MS, and HPLC—have enabled the identification and characterization of numerous bioactive constituents distributed across different plant parts, including fruits, leaves, seeds, and roots. These studies highlight the presence of flavonoids, phenolic acids, triterpenoids, saponins, alkaloids, sterols, proteins, and essential fatty



acids, each playing a role in the plant's pharmacological activities^{2,5}.

The phytochemical composition varies depending on factors such as plant maturity, geographical origin, and extraction methods. Notably, polar solvents such as methanol and ethanol have been shown to extract higher concentrations of phenolics and flavonoids, which are primarily responsible for antioxidant and anti-inflammatory activities^{7,10}.

4.2 Major Phytochemical Classes

4.2.1 Flavonoids and Phenolic Compounds

Flavonoids and phenolic acids represent one of the most extensively studied groups in *L. acutangula*. These compounds are known for their strong antioxidant capacity and ability to modulate various biochemical pathways⁴.

Commonly reported compounds include:

- **Quercetin**
- **Kaempferol**
- **Gallic acid**
- **Caffeic acid**
- **Ferulic acid**

These molecules act as **free radical scavengers**, reducing oxidative stress and preventing cellular damage. Recent studies emphasize their role in chronic disease prevention, particularly in metabolic and inflammatory disorders^{3,5}.

4.2.2 Triterpenoids and Saponins

Triterpenoids and saponins are important contributors to the plant's pharmacological effects, especially in anti-inflammatory and hepatoprotective activities.

Reported constituents include:

- **Oleanolic acid derivatives**
- **Cucurbitacin-like compounds**

• **Triterpenoid saponins**

These compounds exhibit **membrane-stabilizing, anti-inflammatory, and anticancer properties**, often through modulation of signaling pathways such as NF- κ B (Thomas & Arunachalam, 2025).

4.2.3 Alkaloids

Alkaloids are present in moderate quantities and contribute to various biological effects, including antimicrobial and analgesic activities. Though less extensively characterized than other phytochemicals, their presence adds to the pharmacological complexity of the plant (Bano et al., 2025).

4.2.4 Sterols and Lipids

Phytosterols and fatty acids identified in *L. acutangula* include:

- **β -sitosterol**
- **Stigmasterol**
- **Linoleic acid**
- **Oleic acid**

These compounds are associated with **cholesterol-lowering and cardioprotective effects**, supporting the plant's role in managing hyperlipidemia (Borecka & Karaś, 2025).

4.2.5 Proteins and Amino Acids

The plant is also a source of essential amino acids such as:

- **Arginine**
- **Alanine**
- **Cysteine**

Additionally, compounds like **pipecolic acid and phytin** have been reported, which may play roles in metabolic regulation and antioxidant defense (Thomas & Arunachalam, 2025).

4.3 Phytochemical Distribution in Plant Parts



Table 1: Different plant parts exhibit distinct phytochemical profiles:

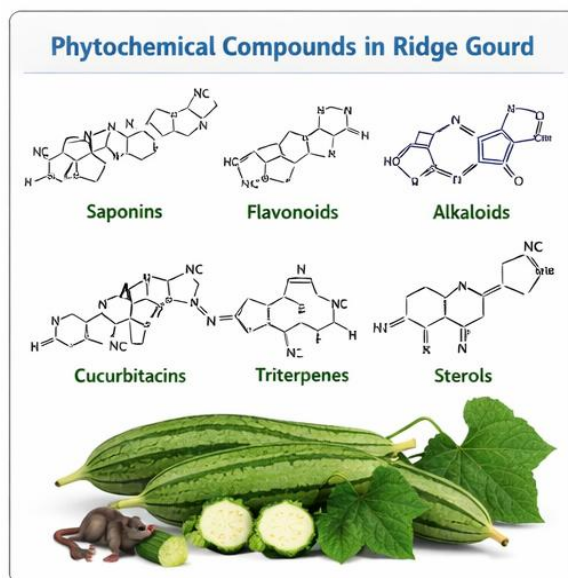
Plant Part	Major Compounds Identified	Key Activities
Fruits	Flavonoids, phenolics, vitamins	Antioxidant, nutritional
Leaves	Saponins, alkaloids, phenolics	Anti-inflammatory, lipid-lowering
Seeds	Fatty acids, proteins, sterols	Nutritional, cardioprotective
Roots	Alkaloids, triterpenoids	Antimicrobial, traditional uses

This variation highlights the importance of selecting appropriate plant material for specific therapeutic applications (Madhumathi et al., 2026).

4.4 Representative Phytochemical Compounds¹¹

Table 2: Key Phytochemicals Identified in *Luffa acutangula*

Compound Name	Chemical Class	Reported Activity	Plant Part
Quercetin	Flavonoid	Antioxidant, anti-inflammatory	Leaves, fruits
Kaempferol	Flavonoid	Anticancer, antioxidant	Leaves
Gallic acid	Phenolic acid	Free radical scavenger	Fruits
Caffeic acid	Phenolic acid	Anti-inflammatory	Leaves
Oleanolic acid	Triterpenoid	Hepatoprotective	Roots, leaves
Cucurbitacin	Triterpenoid	Anticancer	Fruits
β-sitosterol	Sterol	Hypolipidemic	Seeds
Linoleic acid	Fatty acid	Cardioprotective	Seeds
Pipecolic acid	Amino acid derivative	Metabolic regulation	Fruits



4.6 Influence of Extraction Techniques

Extraction methods significantly influence phytochemical yield and activity:

- **Methanolic extracts** → high phenolic content

- **Ethyl acetate fractions** → strong antioxidant and lipid-lowering effects
- **Aqueous extracts** → moderate bioactivity but safer for traditional use

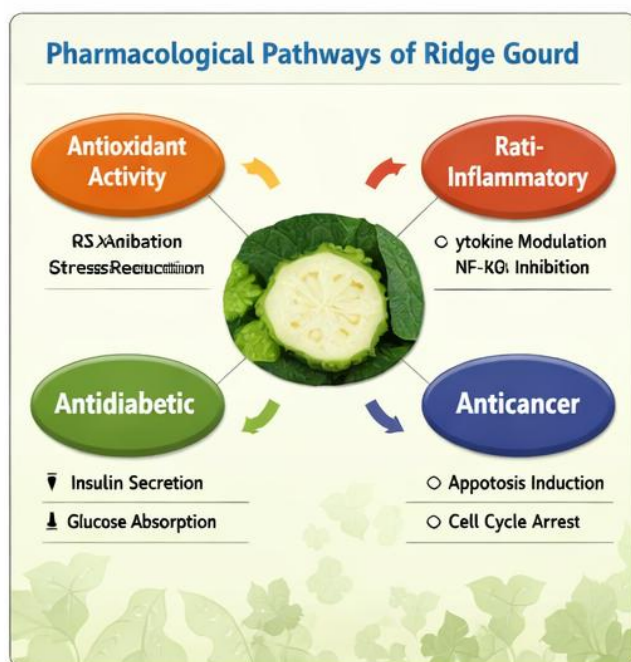
Recent work emphasizes **bioactivity-guided fractionation** as a key strategy for isolating potent compounds (Bano et al., 2025; Chithra et al., 2025).

5. Mechanism-Based Pharmacology of *Luffa acutangula*

5.1 Overview of Mechanistic Insights

The pharmacological effects of *Luffa acutangula* (L.) Roxb. are mediated through a network of

biochemical and molecular pathways, largely driven by its diverse phytochemical composition. Rather than acting via a single target, the plant exhibits **multi-target and synergistic mechanisms**, which are typical of phytomedicines. Recent studies indicate that its bioactive constituents—particularly flavonoids, phenolics, and triterpenoids—modulate oxidative stress, inflammatory signaling, metabolic pathways, and cellular homeostasis¹².



5.2 Antioxidant Mechanisms

Oxidative stress is a central factor in the development of chronic diseases, including diabetes, cardiovascular disorders, and cancer. Extracts of *L. acutangula* have demonstrated strong antioxidant activity through multiple mechanisms¹³:

Key Pathways:

- **Direct scavenging of reactive oxygen species (ROS)**
- **Upregulation of endogenous antioxidant enzymes:**
 - Superoxide dismutase (SOD)
 - Catalase (CAT)
 - Glutathione peroxidase (GPx)

- Catalase (CAT)
- Glutathione peroxidase (GPx)

Mechanistic Insight:

Phenolic compounds such as quercetin and gallic acid donate electrons to neutralize free radicals, thereby preventing lipid peroxidation and DNA damage. Additionally, these compounds may activate the **Nrf2 (nuclear factor erythroid 2-related factor 2) pathway**, leading to enhanced expression of antioxidant defense genes^{13,14}.

5.3 Anti-inflammatory Mechanisms

Inflammation is closely linked to oxidative stress and is regulated by several signaling pathways. *L.*

acutangula exhibits anti-inflammatory effects by modulating key mediators and transcription factors.

Key Pathways:

- **NF-κB (nuclear factor kappa B) inhibition**
- **Downregulation of pro-inflammatory cytokines:**
 - TNF-α
 - IL-6
 - IL-1β
- **Inhibition of COX and LOX enzymes**

Mechanistic Insight:

Triterpenoids and flavonoids present in the plant suppress the activation of NF-κB, a central regulator of inflammation. This leads to reduced transcription of inflammatory genes and decreased production of mediators such as prostaglandins and nitric oxide. The combined antioxidant and anti-inflammatory effects create a protective environment against chronic inflammatory diseases¹⁵⁻¹⁷.

5.4 Antidiabetic Mechanisms

The antidiabetic activity of *L. acutangula* is supported by its ability to regulate glucose metabolism and improve insulin function.

Key Pathways:

- **Inhibition of carbohydrate-digesting enzymes:**
 - α-amylase
 - α-glucosidase
- **Enhancement of insulin sensitivity**
- **Modulation of glucose uptake pathways (GLUT transporters)**

Mechanistic Insight:

Flavonoids and saponins play a major role by delaying carbohydrate digestion and absorption, thereby reducing postprandial hyperglycemia. Additionally, these compounds may influence insulin signaling pathways, including **PI3K/Akt signaling**, improving glucose uptake in peripheral tissues. Antioxidant effects further protect pancreatic β-cells from oxidative damage¹⁸.

5.5 Hepatoprotective Mechanisms

Liver protection is another well-documented effect of *L. acutangula*, particularly against toxin-induced damage.

Key Pathways:

- **Reduction of oxidative stress in hepatic cells**
- **Stabilization of hepatocyte membranes**
- **Regulation of detoxification enzymes**

Mechanistic Insight:

Bioactive compounds reduce levels of liver enzymes such as ALT and AST, indicating improved liver function. The hepatoprotective effect is largely attributed to antioxidant activity and the ability to prevent lipid peroxidation in hepatic tissues. Triterpenoids may also contribute by enhancing cellular repair mechanisms¹⁹.

5.6 Antihyperlipidemic Mechanisms

L. acutangula has shown promising effects in lipid metabolism regulation.

Key Pathways:

- **Reduction of LDL and triglycerides**
- **Increase in HDL cholesterol**
- **Inhibition of lipid peroxidation**

Mechanistic Insight:

Phytosterols such as β-sitosterol compete with cholesterol absorption in the intestine, thereby reducing serum cholesterol levels. Additionally,



antioxidant compounds prevent oxidative modification of lipids, which is a key step in atherosclerosis development.

5.7 Antimicrobial Mechanisms

The antimicrobial activity of *L. acutangula* is attributed to its ability to disrupt microbial integrity and function.

Key Mechanisms:

- Disruption of microbial cell membranes
- Inhibition of enzyme systems essential for microbial survival

- Interference with DNA replication

Mechanistic Insight:

Alkaloids, phenolics, and saponins contribute to antimicrobial effects by altering membrane permeability and inhibiting microbial growth. These properties make the plant a potential candidate for developing natural antimicrobial agents¹⁵.

5.8 Integrated Mechanistic Pathway

Simplified Mechanism Flow:

Phytochemicals (Flavonoids, Phenolics, Triterpenoids)



Primary Targets:

- ROS scavenging
- Enzyme inhibition (α -amylase, COX)
 - Cytokine suppression



Signaling Pathways Modulated:

- Nrf2 $\rightarrow$ antioxidant defense

- NF- κ B $\rightarrow$ inflammation suppression
- PI3K/Akt $\rightarrow$ glucose metabolism



Biological Outcomes:

- Reduced oxidative stress
- Decreased inflammation
- Improved glucose and lipid metabolism
 - Cellular protection

6. Pharmacological Activities of *Luffa acutangula*

6.1 Overview

A growing body of experimental evidence supports the pharmacological potential of *Luffa acutangula* (L.) Roxb., validating many of its traditional medicinal uses. Recent in vitro and in vivo studies demonstrate that extracts derived from different parts of the plant exhibit a broad spectrum of biological activities, including antioxidant, anti-inflammatory, antidiabetic, hepatoprotective, antihyperlipidemic, and antimicrobial effects. These activities are largely attributed to the synergistic action of phytochemicals such as flavonoids, phenolics, saponins, and triterpenoids (Bano et al., 2025; Madhumathi et al., 2026).

6.2 Antioxidant Activity

Oxidative stress plays a central role in the pathogenesis of chronic diseases. Several studies have evaluated the antioxidant capacity of *L. acutangula* using standard assays such as DPPH, ABTS, and FRAP.

Table 3: Experimental Evidence

Study	Extract/Part Used	Method	Key Findings
Yadav & Yadav (2024)	Fruit (thermal-treated)	DPPH, FRAP	Significant radical scavenging; activity influenced by heat processing
Bano et al. (2025)	Leaf (methanol extract)	DPPH	High antioxidant activity due to phenolic content
Chithra et al. (2025)	Whole plant	ABTS	Dose-dependent antioxidant response



Interpretation

The antioxidant activity is strongly correlated with phenolic and flavonoid content. Methanolic extracts generally show higher activity, suggesting the importance of solvent selection in bioactive compound extraction.

6.3 Anti-inflammatory Activity

Inflammation is a key factor in many chronic conditions. *L. acutangula* extracts have demonstrated anti-inflammatory effects through inhibition of inflammatory mediators.

Table 4: Experimental Evidence

Study	Model	Extract Used	Key Findings
Bano et al. (2025)	In vitro (enzyme inhibition)	Leaf extract	Inhibition of COX enzymes and nitric oxide production
Thomas & Arunachalam (2025)	In vivo	Fruit extract	Reduced inflammatory markers (TNF- α , IL-6)
Madhumathi et al. (2026)	Animal model	Leaf extract	Decreased edema and inflammatory response

Interpretation

The anti-inflammatory effects are mediated through suppression of cytokines and inhibition of key enzymes such as COX and LOX, consistent with the presence of triterpenoids and flavonoids.

6.4 Antidiabetic Activity

The plant has been extensively studied for its role in glucose regulation and diabetes management.

Table 5: Experimental Evidence

Study	Model	Extract/Part	Key Findings
Madhumathi et al. (2026)	Diabetic rats	Fruit extract	Significant reduction in blood glucose levels
Bano et al. (2025)	In vitro enzyme assay	Leaf extract	Inhibition of α -amylase and α -glucosidase
Chithra et al. (2025)	Animal model	Methanol extract	Improved insulin sensitivity

Interpretation

The antidiabetic activity is associated with enzyme inhibition, improved insulin signaling, and antioxidant protection of pancreatic β -cells¹³.

6.5 Hepatoprotective Activity

Liver-protective effects of *L. acutangula* have been demonstrated in toxin-induced liver injury models.

Table 6: Experimental Evidence

Study	Model	Extract Used	Key Findings
Bano et al. (2025)	CCl ₄ -induced toxicity	Leaf extract	Reduced ALT, AST levels
Madhumathi et al. (2026)	Animal model	Fruit extract	Improved liver histology
Thomas & Arunachalam (2025)	Experimental study	Whole plant extract	Enhanced antioxidant defense in liver

Interpretation



Hepatoprotective effects are mainly due to antioxidant properties and stabilization of hepatocyte membranes.

6.6 Antihyperlipidemic Activity

Recent studies highlight the lipid-lowering potential of *L. acutangula*.

Table 7: Experimental Evidence

Study	Model	Extract Used	Key Findings
Bano et al. (2025)	Hyperlipidemic rats	Ethyl acetate extract	Decreased LDL, triglycerides; increased HDL
Borecka & Karaš (2025)	Review analysis	Fruit	Cardioprotective effects due to phytosterols

Interpretation

The presence of phytosterols and antioxidants contributes to improved lipid metabolism and reduced cardiovascular risk.

6.7 Antimicrobial Activity

The antimicrobial properties of *L. acutangula* have been evaluated against various bacterial strains.

Table 8: Experimental Evidence

Study	Microorganisms Tested	Extract Used	Key Findings
Bano et al. (2025)	<i>E. coli</i> , <i>S. aureus</i>	Leaf extract	Moderate antibacterial activity
Thomas & Arunachalam (2025)	Gram-positive & Gram-negative bacteria	Fruit extract	Growth inhibition observed

Interpretation

The antimicrobial effects are attributed to alkaloids, saponins, and phenolic compounds that disrupt microbial cell membranes.

6.8 Other Pharmacological Activities

Additional biological activities reported include:

- **Anticancer activity:** Preliminary in vitro cytotoxic effects against cancer cell lines

- **Anthelmintic activity:** Traditional use supported by experimental evidence
 - **Gastroprotective effects:** Reduction in ulcer formation in animal models
- Although promising, these areas require further investigation to establish clinical relevance⁴.

7. Toxicity and Safety Evaluation of *Luffa acutangula*

7.1 Overview of Safety Profile

The safety evaluation of *Luffa acutangula* (L.) Roxb. is essential for its development as a nutraceutical or therapeutic agent. Although the plant is widely consumed as a vegetable and used in traditional medicine, scientific validation of its toxicity profile remains relatively limited. Available studies suggest that *L. acutangula* exhibits **low acute toxicity**, particularly when consumed in its natural dietary form. However, the safety profile may vary depending on factors such as plant part, extraction method, dosage, and duration of exposure (Bano et al., 2025; Madhumathi et al., 2026).

7.2 Acute Toxicity Studies

Acute toxicity studies are typically conducted to determine the median lethal dose (LD₅₀), which provides an estimate of the dose required to cause mortality in 50% of experimental animals.



Table 9: Experimental Evidence

Study	Extract/Part Used	Model	LD ₅₀ / Dose Range	Observations
Madhumathi et al. (2026)	Fruit extract (aqueous)	Rodents	>2000 mg/kg (oral)	No mortality; considered safe
Bano et al. (2025)	Leaf extract (methanol)	Rats	>2000 mg/kg	No significant behavioral changes
Thomas & Arunachalam (2025)	Whole plant extract	Animal model	Not specified (high-dose tolerance)	No acute toxicity reported

Interpretation

According to OECD toxicity classification, substances with LD₅₀ values greater than 2000 mg/kg are considered **relatively non-toxic**, suggesting that *L. acutangula* extracts are generally safe at lower doses.

7.3 Subacute and Chronic Toxicity

Subacute and chronic toxicity studies provide insights into the effects of repeated exposure over time.

Table 10: Experimental Evidence

Study	Duration	Dose	Key Findings
Bano et al. (2025)	28 days	200–500 mg/kg	No significant changes in hematological or biochemical parameters
Madhumathi et al. (2026)	Subacute	Moderate doses	Normal liver and kidney function markers
Borecka & Karaś (2025)	Review data	Dietary intake	No adverse effects reported in humans

Interpretation

Repeated administration of *L. acutangula* extracts at moderate doses does not appear to produce

significant toxicity, indicating a favorable safety profile for short-term use. However, long-term safety data remain limited.

7.4 Organ-Specific Toxicity

Liver and Kidney Function

- Studies report **no significant elevation in liver enzymes (ALT, AST)**
- Kidney markers such as **creatinine and urea remain within normal ranges**

Histopathological Findings

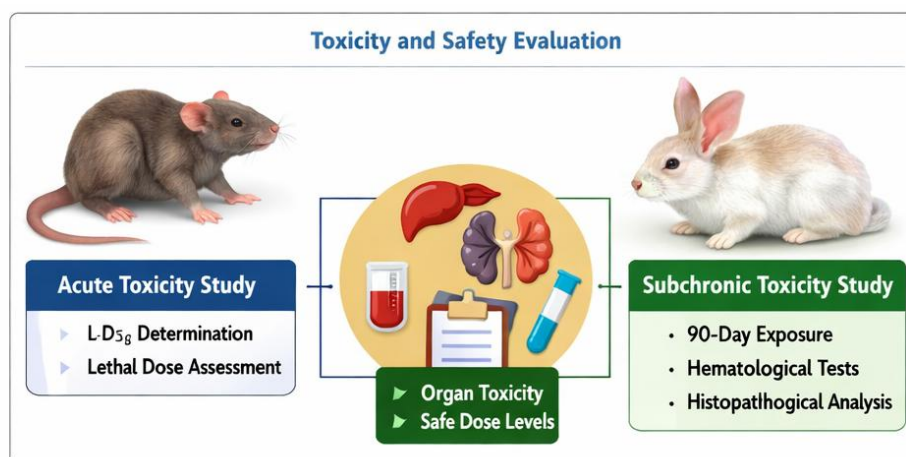
- No major tissue damage observed in liver or kidney at therapeutic doses
 - Mild changes may occur at very high concentrations, suggesting dose-dependent effects
- These findings support the **hepatoprotective rather than hepatotoxic nature** of the plant at appropriate doses (Bano et al., 2025).

7.5 Cytotoxicity and Genotoxicity

Limited in vitro studies have evaluated cytotoxic effects:

- Mild cytotoxicity observed at high concentrations in certain cell lines
- No strong evidence of genotoxicity reported in recent literature

However, these findings are preliminary and require further validation using standardized assays²⁰.



7.6 Potential Toxic Constituents and Risks

While generally safe, certain considerations should be noted:

- **Cucurbitacin-like compounds**, present in trace amounts, may exhibit toxicity at high concentrations
- Excessive consumption of concentrated extracts may lead to:
 - Gastrointestinal discomfort
 - Mild irritation or toxicity

Variability in phytochemical composition due to environmental factors may also influence safety.

7.7 Human Safety and Dietary Use

As a commonly consumed vegetable, *L. acutangula* is considered safe for human consumption under normal dietary conditions. No significant adverse effects have been reported in populations where it is regularly included in the diet. Its use in traditional medicine further supports its safety, although **standardized dosing guidelines are lacking** (Borecka & Karaś, 2025).

7.8 Limitations and Research Gaps

Despite encouraging findings, several limitations remain:

- Lack of **well-designed chronic toxicity studies**
- Limited **clinical safety data in humans**

- Absence of **standardized extract formulations**
- Insufficient data on **drug–herb interactions**

Addressing these gaps is essential for advancing *L. acutangula* toward clinical and pharmaceutical applications.

8. Research Gaps and Future Perspectives

8.1 Overview

Although *Luffa acutangula* (L.) Roxb. has demonstrated considerable pharmacological potential in recent years, its transition from traditional use to evidence-based therapeutic application remains incomplete. Current research is largely confined to **in vitro and in vivo preclinical studies**, with limited translational and clinical validation. Addressing these gaps is critical to fully harness the plant's medicinal value and integrate it into modern healthcare systems (Bano et al., 2025; Madhumathi et al., 2026).

8.2 Key Research Gaps

8.2.1 Lack of Clinical Trials

One of the most significant limitations in the current body of research is the **absence of well-designed clinical trials**. While experimental models have demonstrated promising antioxidant,

antidiabetic, and hepatoprotective effects, there is insufficient evidence regarding:

- Efficacy in human populations
- Optimal therapeutic dosage
- Long-term safety and tolerability

Without clinical validation, the pharmacological potential of *L. acutangula* cannot be reliably translated into therapeutic applications. Future studies must prioritize **randomized controlled trials (RCTs)** to establish its clinical relevance.

8.2.2 Limited Standardization of Extracts

Another major challenge is the **lack of standardized extraction protocols and formulations**. Variations in:

- Solvent systems
- Extraction techniques
- Plant part selection
- Geographical origin

lead to inconsistencies in phytochemical composition and biological activity. This variability makes it difficult to reproduce results across studies and hinders regulatory approval. Establishing **standardized extraction methods and quality control parameters** is essential for ensuring consistency and reliability (Chithra et al., 2025).

8.2.3 Need for Bioactive Compound Isolation

Although several classes of phytochemicals have been identified, **specific bioactive compounds responsible for distinct pharmacological effects are not fully characterized**. Most studies rely on crude extracts, which may mask the activity of individual constituents.

Future research should focus on:

- Bioactivity-guided fractionation
- Isolation and purification of active compounds
- Structural elucidation using advanced spectroscopic techniques

Such efforts will facilitate **target-based drug discovery** and improve understanding of structure–activity relationships (Bano et al., 2025).

8.2.4 Insufficient Mechanistic and Molecular Studies

While general mechanisms such as antioxidant and anti-inflammatory pathways have been proposed, **detailed molecular-level investigations remain limited**. There is a need for:

- Gene expression studies
- Proteomic and metabolomic analyses
- Identification of specific molecular targets

Advanced approaches such as **omics technologies and molecular docking studies** can provide deeper insights into the mechanisms of action and help validate therapeutic claims (Thomas & Arunachalam, 2025).

8.3 Future Perspectives

8.3.1 Integration into Drug Development Pipelines

Given its diverse pharmacological activities, *L. acutangula* represents a promising candidate for **natural product-based drug discovery**. Future efforts should aim to:

- Identify lead compounds with high bioactivity
- Conduct preclinical pharmacokinetic and toxicity studies
- Develop standardized formulations for therapeutic use

Collaboration between phytochemists, pharmacologists, and pharmaceutical industries will be crucial for advancing this plant through the drug development pipeline.

8.3.2 Nanotechnology-Based Delivery Systems

One of the emerging strategies to enhance the therapeutic potential of plant-derived compounds



is the use of **nanotechnology-based delivery systems**. Encapsulation of bioactive compounds into nanoparticles can:

- Improve bioavailability and stability
- Enable targeted drug delivery
- Reduce toxicity and side effects

Applying nanotechnology to *L. acutangula*-derived compounds could significantly enhance their clinical applicability and therapeutic efficiency (Borecka & Karaś, 2025).

8.3.3 Clinical Validation and Translational Research

To bridge the gap between laboratory findings and real-world applications, **clinical validation is essential**. Future research should focus on:

- Designing well-structured clinical trials
- Evaluating efficacy in specific disease conditions (e.g., diabetes, liver disorders)
- Establishing standardized dosage regimens

In addition, **translational research approaches** that integrate laboratory findings with clinical practice will be key to unlocking the full therapeutic potential of *L. acutangula*.

8.3.4 Functional Food and Nutraceutical Development

Given its nutritional and pharmacological properties, *L. acutangula* has strong potential as a **functional food ingredient**. Future studies can explore:

- Fortified food products
- Dietary supplements
- Synergistic formulations with other medicinal plants

Such applications may offer preventive health benefits and contribute to the management of chronic diseases.

CONCLUSION

Luffa acutangula (L.) Roxb. has emerged as a scientifically relevant medicinal plant with substantial ethnopharmacological importance and growing experimental validation. The present review consolidates recent findings (2024–2026) on its botanical characteristics, phytochemical composition, pharmacological activities, and safety profile, highlighting its potential as a multi-functional therapeutic agent. The plant is rich in diverse bioactive compounds, including flavonoids, phenolics, triterpenoids, and sterols, which collectively contribute to its broad spectrum of biological activities.

Mechanistic studies indicate that *L. acutangula* exerts its pharmacological effects through modulation of key molecular pathways, particularly those associated with oxidative stress (Nrf2), inflammation (NF-κB), and metabolic regulation (PI3K/Akt). These multi-target interactions support its traditional use in managing conditions such as diabetes, liver disorders, and inflammatory diseases. Experimental evidence further confirms its antioxidant, anti-inflammatory, antidiabetic, hepatoprotective, and antihyperlipidemic properties, with relatively low toxicity observed in preclinical studies.

Despite these promising findings, the translation of *L. acutangula* into clinical and pharmaceutical applications remains limited. The absence of well-designed clinical trials, lack of standardized extract formulations, and insufficient molecular-level investigations represent major challenges. Addressing these limitations through multidisciplinary research approaches will be essential for advancing its therapeutic potential. Future directions should focus on bioactive compound isolation, mechanistic validation using advanced omics technologies, and the development of innovative delivery systems such as nanocarriers. With continued research, *L.*

acutangula holds significant promise as a source of novel drugs and functional food ingredients, contributing to the growing field of plant-based therapeutics and integrative medicine.

AUTHORS CONTRIBUTION

All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published; and agree to be accountable for all aspects of the work. All the authors are eligible to be an author as per the international committee of medical journal editors (ICMJE) requirements/guidelines.

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CONFLICTS OF INTEREST

No Conflict of interest

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