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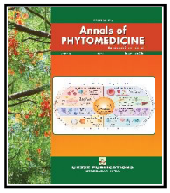

Review Article : Open Access

Phytochemical profiling and multitarget therapeutic potential of Okra (*Abelmoschus esculentus* L. Moench) : A pharmacology approach

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Abstract

Abelmoschus esculentus L. Moench, have wide range of pharmacological action and varied phytochemical makeup. The objective of this study is to thoroughly assess phytochemical profile of Okra, multitarget therapeutic potential and systems pharmacology viewpoint. The scope includes the distribution, extraction and analytical characterisation of the main bioactive components, such as flavonoids, phenolic acids, polysaccharides and sterols. Mechanistic insights are used to critically examine evidence-based pharmacological actions, including antidiabetic, antioxidant, anti-inflammatory, anticancer, cardioprotective and neuroprotective benefits. The multicomponent multitarget interactions of Okra phytochemicals are explained using a systems pharmacology paradigm that highlights important molecular pathways such as AMPK, PI3K/Akt, NF-κB and MAPK. Its polypharmacological character is further supported by network pharmacology, molecular docking and pathway enrichment analysis. The impact of Okra polysaccharides on gut microbiota regulation and their metabolic consequences is also discussed. Its translational potential is highlighted by growing clinical data and nutraceutical uses, while toxicological tests show a positive safety profile. Despite encouraging results, issues such phytochemical variability, lack of standardization and insufficient clinical validation still exist. In order to improve drug development, future views place a strong emphasis on integrating multi-omics technologies with AI-driven methodologies. All things considered, Okra is a useful functional dietary and medicinal option that has great promise for the multitarget management of complicated chronic illnesses.

1. Introduction

Medicinal plants continue to have a significant place in modern pharmacology and remain essential for the development of new therapeutics. The World Health Organization estimates around 80 per cent of the global population relies on plant-based medicines for primary healthcare, particularly in developing countries (World Health Organization, 2014). Furthermore, approximately 25-30% of approved drugs are derived directly or indirectly from natural products, highlighting their contribution to modern drug discovery (Newman and Cragg, 2020). Natural products possess remarkable chemical diversity, including complex scaffolds, stereochemistry and diverse functional groups, enabling interactions with multiple biological targets (Atanasov *et al.,* 2015). The successful translation of phytochemicals into clinically effective drugs is exemplified by compounds such as morphine, artemisinin and paclitaxel (Butler, 2008). Medicinal plants are increasingly recognized for managing multifactorial diseases, including diabetes, cancer, cardiovascular disorders and neurodegenerative diseases, which involve complex biological networks (Hopkins, 2007). Their bioactive constituents, such as flavonoids, alkaloids, terpenoids and phenolics, exhibit antioxidant, anti-inflammatory and immunomodulatory properties (Pan *et al.,* 2010). Advances in analytical and computational techniques, including nuclear magnetic resonance and high-resolution mass spectrometry, have enhanced the identification and mechanistic understanding of plant-derived bioactives (Wolfender *et al.,* 2019). The traditional “one drug-one target-one disease” paradigm is often insufficient for complex chronic diseases such as cancer, type 2 diabetes and Alzheimer’s disease, which involve multiple genes and signalling pathways (Kola and Landis, 2004; DiMasi *et al*., 2010). In contrast, multitarget therapeutics (polypharmacology) provide improved efficacy, reduced resistance and better safety profiles (Ramsay *et al*., 2018). Medicinal plants inherently follow this approach; for instance, Okra contains diverse phytochemicals that act synergistically, where flavonoids regulate oxidative stress and polysaccharides modulate immune responses and gut microbiota (Elkhalifa *et al*., 2021). Systems pharmacology and network pharmacology have emerged as powerful frameworks to study such interactions, integrating pharmacokinetics, pharmacodynamics and systems biology while constructing compound-target-pathway networks (Xia *et al*., 2015; Hopkins, 2008). Recent studies indicate that plant-based multicomponent therapies modulate key signalling pathways such as NF-κB, AMPK and PI3K/Akt, which are central to inflammation, metabolism and cell survival (Zhang *et al*., 2019). This paradigm shift has renewed interest in medicinal plants as sources of multitarget therapeutics and functional foods. The annual herbaceous plant Okra (family Malvaceae) is widely cultivated in

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tropical and subtropical regions, including Asia and is characterized by its mucilaginous pods and nutritional richness (Gemede *et al*., 2020). It is recognized as a functional food rich in dietary fibre, vitamins, minerals and bioactive compounds such as flavonoids and polysaccharides, supporting its ethnomedicinal use in diabetes, inflammation and gastrointestinal disorders (Islam, 2019; Fan *et al*., 2021). Despite extensive pharmacological studies, integrated systems pharmacology analyses linking phytochemicals with molecular targets remain limited (Zhang *et al*., 2019), emphasizing the need for network-based approaches to elucidate its multi-target mechanisms.

2. Phytochemical profiling of *A. esculentus*

Okra is a rich source of diverse phytochemicals that underpin its broad pharmacological activities (Table 1). Among these, flavonoids constitute a major class, with compounds such as quercetin and isoquercitrin widely reported. These flavonoids exhibit potent antioxidant, anti-inflammatory and antidiabetic effects through modulation of oxidative stress and key cellular signalling pathways (Romdhane *et al.,* 2020). Phenolic acids, including caffeic and ferulic acids, further contribute to the antioxidant capacity of Okra by scavenging free radicals and inhibiting lipid peroxidation (Afmi *et al*., 2021). Polysaccharides, particularly the mucilage derived from Okra pods (Figure 1) represent another important component, known for their immunomodulatory, hypoglycemic and gastroprotective properties. These high-molecular-weight compounds also demonstrate prebiotic effects, supporting the regulation of gut microbiota (Fan *et al*., 2025; Liu *et al*., 2021). Additionally, sterols and terpenoids present in Okra, such as β-sitosterol, are associated with cholesterol-lowering, anti-inflammatory and anticancer activities (Abdel-Razek *et al*., 2023). Collectively, these phytochemical classes may act synergistically, contributing to the multi-target therapeutic potential of Okra and reinforcing its relevance in systems pharmacology-based drug discovery.

Table 1: Distribution of phytochemicals in different parts of *A. esculentus*

Plant part	Major phytochemicals	Key biological activities	References
Pods	Polysaccharides (mucilage), flavonoids (quercetin, isoquercitrin) and phenolic acids	Antioxidant, antidiabetic and gastroprotective	Sabitha *et al*., 2011; Fan *et al*., 2025
Seeds	Flavonoids, sterols (β-sitosterol), lipids and tocopherols	Antioxidant, hypolipidemic and anticancer	Adetuyi *et al*., 2025; Gemede *et al*., 2020
Leaves	Phenolics, flavonoids and minerals	Anti-inflammatory and antimicrobial	Abdel-Razek *et al*., 2023

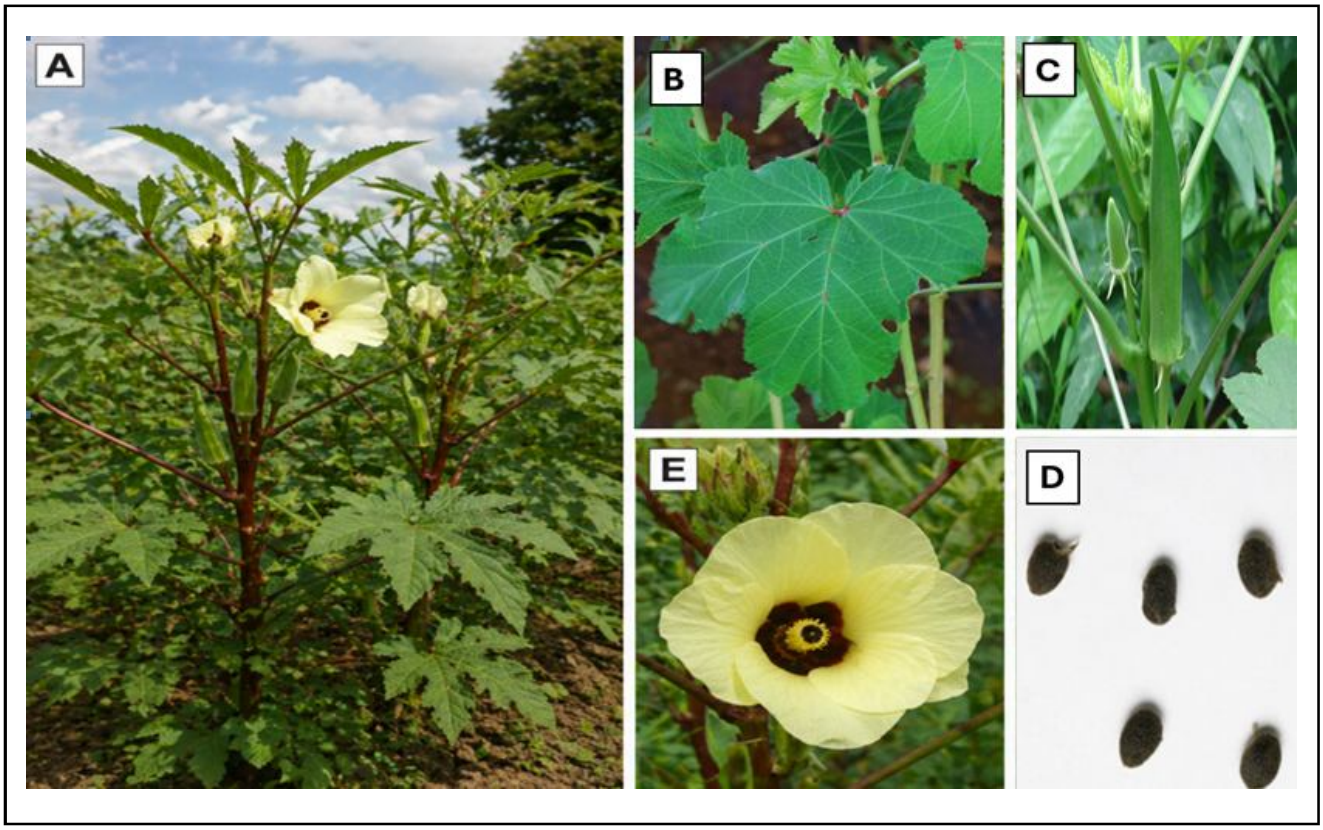

Figure 1: Morphology of Okra represents (A) Whole plant: Erect, herbaceous *A. esculentus* plant showing branching stem and overall growth habit. (B) Leaf: Broad, palmately lobed leaf with serrated margins and prominent venation. (C) Fruit (pod): Immature green capsule, longitudinally sectioned to reveal mucilage and numerous round seeds. (D) Seeds of *A. esculentus* and (E) Flower: Yellow hibiscus-like flower with a dark purple central eye and prominent reproductive structures.

2.1 Flavonoids (quercetin, isoquercitrin and derivatives)

In *A. esculentus,* flavonoids constitute the predominant class of polyphenolic chemicals. The most prevalent components are quercetin and its glycosylated derivatives, including isoquercitrin and quercetin-3-O-gentiobioside. The main flavonoids found in Okra pods have been reliably identified by high-performance liquid chromatography (HPLC) and LC-MS/MS investigations as isoquercitrin, quercetin, rutin and quercetin glycosides (Wu *et al.,* 2020; Yang *et al.,* 2018). By scavenging free radicals and chelating metal ions, isoquercitrin and quercetin derivatives have potent antioxidant qualities that shield cellular macromolecules from oxidative damage. Additionally, these flavonoids have shown strong inhibitory effect against digestive enzymes including α-glucosidase and α-amylase, indicating their possible involvement in type 2 diabetes management and glycemic control (Kumar *et al.,* 2013; Wu *et al.,* 2020). Certain flavonoids extracted from Okra, such as isoquercitrin and quercetin glycosides, have demonstrated antiproliferative effects against a variety of cancer cell lines (such as A549, A375 and NCI-N87) in addition to antioxidant activity. This suggests their potential as multi-target anticancer agents through modulation of apoptosis and cell cycle pathways (Yang *et al.,* 2022; Abdel-Razek *et al.,* 2023).

2.2 Phenolic acids and polyphenolic compounds

Another significant class of bioactive components in *A. esculentus* are phenolic acids, which include substances like protocatechuic acid and catechin derivatives that are regularly reported. Although, phenolic content varies greatly depending on cultivar, maturation stage and environmental factors, quantitative assessments show that it still plays a substantial role in the biological activity of the plant (Gemede *et al.,* 2020). Assays like DPPH, ABTS, and FRAP show a substantial correlation between these phenolic chemicals and antioxidant ability. According to Wu *et al.* (2020), there is a high positive connection between total phenolic content and antioxidant activity, suggesting that phenolics play a major role in mitigating oxidative stress in Okra. Mechanistically, phenolic acids contribute to anti-inflammatory, hepatoprotective and cardioprotective actions by modulating oxidative stress pathways, donating hydrogen and transferring electrons. Additionally, phenolic-rich Okra extracts have demonstrated inhibitory effects on carbohydrate-hydrolyzing enzymes and pancreatic lipase, indicating their therapeutic significance in metabolic diseases including diabetes and obesity (Fan *et al.,* 2021; Kumar *et al.,* 2013).

2.3 Polysaccharides (pectic polysaccharides and mucilage)

Distinctive phytoconstituents of Okra include polysaccharides, especially pectic polysaccharides and mucilage components, which are in charge of many of its medicinal properties. Complex polysaccharides like rhamnogalacturonan-I with arabinogalactan side chains, which are made up of monosaccharides including rhamnose, galacturonic acid, galactose and arabinose, have been found by structural analysis (Liu *et al.,* 2020; Liu *et al.,* 2021). By boosting the activity of enzymes including glutathione peroxidase (GPx), catalase (CAT) and superoxide dismutase (SOD) these polysaccharides have been demonstrated to improve endogenous antioxidant defense mechanisms. Okra polysaccharides have been shown to have antidiabetic potential by improving insulin secretion and restoring pancreatic β-cell function in diabetic animals (Liu *et al.,* 2020; Fan *et al.,* 2021). Significance of Okra in glycemic management and metabolic regulation is further supported by the viscous mucilage it contains, which delays stomach emptying and reduces intestinal glucose absorption (Kumar *et al.,* 2013).

2.4 Vitamins and nutritional bioactives

Total pharmacological profile of Okra is influenced by vital vitamins, minerals, proteins and carbs in addition to polyphenols and polysaccharides. Its immune system supported and its antioxidant defense system is strengthened by the presence of vitamins like vitamin C and other minerals (Abdel-Razek *et al.,* 2023). These nutritional elements work in concert with phytochemicals to improve overall therapeutic effectiveness in Okra, especially in lowering inflammation, oxidative stress and metabolic dysfunction (Gemede *et al.,* 2020).

3. Extraction and characterization techniques

Advanced extraction and analytical methods that guarantee sensitivity, specificity and repeatability are essential for the precise identification and measurement of phytochemicals in *A. esculentus*. Extraction techniques include solvent extraction (methanol, ethanol, aqueous solutions), ultrasound-assisted extraction and microwave-assisted extraction, which are frequently used to efficiently isolate bioactive compounds while preserving structural integrity (Azmir *et al*., 2013). High-performance liquid chromatography (HPLC) is widely employed for the separation and quantification of flavonoids and phenolic compounds due to its high resolution and accuracy, enabling identification based on retention time and spectral characteristics (Khoddami *et al*., 2013). Liquid chromatography-tandem mass spectrometry (LC-MS/MS) further enhances analytical capability by providing structural elucidation and high sensitivity, allowing metabolomic profiling even at trace levels (Wolfender *et al*., 2019). Nuclear magnetic resonance (NMR) spectroscopy plays a crucial role in determining molecular structure and stereochemistry, particularly for polysaccharides and complex compounds (Emwas *et al*., 2019). Fourier-transform infrared (FTIR) spectroscopy is commonly used to identify functional groups and confirm chemical structures through characteristic absorption spectra. Together, these techniques provide a comprehensive platform for phytochemical characterization and standardization.

4. Quantitative and qualitative variability

The phytochemical composition of Okra varies significantly depending on factors such as geographic origin, cultivation practices and post-harvest processing. Environmental conditions, including soil composition, temperature and sunlight exposure can significantly influence the synthesis and accumulation of bioactive compounds (Yang *et al*., 2018). Cultivation practices such as irrigation, fertilization and harvesting stage also affect phytochemical content, with some studies indicating higher bioactive compound levels under optimized or organic farming conditions (Oliveira *et al*., 2019). Additionally, the developmental stage of the plant influences compound concentration, with younger pods often exhibiting higher bioactivity. Post-harvest processing methods including drying, storage and heat treatment further impact phytochemical stability and bioavailability. High temperatures may degrade heat-sensitive compounds, whereas controlled processing helps preserve phytochemical integrity (Deng *et al*., 2018). These variations highlight the importance of standardization to ensure consistent pharmacological efficacy.

5. Pharmacological activities (evidence-based)

5.1 Antidiabetic activity

Okra exhibits significant antidiabetic effects through multiple mechanisms (Table 2) targeting glucose homeostasis. Studies have demonstrated that Okra extracts enhance insulin sensitivity by modulating insulin signalling pathways, particularly through activation of AMP-activated protein kinase (AMPK) and improvement of glucose transporter (GLUT4) translocation (Liao *et al*., 2019; Fan *et al*., 2023; Mokgalaboni *et al*., 2023; Kwok *et al*., 2025). Additionally, the viscous polysaccharides present in Okra pods delay intestinal glucose absorption, thereby reducing postprandial hyperglycaemia (Sabitha *et al*., 2011). In vivo studies in diabetic animal models have shown that Okra supplementation significantly lowers fasting blood glucose levels and improves lipid profiles (Afmi *et al*., 2021). Emerging clinical evidence also suggests that dietary intake of Okra may contribute to improved glycemic control in patients with type 2 diabetes, although large-scale trials are still limited (Geng *et al*., 2022).

5.2 Antioxidant activity

Okra possesses strong antioxidant properties primarily due to its high content of flavonoids and phenolic compounds. These phytochemicals act as reactive oxygen species (ROS) scavengers, neutralizing free radicals and preventing oxidative damage to cellular components (Adetuyi *et al*., 2025). Furthermore, Okra extracts have been shown to enhance endogenous antioxidant defense systems, including superoxide dismutase (SOD), catalase and glutathione peroxidase, thereby reducing oxidative stress and lipid peroxidation (Gemede *et al*., 2020). This antioxidant capacity plays a crucial role in preventing chronic diseases associated with oxidative damage.

5.3 Anti-inflammatory activity

The anti-inflammatory effects of Okra are mediated through the inhibition of pro-inflammatory cytokines such as TNF-α, IL-1β and IL-6 (Khatun *et al*., 2021). Bioactive compounds, particularly flavonoids, suppress inflammatory responses by modulating key signalling pathways. One major mechanism involves inhibition of the nuclear factor kappa B (NF-κB) pathway, which regulates the expression of inflammatory mediators. By suppressing NF-êB activation, Okra extracts reduce inflammation at the molecular level (Mahdavi *et al*., 2022). These effects support its traditional use in inflammatory conditions.

5.4 Anticancer activity

Okra-derived phytochemicals exhibit promising anticancer potential through multiple mechanisms. Flavonoids and phenolic compounds have been shown to induce apoptosis in cancer cells by activating caspase-dependent pathways and regulating pro- and anti-apoptotic proteins (Ngan *et al*., 2024). Additionally, these compounds can cause cell cycle arrest at various phases, thereby inhibiting cancer cell proliferation (Adetuyi *et al*., 2025). Experimental studies indicate that Okra extracts may also suppress tumor growth through antioxidant and anti-inflammatory mechanisms, highlighting their potential as complementary anticancer agents.

5.5 Cardioprotective effects

The cardioprotective effects of Okra are largely attributed to its ability to regulate lipid metabolism and reduce cardiovascular risk factors. Okra consumption has been associated with decreased levels of total cholesterol, low-density lipoprotein (LDL) and triglycerides, while increasing high-density lipoprotein (HDL) levels (Gemede *et al*., 2020). Moreover, its antioxidant and anti-inflammatory properties contribute to the prevention of atherosclerosis by inhibiting lipid oxidation and endothelial dysfunction (Liao *et al*., 2019). The presence of soluble fibre and phytosterols further supports its role in maintaining cardiovascular health.

5.6 Neuroprotective effects

Okra exhibits neuroprotective properties through its antioxidant and anti-inflammatory actions. Bioactive compounds help protect neuronal cells from oxidative stress-induced damage, which is a major factor in neurodegenerative diseases (Liu *et al*., 2020). Additionally, Okra extracts have been shown to reduce neuroinflammation by modulating inflammatory mediators and signalling pathways, thereby preserving neuronal function and integrity (Zhao *et al*., 2021). These findings suggest its potential application in the prevention and management of disorders such as Alzheimer and Parkinson disease.

Table 2 : Multifaceted health impact of Okra through various mechanism

Activity	Major bioactive compounds	Mechanism of action	References
Antioxidant activity	Flavonoids (quercetin, isoquercitrin), phenolic compounds and vitamin C	Scavenging of reactive oxygen species (ROS), inhibition of lipid peroxidation, enhancement of antioxidant enzymes (SOD, CAT, GPx)	Sabitha *et al.,* 2011
Anti-inflammatory effects	Polyphenols and flavonoids	Inhibition of pro-inflammatory cytokines (TNF-α, IL-1β, IL-6) and suppression of inflammatory pathways	Wang *et al.,* 2022
Anticancer activity	Flavonoids and phenolic compounds	Induction of apoptosis, inhibition of tumour cell proliferation, cell cycle arrest	Abdel-Razek *et al.,* 2023
Cardioprotective effects	Dietary fibre (mucilage), polyphenols and flavonoids	Regulation of lipid metabolism, reduction of LDL cholesterol, prevention of oxidative stress in vascular tissues	Abdel-Razek *et al.,* 2023
Neuroprotective effects	Flavonoids and antioxidants	Reduction of oxidative stress, suppression of neuroinflammation, activation of Nrf2 pathway	Luo *et al.,* 2018

6. Analysis and mechanism involved

6.1 Concept of systems pharmacology

Systems pharmacology has emerged as an advanced approach to understand complex interactions between drugs and biological systems by integrating pharmacokinetics, pharmacodynamics and systems biology. Unlike traditional reductionist models, it operates on a multicomponent multitarget paradigm, which is particularly relevant for plant-based therapeutics such as Okra (El-Saber Batiha *et al*., 2020; Zhao *et al*., 2012). Medicinal plants contain diverse phytochemicals capable of interacting with multiple molecular targets simultaneously, producing synergistic therapeutic effects. This approach integrates experimental pharmacology with computational tools, including bioinformatics, cheminformatics and omics technologies, to map interactions and predict therapeutic outcomes, providing a holistic understanding of drug action in complex diseases (Li *et al.,* 2020).

6.2 Network pharmacology analysis

Network pharmacology enables visualization and analysis of interactions among compounds, targets and biological pathways. In *A. esculentus*, compound-target networks help identify relationships between phytochemicals such as flavonoids and phenolics and their associated protein targets (El-Saber Batiha *et al*., 2020). Additionally, target-pathway networks elucidate how these targets participate in various biological pathways, offering insights into therapeutic mechanisms. This approach also facilitates identification of targets that play central roles in disease modulation and helps explain synergistic and additive effects characteristic of plant-based therapies (Li *et al*., 2020).

6.3 Key molecular targets

The therapeutic effects of Okra are mediated through modulation of several key molecular targets and signalling pathways. AMP-activated protein kinase (AMPK) acts as a central regulator of cellular energy homeostasis, enhancing glucose uptake, fatty acid oxidation and insulin sensitivity (Hardie *et al*., 2012). The PI3K/Akt pathway plays a crucial role in cell survival, metabolism and growth and its modulation contributes to improved insulin signalling and cellular protection (Manning *and* Cantley, 2007). Nuclear factor kappa B (NF-κB) is a key transcription factor involved in inflammation, regulating pro-inflammatory cytokine expression; its inhibition contributes to anti-inflammatory effects (Singh *et al*., 2020). Mitogen-activated protein kinase (MAPK) pathways regulate cellular processes such as proliferation, differentiation and stress responses and their modulation is associated with antioxidant, anti-inflammatory and anticancer activities (Chirumbolo, 2014).

6.4 Pathway enrichment analysis

Pathway enrichment analysis is used to identify biological pathways significantly associated with target genes or proteins. In *A. esculentus*, enrichment studies reveal involvement in multiple interconnected pathways. Metabolic pathways, including glucose and lipid metabolism, are central to its antidiabetic and cardioprotective effects (Zhang *et al*., 2019). Inflammatory pathways such as NF-κB and cytokine signalling are crucial for immune regulation (Singh *et al*., 2020). Cancer-related pathways, including apoptosis, cell cycle regulation and PI3K/Akt, highlight its potential anticancer properties (Manning and Cantley, 2007). These findings emphasize that therapeutic effects are mediated through coordinated regulation of multiple biological networks rather than a single pathway.

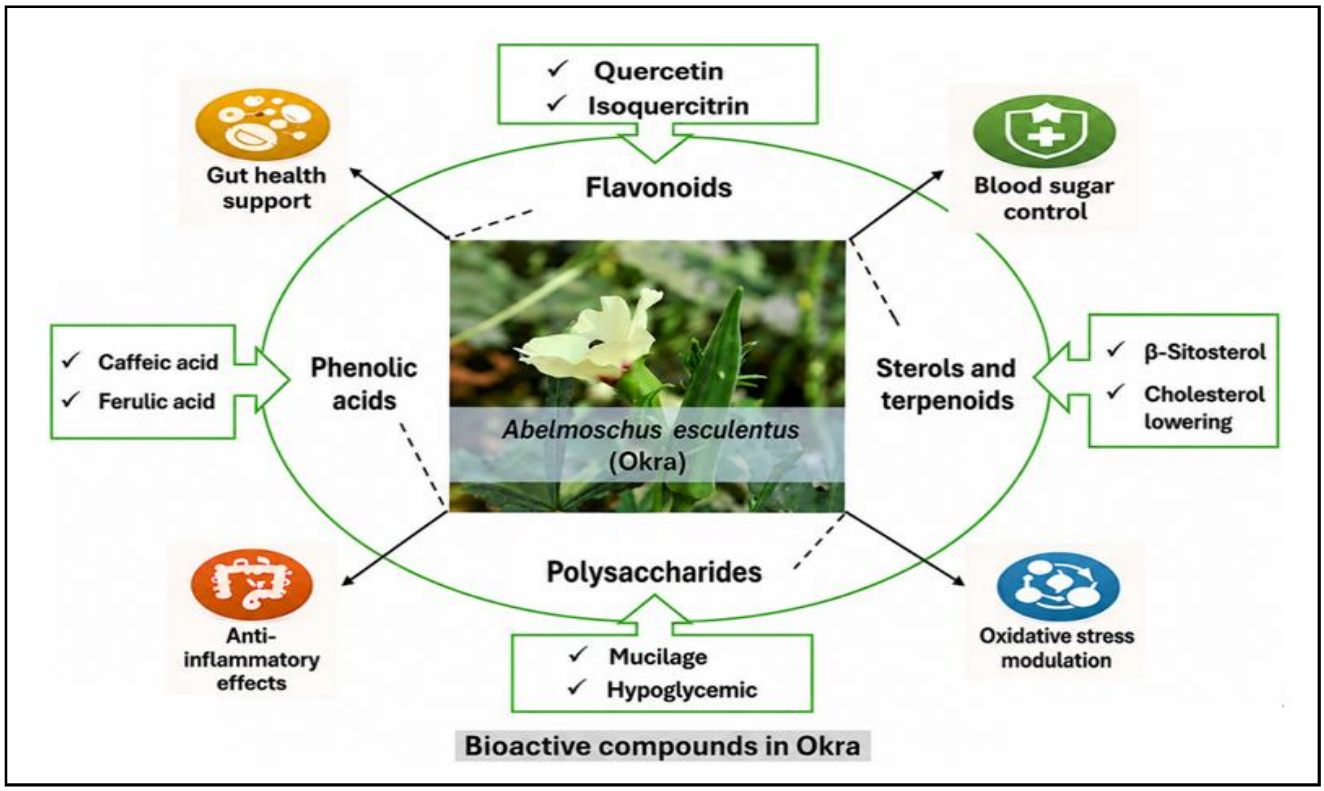

Figure 2: Multitarget therapeutic potential of Okra and its bioactive compounds.

6.5 Multitarget therapeutic mechanisms

The therapeutic efficacy of Okra is attributed to synergistic interactions among its diverse phytochemicals, including flavonoids, phenolic acids, polysaccharides and sterols, aligning with the concept of polypharmacology (Figure 2) where multiple compounds modulate various molecular targets simultaneously (Hopkins, 2008). Flavonoids primarily exert antioxidant and anti-inflammatory effects, while polysaccharides contribute to immunomodulatory and hypoglycemic activities, collectively enhancing therapeutic outcomes through modulation of interconnected pathways such as oxidative stress, inflammation and metabolism (Li *et al*., 2020). In disease-specific contexts, Okra targets multiple mechanisms:in diabetes, it enhances insulin sensitivity, inhibits carbohydrate digestion and reduces oxidative stress *via* AMPK and PI3K/Akt pathways; in cancer, it induces apoptosis, inhibits proliferation and modulates MAPK and PI3K/Akt signalling; and in cardiovascular diseases, it regulates lipid metabolism, reduces oxidative stress and prevents atherosclerosis through antioxidant and anti-inflammatory actions (Manning and Cantley, 2007; Chirumbolo, 2014). Compared to single-target drugs, this multitarget approach offers advantages such as reduced drug resistance, particularly in chronic diseases like cancer and improved therapeutic efficacy due to synergistic interactions among compounds. It also allows modulation of complex disease networks with potentially fewer adverse effects, as lower concentrations of individual bioactive compounds are required (Hopkins, 2008; Li *et al*., 2020).

6.6 Molecular docking and *in silico* validation

Molecular docking and *in silico* approaches are essential for validating the multitarget potential of phytochemicals from *A. esculentus*. Docking studies indicate that key compounds such as quercetin, isoquercitrin and phenolic acids exhibit strong binding affinities toward critical protein targets involved in metabolic and inflammatory pathways, including AMPK, PI3K and NF-κB regulators (Trott and Olson, 2010). These interactions are stabilized through hydrogen bonding, hydrophobic interactions and reflecting favourable protein-ligand conformations and biological relevance (Ferreira *et al*., 2015). In addition, *in silico* pharmacokinetic predictions (ADMET profiling) suggest that many Okra-derived compounds possess acceptable absorption, distribution, metabolism and excretion characteristics with low toxicity, supporting their drug-likeness and therapeutic potential (Daina *et al*., 2017). Such computational validations complement experimental findings and accelerate identification of bioactive candidates for further development.

6.7 Gut microbiota and systems interaction

The polysaccharide-rich mucilage of Okra plays a significant role in modulating gut microbiota, acting as a natural prebiotic (Liu *et al*., 2021). These complex carbohydrates resist digestion in the upper gastrointestinal tract and are fermented by beneficial gut bacteria such as *Lactobacillus* and *Bifidobacterium*, producing short-chain fatty acids (SCFAs) that support intestinal health and metabolic regulation (Baky *et al*., 2024). Microbiome modulation by Okra polysaccharides has been associated with improved glucose metabolism, reduced inflammation and enhanced gut barrier function, highlighting the importance of gut-metabolism interactions in mediating antidiabetic and anti-inflammatory effects (Koh *et al*., 2020). Thus, Okra contributes to systemic health through both direct pharmacological actions and microbiome-mediated pathways.

7. Toxicological and safety profile

Toxicological evaluations indicate that Okra is generally safe for consumption, with both acute and chronic toxicity studies demonstrating minimal adverse effects at commonly consumed doses (Saganuwan *et al*., 2017). Animal studies report high safety margins with no significant toxicity observed even at relatively high extract concentrations, suggesting a wide therapeutic window. Safe dosage ranges vary depending on the form of consumption, but dietary intake is widely regarded as safe and beneficial. From a regulatory perspective, Okra is classified as a food-grade plant and is generally recognized as safe (GRAS) in many regions, although standardized extracts intended for therapeutic use require further validation (Khatun *et al*., 2020).

8. Clinical evidence and translational potential

New clinical research indicates that *A. esculentus* may have therapeutic properties particularly in the treatment of metabolic illnesses including dyslipidemia and diabetes. A number of small-scale clinical studies and recent meta-analyses have reported improvements in fasting blood glucose, HbA1c, total cholesterol and triglyceride levels after supplementation with Okra medicinal products that consisting of powders, extracts and dietary formulations, despite the fact that the available evidence is still limited by small sample sizes, minimal treatment durations and methodological heterogeneity (Zhang *et al.,* 2024; Nikpayam *et al.,* 2021). It should be noted that typical treatment dosages reported in human research vary greatly depending on the formulation and study technique highlights the absence of standardized therapeutic protocols. Strong randomized controlled human trials are still insufficient to prove conclusive effectiveness, safety and long-term therapeutic application. The majority of evidence presently available is based on preclinical or animal investigations. Okra has begun to be recognized as a promising functional food and nutraceutical alternative with potential preventive benefits against chronic metabolic and cardiovascular disorders due to its rich composition of dietary fibre, polysaccharides, flavonoids and antioxidant compounds (Elkhalifa *et al.,* 2021; Zhu *et al.,* 2020). Okra translational relevance in connecting traditional medicinal use with evidence-based therapeutic applications is further supported by the expanding development of Okra-derived nutraceuticals, such as capsules, powders and standardized extracts. However, issues with bioavailability, dose standardization and clinical validation still need to be investigated (Daliu *et al*., 2020).

9. Challenges and future perspectives

Despite its promising therapeutic potential, several challenges limit the clinical translation of *A. esculentus*, including lack of standardized extracts, limited large-scale clinical trials and significant variability in phytochemical composition due to environmental and processing factors. Future research should focus on integrating multi-omics approaches such as genomics and metabolomics, along with AI-driven drug discovery and personalized medicine strategies, to better understand its mechanisms and optimize its therapeutic applications.

10. Conclusion

Okra demonstrates significant multitarget therapeutic potential due to its diverse phytochemical composition and ability to modulate key molecular pathways involved in metabolic, inflammatory and

chronic diseases. The application of systems pharmacology provides a comprehensive framework for understanding these complex interactions and supports its relevance in modern drug discovery. With further standardization, clinical validation and integration of advanced technologies, Okra holds considerable promise for future development as a functional food, nutraceutical and therapeutic agent.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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