



## Phytochemical Composition and Antioxidant-Mediated Pharmacological Activities of *Aegle marmelos* (L.) Corr.: A Narrative Review

Sharuk Khan\*, Jubayer Mehbub Jinnah, Mousumi Sultana, Adib Hussain

Department of Pharmacology, Girijananda Chowdhury University, Azara, Guwahati, Assam, India

\*Corresponding author: [Sharuk15times7@gmail.com](mailto:Sharuk15times7@gmail.com)

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### ABSTRACT

*Aegle marmelos* (L.) Corr. is a medicinal plant extensively used in traditional systems for the management of gastrointestinal, metabolic, and inflammatory disorders. Increasing experimental evidence suggests that many of its pharmacological effects are mediated through antioxidant mechanisms. The present narrative review aims to critically summarize and evaluate published literature on the phytochemical composition and antioxidant-related pharmacological activities of *Aegle marmelos*. Relevant studies were retrieved from scientific databases including PubMed, Scopus, Google Scholar, and ScienceDirect using appropriate keywords. Experimental findings indicate that different parts of the plant, particularly leaves and fruits, possess significant antioxidant activity in various in vitro and in vivo models, largely attributed to the presence of phenolics, flavonoids, coumarins, and terpenoids. However, most studies rely on crude extracts and in vitro assays, with limited standardization and insufficient clinical validation. This review highlights existing research gaps and emphasizes the need for compound-level investigations, bioavailability studies, and well-designed clinical trials to support the therapeutic potential of *A. marmelos* in oxidative stress-related disorders.

**Keywords:** *Aegle marmelos*, Antioxidant activity, Phytochemicals, Oxidative stress, Pharmacological properties

### INTRODUCTION

Medicinal plants continue to play a significant role in healthcare systems worldwide due to their chemical diversity and therapeutic potential. Among plant-derived bioactives, natural antioxidants have attracted considerable attention because of their ability to modulate oxidative stress, a key contributor to the pathogenesis of several chronic diseases. Consequently, identification and scientific validation of antioxidant-rich medicinal plants remain an important area of pharmaceutical research.

*Aegle marmelos* (L.) Corr., belonging to the family Rutaceae, is a medicinal tree widely distributed in the Indian subcontinent. The plant has been traditionally used for the management of gastrointestinal disorders, diabetes, inflammation, and infectious conditions. Owing to its diverse phytochemical composition, *A. marmelos* has gained scientific interest for its potential antioxidant and pharmacological activities.

In recent years, increasing scientific interest has focused on the antioxidant potential of *Aegle marmelos*, as oxidative stress is known to be a key contributor to the pathogenesis of several chronic and degenerative diseases. Oxidative stress results from an imbalance between reactive oxygen species production and antioxidant defense mechanisms, leading to cellular and molecular damage. Plant-derived antioxidants, particularly phenolic compounds and flavonoids, have shown significant potential in neutralizing free radicals and reducing oxidative damage [1].

Although several experimental studies have evaluated the antioxidant and pharmacological activities of *Aegle marmelos*, a comprehensive and updated review correlating its phytochemical profile with antioxidant-mediated biological effects remains limited. Therefore, the present review aims to systematically compile, analyze, and interpret available literature on the phytochemistry and antioxidant-related pharmacological activities of *Aegle marmelos*.

### METHODOLOGY OF THE REVIEW

A comprehensive literature search was conducted using electronic databases including PubMed, Google Scholar, Scopus, and ScienceDirect. Relevant articles were identified using keywords such as "*Aegle marmelos*", "wood apple", "*A. marmelos* antioxidant activity", "phytochemical constituents of *Aegle marmelos*", and "oxidative stress and medicinal plants".

The inclusion criteria comprised original research articles and review papers published in the English language that reported phytochemical characterization, in vitro antioxidant assays, or in vivo pharmacological studies related to *Aegle marmelos*. Studies focusing on unrelated plant species, duplicate publications, or articles lacking experimental evidence were excluded. Data from the selected studies were analyzed and summarized to highlight phytochemical diversity, experimental models employed, and antioxidant-related outcomes.

## Oxidative Stress and Antioxidants

Oxidative stress results from an imbalance between the generation of reactive oxygen species and endogenous antioxidant defense mechanisms, leading to cellular damage. Persistent oxidative stress is implicated in the development of metabolic, inflammatory, cardiovascular, and neurodegenerative disorders. Therefore, plant-derived antioxidants have gained attention for their role in protecting against oxidative damage and associated pathological conditions [2].

### Antioxidant Activity of *Aegle marmelos*

Several experimental studies have reported significant antioxidant activity in different parts of *Aegle marmelos*, as summarized in Table 2. In vitro assays such as DPPH, ABTS, FRAP, and nitric oxide scavenging methods are commonly employed to evaluate free radical scavenging and reducing capacity. Methanolic and ethanolic extracts, particularly from leaves and fruits, consistently exhibit higher antioxidant activity compared to aqueous extracts. Most studies have evaluated crude plant extracts without isolating individual bioactive compounds; therefore, the observed antioxidant effects are attributed to the collective presence of phenolic and flavonoid compounds rather than specific molecules [3-4].

### Limitations of Existing Studies

Despite promising experimental evidence, several limitations are evident in the existing literature on *Aegle marmelos*. Most studies are limited to in vitro antioxidant assays, which may not accurately reflect in vivo antioxidant efficacy due to factors such as metabolism and bioavailability. Additionally, there is considerable variability in plant parts used, extraction methods, assay protocols, and dosages, making direct comparison between studies difficult. Limited efforts have been made toward standardization of extracts or identification of marker compounds. Furthermore, well-designed clinical studies validating antioxidant efficacy in humans are scarce. Therefore, direct extrapolation of experimental findings to clinical efficacy should be approached with caution [5].

### Plant Profile (Reddy J. et al. 2018)

*A. marmelos* (L.) Corr., commonly known as bael, is a perennial deciduous tree belonging to the family Rutaceae and is widely distributed throughout the Indian subcontinent. The plant has long been utilized in traditional medicine systems for the management of gastrointestinal disorders, diabetes, inflammation, and infections. Different parts of the plant, including leaves, fruits, bark, roots, and seeds, are reported to possess medicinal properties. Due to its rich phytochemical composition, *A. marmelos* has attracted considerable scientific attention for its antioxidant and pharmacological potential [6].

### REPORTED PHYTOCHEMICAL CONSTITUENTS:

Various parts of *Aegle marmelos* yield different sets of phytoconstituents, which can be categorized as:. Summary of main phytochemical constituents reported in various parts of *Aegle marmelos* is presented in Table 1.

## Ethnomedicinal Uses of *Aegle Marmelos*: (Tripathy Y. et. al. 2018)

Traditionally, various parts of *A. marmelos* have been used for medicinal purposes:

- Leaves and fruits for management of diarrhea and dysentery
- Fruit pulp for gastrointestinal disorders
- Leaf extracts for diabetes and inflammation
- Bark and root extracts for mild infections
- Seeds and pulp as supportive remedy in general digestive complaints

### Mechanism of Action

These antioxidant-related activities of various extract of *Aegle marmelos* were explained to be due to the presence of a good quantity of phenolic compounds, coumarins and flavonoids in the extracts which scavenge the reactive oxygen species (ROS), reduce the lipid peroxidation and boost up the activity of endogenous antioxidant enzymes (like glutathione peroxidase, catalase, SOD, etc.). Besides, they could influence redox-sensitive signaling pathways and potentially be used in the protection of cells against damage caused by ROS.

### Molecular Mechanism Involved

Oxidative stress activates the Nrf2 signaling pathway, a central regulator of cellular antioxidant defense. Under basal conditions, Nrf2 is sequestered in the cytoplasm by Keap1 and undergoes proteasomal degradation. Upon exposure to reactive oxygen species or electrophilic compounds, conformational modification of Keap1 inhibits Nrf2 ubiquitination, leading to stabilization and nuclear translocation of Nrf2. In the nucleus, Nrf2 heterodimerizes with small Maf proteins and binds to antioxidant response elements (ARE), thereby inducing the transcription of cytoprotective genes such as heme oxygenase-1 (HO-1), NAD(P)H quinone oxidoreductase-1 (NQO1), superoxide dismutase (SOD), and glutathione-related enzymes. This pathway collectively enhances cellular redox homeostasis and protects against oxidative damage [14-18]. The molecular mechanisms underlying antioxidant activity are illustrated in Fig. 1.

### Synthesis of Evidence

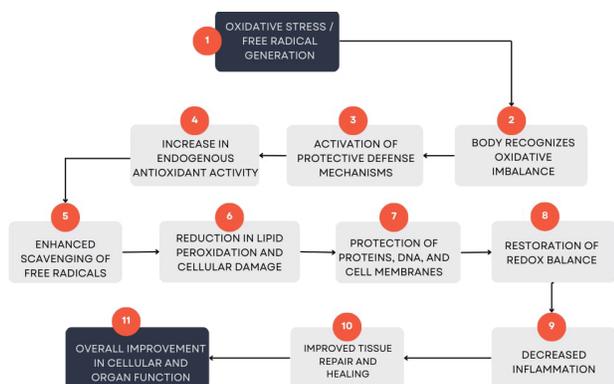
Available literature indicates that different parts of *A. marmelos* possess notable antioxidant activity across various experimental models. Studies employing in vitro assays such as DPPH, ABTS, and FRAP

**Table 1:** Major phytochemical constituents reported from different parts of *A. marmelos* (Henna A et.al. 2017)

Serialno	Parts	Phytoconstituents
1.	Fruit pulp	Flavonoids, phenolics, coumarins, carotenoids, vitamins
2.	Leaves	Flavonoids (orientin, vitexin), alkaloids, saponins, essential oils
3.	Bark	Coumarins (marmesin, bergapten), sterols, terpenoids
4.	Roots	Lactones, coumarins, quinolone alkaloids.
5.	Seeds	Fixed oils, proteins, amino acids

**Table 2:** The major phytochemical constituents reported from different parts of *Aegle marmelos*

Author	Year	Extracted	Extracts	Methods	Outcome	Phytochemical identified
Pandey S. et al.	2014	Fruit	Methanol	ABTS radical scavenging assay, FRAP assay	ABTS IC <sub>50</sub> =0.7mg/ml, FRAP activity =46.03μg BHTE/ml	Alkaloids saponins, flavonoids, total phenolics
Neraaj Kumar S. et al.	2014	Leaves, fruit, bark	Methanol	DPPH radical assay	DPPH IC <sub>50</sub> =143.33 μg/ml	Alkaloids saponins, flavonoids, total phenolics
A.Senthil Kumar et al.	2013	Fruit pulp	Methanol	DPPH radical assay	IC <sub>50</sub> =30.86 μg/ml	Essential oil thymol
Rajitha R. et al.	2013	Fruit pulp	Water	DPPH, Reducing power assay	DPPH %inhibition=76±0.286	Flavonoids polyphenol
Asna N et al.	2012	Leaves	Methanol extract	DPPH Assay	% of radical scavenging activity =81± 2.064	Highly contains flavonoids and phenolics
S. Rajan	2010	Fruit pulp	Ethanol	DPPH, reducing power assay	IC <sub>50</sub> =106.15 ±25.33	Steroids terpenoids lignins flavonoids
Kumar S. et al	2016	Leaves	Methanol	DPPH ABTS assays	DPPH IC <sub>50</sub> =160.47μg/ml ABTS IC <sub>50</sub> = 282.46μg/ml	Total phenolic content, total flavonoid content

**Fig 1:** Schematic representation of antioxidant mechanisms and Nrf2-mediated signaling pathway involved in the pharmacological effects of *Aegle marmelos*

have consistently reported higher antioxidant potential in methanolic and ethanolic extracts, particularly from leaves and fruits [7-8].

## DISCUSSION

The present review summarizes and critically evaluates the available literature on the phytochemical composition and antioxidant-related pharmacological activities of *Aegle marmelos*. Evidence from multiple in vitro and in vivo studies demonstrates that different parts of the plant, including leaves, fruit, bark, roots, and seeds, possess significant antioxidant potential. This activity is largely attributed to the presence of bioactive phytoconstituents such as flavonoids, phenolic acids, coumarins, alkaloids, and terpenoids.

Most studies reviewed employed in vitro antioxidant assays, including DPPH, ABTS, FRAP, nitric oxide scavenging, and reducing power assays, to assess free radical scavenging ability. Methanolic and ethanolic extracts were the most commonly used extraction solvent and consistently showed higher antioxidant activity compared to aqueous extracts. This variation may be explained by the greater solubility of phenolic and flavonoid compounds in organic solvents, leading to improved extraction efficiency. Several studies reported a positive correlation between total phenolic content (TPC), total

flavonoid content (TFC), and antioxidant activity, indicating that these phytochemicals play a central role in mediating the antioxidant effects of *A. marmelos* [14-18].

In addition to antioxidant activity, *A. marmelos* has demonstrated multiple pharmacological effects, including anti-inflammatory, antidiarrheal, antidiabetic, hepatoprotective, antimicrobial, and anticancer activities. Oxidative stress is known to contribute to the pathophysiology of many of these conditions; therefore, the antioxidant properties of *A. marmelos* may partially explain its broad therapeutic potential. For instance, flavonoids and coumarins present in the plant have been reported to inhibit lipid peroxidation, scavenge reactive oxygen species, and modulate inflammatory mediators, thereby providing cytoprotective effects [15-16].

Despite promising experimental findings, several limitations were identified in the reviewed studies. A large proportion of the evidence is based on in vitro assays, which may not accurately reflect in vivo antioxidant behavior due to factors such as metabolism, bioavailability, and distribution of phytochemicals. Furthermore, there is considerable variability in experimental design, plant parts used, extraction methods, and dosage, making direct comparison between studies challenging. Limited studies have focused on the isolation of individual active compounds and elucidation of precise molecular mechanisms [19-21].

Another important gap identified is the lack of well-designed clinical studies evaluating the safety, efficacy, and pharmacokinetics of *A. marmelos* extracts or isolated compounds in humans. Standardization of extracts based on marker compounds is also insufficiently addressed in the existing literature. Addressing these gaps is essential for the successful translation of *A. marmelos* from traditional medicine to evidence-based phytotherapeutic applications [8-14].

## CONCLUSION AND FUTURE PERSPECTIVES

The present review highlights *A. marmelos* as a valuable medicinal plant with significant antioxidant potential, primarily attributed to its rich phytochemical composition, particularly phenolics and flavonoids. *A. marmelos* represents a promising natural source of antioxidant compounds, and available experimental evidence suggests its

potential relevance in oxidative stress-associated disorders; however, further mechanistic investigations and well-designed clinical studies are required to confirm its therapeutic applicability. Although the antioxidant efficacy of *A. marmelos* has been well demonstrated in experimental models, further research is required to bridge the gap between laboratory findings and clinical application. Future studies should focus on the isolation and characterization of bioactive compounds, standardization of extracts, evaluation of bioavailability, and validation through controlled clinical trials. Additionally, advanced formulation approaches such as nano-delivery systems may enhance the therapeutic potential of *A. marmelos* by improving stability and bioefficacy.

Overall, *A. marmelos* represents a promising natural source of antioxidants and bioactive compounds, with potential applications in the development of novel phytopharmaceuticals for the management of oxidative stress-related disorders [22-26].

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